Quality of Life Technology Center

2014 Annual Report
Volume 1

Project Summary

Quality of Life Technology Engineering Research Center

Director: Daniel P. Siewiorek Co-Director: Rory A. Cooper

Lead Institution: Carnegie Mellon University Core Partner: University of Pittsburgh

The Quality of Life Technology Engineering Research Center (QoLT ERC) will transform lives in a large and growing segment of the population - people with functional impairment due to aging or disability. Future compassionate intelligent QoLT systems will monitor and communicate with a person, understand her daily needs and tasks, and provide reliable and happily accepted assistance by compensating and substituting for diminished capabilities.

Intellectual Merit: Many previous attempts to use sophisticated assistive technology failed for lack of basic understanding of human functions (psychological, physiological, physical, and cognitive) and how to relate them to the design of devices and systems intended to aid people. Whereas the goal of traditional robot autonomy is intelligence to function with minimal human involvement, the goal of QoLT symbiosis is for intelligent systems to function in concert with a person. We have defined a new form of engineering that explicitly accounts for how human-technology interactions govern overall performance.

QoLT *Perception and Awareness* research uses multiple sensing modalities and pioneered the First-Person camera perspective to understand and predict a person's intentions, movements, activities, and behaviors and to reliably recognize and track everyday objects in cluttered real-life environments. QoLT *Mobility and Manipulation* research creates techniques to robustly plan handling of everyday objects in near real-time and for inherently safe physical interaction of machines and people, so that robotic effectors touch people gently, even while lifting them. QoLT *Human-System Interaction* research expands universal design to include self-adaptability to a person's changing need and capability. It created methods for non-technical support providers to modulate the level of compensation that QoLT systems provide in order to achieve desired clinical outcomes. QoLT *Person and Society* research brings personal and socioeconomic considerations to the forefront of technology research. It creates techniques to engage potential QoLT users in system selection, design, development and evaluation; it has begun to reveal the individual decision making factors that people use to trade off privacy against loss of independence.

QoLT systems respond to the population with the largest variety of functional support needs – older adults and people with disabilities, and for the most diverse needs – everyday life. QoLT system prototypes measure human driving behaviors in everyday settings and give clinicians new tools for instructing proper use of home medical equipment. Through *QoLT Testbed Systems* that are applied in settings such as senior citizen high-rise apartment buildings, the QoLT ERC not only integrates components and subsystems, but integrates systems with people's lives. A number of QoLT engineering principles have emerged from the Center's basic and applied translational research, and successful models for translational research have been proven through the QoLT Foundry, all of which are lowering fundamental barriers of knowledge creation, enabling technology development, system evolution and commercialization.

Broader Impacts: The technologies that the QoLT ERC develops will enable older adults and people with disabilities to more independently perform activities of daily living and give them opportunity to participate in society longer and more fully. QoLT will augment the capabilities and extend the reach of professional and informal caregivers, increasing their cost effectiveness and improving their own quality of life. Having more people gainfully employed and reducing the need for or delaying the onset of institutionalization will have an even more profound impact on the national economy. QoLT will transform and eventually subsume the present assistive technology industry, one that is fragmented and composed primarily of very small companies serving a small market, into a space with a large consumer base including the soon-to-retire Baby Boomers.

QoLT is an effective platform for industry/practitioner/academic researcher interaction and for engaging the general public in technology research. Since QoLT career and life goals are particularly strong attractors for women and persons with disabilities, a by-product of the Center's initiatives is increased participation of those populations in engineering and other technical fields. Simultaneously, the QoLT ERC is expanding the pool of engineering students with substantial clinical and socio-economic training and experiences, and teaching them how to collaborate effectively – a difficult-to-overcome challenge in the development and implementation of systems for people's use.

Executive Summary

Achievements

Research and technological outcomes – testbed systems

- Participants in a field deployment of the Seating Coach had better compliance with instructions on frequency of adjusting posture in their wheelchairs than the control group. They also reported high degrees of satisfaction. (vol 1, section 2.3.4 and vol 2, section 2.7.3)
- In our DriveCap Advisor project, we developed smartphone and machine learning technology to identify aggressive driving behavior. A preliminary field study showed it to be 80-90% accurate. (vol 2, section 2.6.2)

Research and technological outcomes – enabling technologies

- Techniques for recognizing emotion in voice and through facial expressions showed accuracy equaling or exceeding that of human observers. The technologies were integrated into our Stroke Therapy Coach and Health Kiosk system, respectively. (vol 2, section 2.1.3, vol 2, section 2.7.3, vol 2, section 2.3.2)
- Incorporating feedback into HERB's robotic grasping strategies improved the success rate from 61% to 84% of the time. (vol 2, section 2.5.1)

Research and technological outcomes – fundamental science

- In 2013, we conducted a national *web-based survey of informal family caregivers*, the majority of whom are adult children caring for an ill or disabled parent. The survey covered current use of technology in caregiving, more general use of technology, general attitudes towards technology, and health of the caregiver. Key findings include high caregiver acceptance of kitchen, personal care, and safe driving technologies and caregivers being much more willing than care recipients to pay for QoLTs out of pocket. (vol 1, section 2.2.3 and vol 2, section 2.3.4)

Education and workforce development – university education

(vol 1, sections 3.4 and 3.6)

- We continued to infuse QoLT themes and principles into design courses offered at CMU and Pitt. Seven design courses involving over 70 students from multiple disciplines worked on QoLT-related projects in the reporting year and many of the projects involved our industry and practitioner partners.
- Our QoLT REU program was successfully renewed for its 3rd cycle. One reviewer suggested that we have developed a model REU program for others to follow.
- We rolled out a web-based evaluation mechanism for tracking the progress of QoLT students towards achieving competency in six key areas: technical, research, person-centered design, innovation, leadership, and communication. Over 70% of QoLT students completed the 1st round of evaluation.

Education and workforce development – pre-college education

(vol 1, section 3.3)

- Google co-hosted several of our events in this reporting cycle, including job shadow day, black girls' code, and financially supported our Young Scholars Program through a Google community grant. We anticipate this partnership will continue to grow, allowing us to expand our reach and visibility among the community and high-tech sector in Pittsburgh.
- We had 7 participants representing 5 different schools (2 public, 3 private) in this year's iteration of our Research Experience for Teachers program. The teachers' students participated in a 4-week product development unit that was developed at our partner facility, the Learning Research and Development Center (LRDC). The products developed in the unit were entered in a virtual online design competition. Approximately 100 students competed in the completion, split up

over 25 teams. Top awards were received by 6 unique teams from 4 different schools (Grand Prize, Peer Choice, Best Design, Best Science, QoLT Award, Best Math).

Education and workforce development – general outreach
(vol 1, section 3.8)

- Our QoLT Ambassadors (QA) extended their effort from developing initiatives within the center to assisting other organizations realize their QoLT program potential: In addition to continued representation of QoLT at public events, the QAs play a central role in the new Elderbots program. This collaborative effort of QoLT, long-term care provider Members, and schools near them, is an exploration of novel ways to use the Romibo personal robot for educational and intergenerational purposes. The QAs have played the key liaison role in this project's implementation.

Education and workforce development – diversity advancement
(vol 1, section 3.5)

- We expanded our Veteran's initiatives to include vocational training.
- We hosted a "Black Girls Code" workshop, in conjunction with Google Pittsburgh.
- With support from Google, we expanded our Tech-Link program and increased participation in it. We hired counselors with expertise in special education and obtained adaptive sports equipment.

Technology transfer and commercialization
(vol 1, section 4)

- Seating Coach was licensed to Permobil (a manufacturer of electric power wheelchairs) and was introduced at their industry's largest convention.
- A recently graduated QoLT PhD student formed a new spin-off company, Navity, to commercialize our driver capability measurement technology. The team also received iCorps funding from NSF.
- The new IPAB ecosystem has been well received and has doubled the size of the IPAB to 24 Members. New Members include two key elements in the QoLT Value Chain: robotics (iRobot), and integrated healthcare (Henry Ford Health System).

International partnerships and collaborations
(While this is not a feature of Gen-2 ERCs, we do in fact have some.)

- We continued our collaborations with the University of Tokyo on the PerMMA project and with the University of Madiera on the Stroke Therapy Coach. Some of the work on integrated information gathering/grasp planning in the HERB project was done in collaboration with ETH Zurich.

Center infrastructure

- The Pitt/VA Human Engineering Research Labs acquired a Computer Assisted Rehabilitation ENviroment (CAREN) six degree-of-freedom dynamic platform. It will be used for testing of our QoLTbots MEBot and Strong Arm.

Status of Response to 2013 SVT's SWOT Analysis

Threats

The unresolved selection of the Center director is a threat.

- The Director Search Committee unanimously selected Dan Siewiorek to be permanent Director on 4/26/13.

The lack of feedback from the policy community is a long-term threat to the adoption of the QoLT technology.

- We instituted a new project "QoLT Policy and Adoption Analysis" that has and continues to assemble expertise on policy pertinent to QoLT product dissemination. Thus far it has emphasized regulatory and reimbursement considerations through experts in Medicare, HIPPA, FDA approval, and Underwriters Laboratory approval. The project is doing case studies of our Health Kiosk and Seating Coach to directly relate those considerations to our research. (see more in vol 2, section 2.3.3)

The new ILO's job description may be pulling him into too many different directions.

- Randy Eager has prioritized Membership cultivation, development and relations. Dues revenue and number of Members have both doubled in the past year.

Weaknesses

Center is too inward looking with respect to research.

- Each core project is cognizant of relevant work outside of the Center and presents that in vol 2, section 2.
- We track activities of our peers and competitors in both academia and industry as part of our regular conduct of research. Many of the venues in which we present and publish are very competitive and thus have high standards for citing competing work. Our faculty members serve on conference committees, have editorial roles with journals and are members of professional society leadership committees.

There are gaps in the IPAB value chain, for example, not enough cutting edge robotics firms.

- In the past year we welcomed iRobot as a new Member, and are in negotiations with 2 other prospects, re2 and HStar Technologies, who have interest in specific projects (Strong Arm, vol 2 section 2.5.7 and MEBot, vol 2 section 2.5.5, respectively). We also welcomed Henry Ford Health system, a large integrated healthcare provider serving the Detroit area, as a new Member.

The current fee structure devalues the QoLT brand.

- We assume this refers to the new "Affiliated Provider" membership category. The rationale for their dues being $1k is because the Providers are essential to the success of the ecosystem: our supplier Members look to the Providers as one of their customer segments and view them as their own test beds since they now have easy access to research and technology-friendly organizations. (vol 1, section 4)

Students are concerned about finding jobs strongly related to QoLT and disability.

- We instituted a process to match student interests in internships and full-time employment with Members and prospects.

The current approach for handling privacy issues is too simplistic.

- Privacy issues specific to QoLT systems is now a focus of Person and Society Thrust research. Two examples of ongoing work on privacy-related issues for QoLT systems are the Health Kiosk (vol 2, section 2.3.2) and the application of First Person Vision (FPV) to dementia caregiving dyads (vol2, section 2.3.1).

There is no subject matter expertise in the Center as relates to Centers for Medicare and Medicaid Services (CMS) and Health Insurance Portability and Accountability Act (HIPAA) policy.

- Our new QoLT Policy and Adoption Analysis project has brought in local experts in each area (see more in vol 2, section 2.3.3)

The sustainability plan is overly reliant on NIH funding post-graduation.

- At the 2013 Site Visit, we mentioned a near-term strategy to leverage ERC funding in order to generate preliminary data that will make our future NIH grant applications more competitive. That statement could have misled one to the conclusion that NIH is our biggest funding target. Our body of Associated Project research is a fair barometer of post-graduation funding, and within it, NIH is a small fraction. Note that the financials are pro-rated by the percent overlap with QoLT's research strategy, meaning that the total funding of the Associated Projects is much higher. For example, the $3.6M in Year 8 stems from over $22M in total annual funding.)

source	Year 7 % of $3.1M direct	Year 8 % of $3.6M direct
DOD	31%	19%
VA	18%	15%
NSF	18%	34%
US Ed	14%	17%
NIH	9%	3%
industry	8%	9%
other	1%	3%

Opportunities

Leverage the students' awareness and interests for the ILO to target and develop relationships with new industry partners.

- We are still working on this.

Use Pittsburgh as a testbed to demonstrate improved Quality of Life outcomes.

- Many of our Affiliated Provider Members, most of which are local, have home care concerns. We are engaged in several projects with them along those lines. The new partnership of CMU, Highmark and the Allegheny Health Network has yielded two new Associated Projects.

Engage state government to support the Center's sustainability.

- We have created a Task Force that includes several Affiliated Provider Members to develop a funding stream based on the premise that QoLT research is an investment that will have a return in the form of reduced future Medicaid expenditures. That dovetails with an existing funding stream to CMU.

Enrich the quality of the QoLT outcomes by involving more behavioral scientists.

- This is still an untapped opportunity.

Make greater use of existing research on assistive devices in other contexts (e.g. marketing, public policy. business).

- This is still an untapped opportunity.

Strengths

- We believe that all of the following continue to be strengths:

Diverse interdisciplinary team is a key asset.

Effective in fostering and inspiring students in assistive technology research, particularly for the disabled.

Continually increasing engagement of clinicians in technology development is a unique asset of QoLT.

Center has world class facilities on both campuses.

Research is focused on a key social problem of growing importance.

Collaborative opportunities between campuses have increased substantially.

The education and educational outreach programs are well thought out, offering both breadth and depth to the target communities.

The Ambassador's program is a unique and inspirational tool.

Both universities see the linkage of robotic-assistive technology with clinical care as an emergent sector.

Growing size of the Industry Practitioner Advisory Board (IPAB) and their enthusiasm for the Center are critically important new developments.

Ecosystem model for the industry partners has sparked a commitment to inter-industry cooperation.

The new ILO is major asset.

QoLT culture creates students with strong communication skills.

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Participant Tables

Name of Institution	City	State
Carnegie Mellon University	Pittsburgh	Pennsylvania
University of Pittsburgh	Pittsburgh	Pennsylvania
Florida State University / Florida A&M University	Tallahassee	Florida
University of Central Florida	Orlando	Florida
University of South Florida	Tampa	Florida

Leadership Team			
Name	**ERC Title**	**Inst.**	**Department**
Daniel Siewiorek	Director	CMU	Human Computer Interaction
Rory Cooper	Co-Director	Pitt	Rehabilitation Science & Technology
Jim Osborn	Executive Director	CMU	Robotics
Kate Seelman	Chief Policy Scientist	Pitt	Rehabilitation Science & Technology
Dan Ding	Education Co-Director	Pitt	Rehabilitation Science & Technology
Reid Simmons	Education Co-Director	CMU	Robotics
Mary Goldberg	Lead Educ. & Outreach Coord.	Pitt	Rehabilitation Science & Technology
Shelly Brown	Education & Outreach Coord.	Pitt	Rehabilitation Science & Technology
Maria Milleville	Education & Outreach Coord.	Pitt	Rehabilitation Science & Technology
Kim Robinson	Education & Outreach Coord.	Pitt	Rehabilitation Science & Technology
Margaret Dowds	Administrative Director	CMU	Robotics
Dan Fisher	Administrative Coordinator	Pitt	Rehabilitation Science & Technology
Mike McConegly	Financial Research Administrator	Pitt	Rehabilitation Science & Technology
Randy Eager	Industrial Liaison Officer	CMU	Robotics
Kristen Sabol	Communications & Media Dir.	CMU	Robotics
Marian D’Amico	Project Manager	CMU	Robotics

Human-System Interaction Thrust			
Jodi Forlizzi	Thrust Leader	CMU	Human-Computer Interaction; Design
Jeff Bigham	Faculty Researcher	CMU	Human-Computer Interaction
Jennifer Collinger	Faculty Researcher	Pitt	Physical Medicine & Rehabilitation
Rory Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Anind Dey	Faculty Researcher	CMU	Human-Computer Interaction
Brad Dicianno	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Steven Dow	Faculty Researcher	CMU	Human-Computer Interaction
Chris Harrison	Faculty Researcher	CMU	Human-Computer Interaction
Jason Hong	Faculty Researcher	CMU	Human-Computer Interaction
Amy Hurst	Faculty Researcher	UMBC	Human Centered Computing
Jen Mankoff	Faculty Researcher	CMU	Human-Computer Interaction
Aubrey Shick	Staff Researcher	CMU	Robotics
Reid Simmons	Faculty Researcher	CMU	Robotics
Rich Simpson	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Asim Smailagic	Faculty Researcher	CMU	Institute for Complex Engineered Systems
John Zimmerman	Faculty Researcher	CMU	Human-Computer Interaction

Mobility and Manipulation Thrust (wind down in Year 8; most projects moved to QoLTbots)			
Chris Atkeson	Thrust Leader	CMU	Robotics; Human-Computer Interaction
Bambi Brewer	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Hartmut Geyer	Faculty Researcher	CMU	Robotics
Sidd Srinivasa	Faculty Researcher	CMU	Robotics

Perception and Awareness Thrust			
Martial Hebert	Thrust Leader	CMU	Robotics
James Bagnell	Faculty Researcher	CMU	Robotics
Fernando de la Torre	Faculty Researcher	CMU	Robotics
Alex Hauptmann	Faculty Researcher	CMU	Computer Science
Takeo Kanade	Faculty Researcher	CMU	Robotics Institute
Kris Kitani	Faculty Researcher	CMU	Robotics Institute
Judith Matthews	Faculty Researcher	Pitt	Nursing; Urban & Social Research
Yaser Sheikh	Faculty Researcher	CMU	Robotics, Mechanical Engineering

Person and Society Thrust			
Richard Schulz	Thrust Leader	Pitt	Institute on Aging
Scott Beach	Faculty Researcher	Pitt	Urban & Social Research
Michael Boninger	Faculty Researcher	Pitt	Physical Medicine and Rehabilitation
Rosemarie Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Karen Courtney	Faculty Researcher	UVBC	Health Information Science
Annette DeVito Dabbs	Faculty Researcher	Pitt	School of Nursing
Julie Downs	Faculty Researcher	CMU	Social & Decision Sciences
Martial Hebert	Faculty Researcher	CMU	Robotics Institute
Annmarie Kelleher	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Alicia Koontz	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Judith Matthews	Faculty Researcher	Pitt	Nursing; Urban & Social Research
Larissa Myaskovsky	Faculty Researcher	Pitt	Medicine
Jonathan Pearlman	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Laurel Person-Mecca	Staff Researcher	Pitt	Urban & Social Research
Kate Seelman	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Pamela Toto	Faculty Researcher	Pitt	Occupational Therapy

Home and Community Health & Well-being Testbed Systems			
Dan Ding	System Leader	Pitt	Rehabilitation Science & Technology
Rory Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Rosemarie Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Karen Courtney	Faculty Researcher	UVBC	Health Information Science
Anind Dey	Faculty Researcher	CMU	Human-Computer Interaction
Fernando de la Torre	Faculty Researcher	CMU	Robotics
Alex Hauptmann	Faculty Researcher	CMU	Computer Science
Scott Hudson	Faculty Researcher	CMU	Human-Computer Interaction
Michael McCue	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Mark Schmeler	Faculty Researcher	Pitt	Rehabilitation Science & Technology

QoLTbots Testbed Systems			
Rory Cooper	System Leader	Pitt	Rehabilitation Science & Engineering
Michael Boninger	Faculty Researcher	Pitt	Physical Medicine and Rehabilitation
Emmanuel Collins	Faculty Researcher	FSU	Robotics; Human-Computer Interaction
Rosemarie Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Dan Ding	Faculty Researcher	Pitt	Rehabilitation Science & Engineering
Jodi Forlizzi	Faculty Researcher	CMU	Human-Computer Interaction
Annmarie Kelleher	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Alicia Koontz	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Jonathan Pearlman	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Motoki Shino	Visiting Researcher	CMU	Robotics
Sidd Srinivasa	Faculty Researcher	CMU	Robotics
Pamela Toto	Faculty Researcher	Pitt	Rehabilitation Science & Technology

Safe Driving Testbed Systems			
Aaron Steinfeld	System Leader	CMU	Robotics
Rory Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Anind Dey	Faculty Researcher	CMU	Human-Computer Interaction
Patricia Karg	Faculty Researcher	Pitt	Rehabilitation Science & Technology
SeungJun Kim	Faculty Researcher	CMU	Human-Computer Interaction
Amy Lane	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Ashli Molinero	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Linda van Roosmalen	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Anthony Tomasic	Faculty Researcher	CMU	Institute for Software Research
John Zimmerman	Faculty Researcher	CMU	Human-Computer Interaction

Virtual Coach Testbed Systems			
Asim Smailagic	System Leader	CMU	Institute for Complex Engineered Systems
David Brienza	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Rory Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Rosemarie Cooper	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Theresa Crytzer	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Anind Dey	Faculty Researcher	CMU	Human-Computer Interaction
Dan Ding	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Brad Dicianno	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Thomas Kamarck	Faculty Researcher	Pitt	Psychology
Patricia Karg	Faculty Researcher	Pitt	Nursing; Urban & Social Research
Annmarie Kelleher	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Judith Matthews	Faculty Researcher	Pitt	Nursing; Urban & Social Research
Michael McCue	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Jonathan Pearlman	Faculty Researcher	Pitt	Rehabilitation Science & Technology
Daniel Siewiorek	Faculty Researcher	CMU	Human Computer Interaction
Reid Simmons	Faculty Researcher	CMU	Robotics
Tzen, Yi-Ting	Faculty Researcher	Pitt	Rehabilitation Science & Technology

Education and Outreach Faculty & Staff		
Name	**Institution**	**Department**
Shelly Brown	Pitt	Rehabilitation Science & Technology
Diane Collins	Pitt	Rehabilitation Science & Technology
Dan Ding	Pitt	Rehabilitation Science & Technology
Mary Goldberg	Pitt	Rehabilitation Science & Technology
Doug Hoecker	CMU	Robotics
Margaret Lindquist	CMU	Robotics
Joseph McLaughlin	CMU	Robotics
Kim Robinson	Pitt	Rehabilitation Science & Technology
Reid Simmons	CMU	Robotics

Translational Research Partners		
Name of company	**City**	**State**
Anthtrotronix, Inc.	Silver Spring	Maryland
Barrett Technology, Inc.	Newton	Massachusetts
Myomo, Inc.	Cambridge	Massachusetts
Rehabtek, LLC	Wilmette	Illinois
TravellingWave, Inc	Seattle	Washington
Wicab, Inc.	Middleton	Wisconsin

IPAB Innovation Partners		
Name of Institution	**City**	**State**
AARP	Washington	DC
Allegheny Conference of Community Development	Pittsburgh	Pennsylvania
Allegheny County Area Agency on Aging	Pittsburgh	Pennsylvania
Center or Innovation and Entrepreneurship, CMU	Pittsburgh	Pennsylvania
Center for Technology Transfer and Enterprise Creation, CMU	Pittsburgh	Pennsylvania
Donald H. Jones Center for Entrepreneurship	Pittsburgh	Pennsylvania
Engineering & Technical Innovation Management Project, CMU	Pittsburgh	Pennsylvania
Faith Based Network	Pittsburgh	Pennsylvania
Idea Foundry	Pittsburgh	Pennsylvania
Innovation Practice Institute, UPitt	Pittsburgh	Pennsylvania
Innovation Works	Pittsburgh	Pennsylvania
Katz School of Business, UPitt	Pittsburgh	Pennsylvania
LeadingAge	Washington	DC
LeadingAge PA	Harrisburg	Pennsylvania
MS World	Sarasota	Florida
National Council on Aging	Washington	DC
Office of Technology Management, UPitt	Pittsburgh	Pennsylvania
PA Homecare Association	Harrisburg	Pennsylvania
PHRQL Inc.	Pittsburgh	Pennsylvania
Pittsburgh Life Sciences Greenhouse	Pittsburgh	Pennsylvania
Pittsburgh Technology Council	Pittsburgh	Pennsylvania
Project Olympus, CMU	Pittsburgh	Pennsylvania

Industry/Practitioner Memberships (all are IPAB members)				
Name	**Title**	**Organization**	**Type of Industry**	**Member Level**
Al Allison	CEO	Baptist Home Society	Long term care	Affiliated Provider
David Fenoglietto	CEO	Lutheran SeniorLife	Long term care	Affiliated Provider
John Dickson	CEO	Redstone Highlands	Long term care	Affiliated Provider
Mary Murray	CEO	Villa St. Joseph	Long term care	Affiliated Provider
Jeff Long	CEO	St. Anne Home	Long term care	Affiliated Provider
Carol Irvine	CEO	Abramson Center for Jewish Life	Long term care	Affiliated Provider
Steve Kelly	CEO	Myomo, Inc.	Medical devices	Associate
Maarten Sierhuis	Research Director	Nissan R&D Center	Automotive	Full
Thomas Seder	Lab Group Manager	GM	Automotive	Associate
Tim Keeney	Director, Corporate Development	iRobot	Robotics	Associate
Mark Coticchia	VP & Chief Innovation Officer	Henry Ford Health System	Health insurance/acute care hospital/home care	Master
Mark Fox	Chief Development Officer	Grane Healthcare	Long term care	Full
Paul Winkler	President & CEO	Presbyterian Seniorcare	Aging seniors	Affiliated Provider
Deborah Larkin	GM	Presbyterian Senior Living	Long term care	Affiliated Provider
Brenda Limone	AVP	Beacon Communities	Senior housing	Affiliated Provider
Brendan McManus	President	First Person Vision	Consumer Electronics	Associate
Kenji Fukasawa	General Manager	Epson Research	Consumer Electronics	Master
Saul Shiffman	Sr. Consultant	Pinney & Associates	Consulting	Associate
Deborah Winn-Horvitz	CEO	Jewish Association on Aging	Long term care	Affiliated Provider
Bill Weir	CFO	Reformed Presbyterian Home	Long term care	Affiliated Provider
Dan March	CEO	Laurel View Village	Long term care	Affiliated Provider
Joe Stafura	CEO	The Affective Computing Company	Healthcare IT	Associate
Jeff Pepper	CEO	Touchtown, Inc.	Healthcare IT	Associate
Ray Washburn	CEO	Vincentian Collaborative System	Long term care	Affiliated Provider

Education Outreach Innovation Partners		
Name of Institution	**City**	**State**
A.W. Beattie Career Center	Pittsburgh	Pennsylvania
Black Girls Code	Pittsburgh	Pennsylvania
BotsIQ	Pittsburgh	Pennsylvania
Carnegie Science Center	Pittsburgh	Pennsylvania
Catalyst Connection	Pittsburgh	Pennsylvania
Center for Assistive Technology	Pittsburgh	Pennsylvania
Crafton Elementary School	Pittsburgh	Pennsylvania
Employer Support of the Guard and Reserves	Alexandria	Virginia
FIRST Lego League	Pittsburgh	Pennsylvania
Google	Pittsburgh	Pennsylvania
Hero2Hired	Alexandria	Virginia
International Science and Engineering Fair	Pittsburgh	Pennsylvania
Junior Achievement	Pittsburgh	Pennsylvania
Kids + Creativity Network	Pittsburgh	Pennsylvania
Leonard Gelfand Service Learning & Outreach Center, CMU	Pittsburgh	Pennsylvania
Living Well With a Disability Conference & Expo	Lancaster	Pennsylvania
National Engineer's Week	Alexandria	Virginia
National Organization on Disability	New York	New York
National Society of Black Engineers Pre-College Initiative	Alexandria	Virginia
North Allegheny School District	Pittsburgh	Pennsylvania
Pennsylvania Junior Academy of Science	Pittsburgh	Pennsylvania
Pine Richland High School	Pittsburgh	Pennsylvania
Pittsburgh Regional Science and Engineering Fair	Pittsburgh	Pennsylvania
Propel School	Pittsburgh	Pennsylvania
School 2 Careers	Pittsburgh	Pennsylvania
Semper Fi Fund	Oceanside	California
The LAB	Pittsburgh	Pennsylvania
Walter Reed Army Hospital	Bethesda	Maryland

Educational Advisory Board		
Name	**Title**	**Organization**
Leigh Abts	Associate Professor, College of Education	University of Maryland
Claire Duggan	Associate Director for Center for the Enhancement of Science and Mathematics Education	Northeastern University
Judy Hallinen	Assistant Vice Provost for Education Outreach	Carnegie Mellon University
Jay Martin	Director of UW-CREATe	University of Wisconsin
Gisele Ragusa	Director of the Center for Outcomes Research and Evaluation	University of Southern California
John Tagg	Science Teacher	Pittsburgh Public Schools

Scientific Advisory Board		
Name	**Title**	**Organization**
Sharon Barnartt	Professor and Chair, Sociology Department	Gallaudet University
Henrik Christensen	Chair, Robotics, College of Computing	Georgia Institute of Technology
Patrick Crago	Chairman, Biomedical Engineering	Case Western Reserve University
Sara Czaja	Professor, Department of Psychiatry and Behavioral Sciences, and Co-Director, Center on Aging	University of Miami Miller School of Medicine
Pamela Duncan	Professor, School of Nursing	Duke University
Joel Myklebust	Deputy Director, Science Evaluation and Coordination, Center for Devices and Radiological Health	U.S. Food & Drug Administration
Marcia Scherer	President, Institute for Matching Person and Technology	Syracuse University
Marjorie Skubic	Director, Center for Eldercare & Rehabilitation Technology	University of Missouri, Columbia
Roger Smith	Professor, Occupational Therapy, Chair of QoLT Scientific Advisory Board	University of Wisconsin Milwaukee
Edward Steinfeld	Professor and Director, IDEA Center	University of Buffalo

Council of Deans		
Name	**Title**	**University**
James Garrett	Dean, Carnegie Institute of Technology	CMU
Randal Bryant	Dean, School of Computer Science	CMU
Cliff Brubaker	Dean, School of Health Rehabilitation Sciences	Pitt
Jacqueline Dunbar-Jacob	Dean, School of Nursing	Pitt
Gerald Holder	Dean, Swanson School of Engineering	Pitt
Mark Redfern	Vice Provost for Research	Pitt
Thanassis Rikakis	Vice Provost for Design, Arts and Technology	CMU

Acronyms and Special Terms

AD..........................Alzheimer's Disease
ADL.........................Activity of Daily Living
AT...........................Assistive Technology
CAT.........................Center for Assistive Technology (Pitt)
CHOMP ....Covariant Hamiltonian Optimization for Motion Planning
CIBRRT ....Constrained Bi-directional Rapidly-exploring Random Tree
CMU........................Carnegie Mellon University
CP...........................Cerebral Palsy
DoF ....Degrees of Freedom
EMBS......................IEEE Engineering Medicine and Biology Society
ERC ....Engineering Research Center
HBCU......................Historically Black Colleges and Universities
HCHW.....................Home and Community Health & Wellness
HCII.........................Human Computer Interaction Institute (CMU)
HERL ....Human Engineering Research Laboratories (Pitt)
HSIT........................Human Systems Interface Thrust
IADL........................Instrumental Activities of Daily Living
ICES ....Institute for Complex Engineered Systems (CMU)
IEEE........................Institute of Electrical and Electronics Engineers
IGERT.....................Integrative Graduate Education and Research Traineeship
IOA..........................Institute on Aging (Pitt)
LSAMP....................Louis Stokes Alliance for Minority Participation
MoMaT....................Mobility and Manipulation Thrust
MS ....Multiple Sclerosis
NIDRR ....National Institute of Disability Research and Rehabilitation
NIH..........................National Institute of Health
NSF.........................National Science Foundation
PAD ....Participatory Action Design
PAT.........................Perception and Awareness Thrust
PerMMA..................Personal Mobility and Manipulation Thrust
pHRI........................Physical Human Robot Interaction
PI ....Principal Investigator
PMR........................Department of Physical Medicine and Rehabilitation (Pitt)
PST.........................Person and Society Thrust
QoLiTy Students .....QoLT Student Organization
QoLT.......................Quality of Life Technology
RESNA ....Rehabilitation Engineering and Assistive Technology Society of North America
RET.........................Research Experiences for Teachers
REU ....Research Experiences for Undergraduates
RI ....Robotics Institute (CMU)
RST.........................Department of Rehabilitation Science and Technology (Pitt)
SCI/D ....Spinal Cord Injury or Dysfunction
SHRS......................School of Health and Rehabilitation Sciences (Pitt)
SLC.........................Student Leadership Council
TBI ....Traumatic Brain Injury
TSR.........................Task Space Constraint
UPMC ....University of Pittsburgh Medical Center
VC...........................Virtual Coach

1. Vision and Value Added of the QoLT Center

1.1 *Systems Vision*

1.1.1 Vision Statement

Our vision is for intelligent systems that augment body and mind functions to improve quality of life. QoLT systems maintain health and prevent or slow decline, compensate for diminished human capabilities and enhance intact ones. They operate in the most fundamental of circumstances – everyday life – and fit seamlessly into people's lives. For many, including people with disabilities, older adults and those who care for them, they enable independent performance of daily living activities; for many others, they afford new possibilities to enjoy life. Originally conceived with older adults and people with disabilities in mind, we have widened the aperture of our vision to include all people.

Person-System Symbiosis. People and technology have begun to become partners. Since the early days of graphical user interfaces people have been able to customize their interactions with technology, limited, however, to setting preferences about look and feel. Interaction has moved off the stationary two-dimensional "desk top" into a mobile, three-dimensional world, and interactive technology is now disbursed throughout our environment. QoLT research aspires to take this partnership further to create systems that recognize situations and our habits, know when and how to intervene, and interact with us in natural, familiar ways.

QoLT systems operate as a person-system symbiosis in which human and engineered components are mutually dependent and work together. Recent advancements in technologies, including computation, sensing, robotics, machine learning, communication, and miniaturization technologies, bring us closer to futuristic visions of compassionate intelligent devices. What's been missing is incorporation of basic human functions and behaviors – psychological, physiological, physical, and cognitive – in the design of intelligent devices and systems that aid, interact with, and work in symbiosis with a person. This presents not only technological challenges, but research methodological challenges as well. Teams of engineers, clinical scientists, social scientists, and end-users must work together throughout the design, development, testing, deployment and evaluation phases to ensure that technical solutions address cultural factors, privacy concerns and other considerations that govern adoption.

Because a person is actually essential to a QoLT system function, QoLT engineering must take into account human elements. Whether it be to cook a meal, perform a set of exercises, or park a car, the human and the system share a common goal to complete a task. The highest level performance metrics, therefore, are **human symbiosis**-related: task completion time, error rate, effort and other resources required, split of human and system responsibility and variability of the split. QoLT systems have **user-interaction** metrics that capture how readily the human can convey information to the system, how readily she can interpret feedback and/or directives from the system, how aware the system is of her status, and how appropriately the system can tune its behavior according to changes in task context and of the user herself. Similar metrics apply to **clinician/caregiver interactions** between the system and a third party. Finally, there are metrics about the **system** itself that describe its ability to perform its role in the task. Those typically are accuracy, speed, and error rates of various actions that the system is to execute, as well as the size and breadth of the repertoire of actions it can perform. Of the four classes of metrics – human-system symbiosis, user-interaction, clinician/caregiver and system – only the last is familiar to most engineers.

Transformative R&D. QoLT systems are person-aware, context aware and environment-aware – transformative capabilities beyond the current state of the art.

- QoLT perception techniques reliably detect, track and recognize objects in a cluttered real-life environment, and understand people's motion, activities, emotion, and intent.
- QoLT systems engage with and even act <u>on</u> people (for example, assisting with eating and grooming and with transfers in and out of chairs), which is a reversal of the long-standing trend in

robotics to have machines work instead of people. Because the system interacts directly and intimately with people, QoLT manipulation is safe and soft, yet appropriately strong and forceful.

- QoLT expands universal design to include technology's self-adaptability to a person's changing needs and capabilities, rather than attempting to create a static design that accounts for the broadest possible range of users and use cases.
- QoLT is a comprehensive effort to make intelligent systems work with people in the most natural, unstructured, changing everyday-life environments.
- QoLT research is conducted as a full partnership of engineers, clinical practitioners, social scientists, designers and end-users.

Need. At times, we all could use some assistance: "I recognize him, but what's his name?" "Where are my keys?" "Why did I come in here?" "How did I make this work before?" "I used to be able to …" "I wish I could…" The gap between what we *want* to do and what we *can* do is larger for some people than others and generally widens as we grow older. Quality of Life Technology offers the potential to bridge the gap between human desire and human capability.

Perceptual, cognitive and musculoskeletal impairments dramatically increase with age. The number and percentages of people in need of QoLT – people with reduced functional capabilities due to aging or disability – increases substantially every year. We face an unprecedented shift in age demographics that has the potential to disrupt every business, industry, and the economy. In the United States there are presently about 35 million people over the age of 65; by 2030, those ranks will double to 70 million with older Americans accounting for 20% of the U.S. population and one in two working adults serving as an informal caregiver. At the same time, the geriatric medicine and long-term care workforces are actually dwindling. Also in the US, over 50 million people self-report a limitation in a functional or social activity. Nearly half of them report having a severe disability and being unable to perform one or more Activities of Daily Living (e.g., eating, bathing, toileting) without assistance. Unemployment rates among people with disabilities are much higher than among the general populace.

Opportunity. The magnitude of the needs outlined above points to potential lucrative business opportunities to deliver technology-based products and services that help people attain, prolong, and preserve quality of life. There are additional factors supporting those opportunities. As a group, the current wave of retiring Baby Boomers are entering retirement with wealth, technological sophistication, and expectations for maintaining quality of life that are unprecedented, hence they are motivated and well positioned to consume and pay for technology-based products. New trends in personal wellness (e.g., the Quantified Self movement), smart homes and appliances, and consumers' demand for products that simplify and aggregate aspects of their lives all require person- and context-aware technology. In fact, many QoLT products have a consumer base extending well beyond our original target populations (older adults and people with disabilities) because they are attractive for convenience, entertainment, leisure and other mainstream applications.

Healthcare is defined largely by quality and cost, and QoLT systems offer improvements to each dimension. For quality service, clinicians want and need to spend more time with clients, and need tools to reach out to clients outside clinical settings. QoLTs extend the clinician's reach and amplify her abilities. An important QoLT Center contribution is our efforts to appropriately simplify clinician and patient interactions with technologies so that they are easy to configure and customize by non-programmers. Others are our explorations of the factors that govern end-user motivation, development of perception techniques to measure the degree to which they are engaged, and development of coaching schemes that react to those signals and provide appropriate encouragement.

Market factors, specifically what goods and services are reimbursed by insurers, are a major barrier to QoLT system adoption in healthcare. However, recent and emerging models in healthcare delivery such as private homecare, the Program of All-inclusive Care for the Elderly, the Medical Home and the Accountable Care Organization are enabled by – and increasingly dependent upon – technological supports such as telemedicine, health monitoring systems, personal health records and electronic medical records. A recent Medicare rule that financially penalizes hospitals for readmissions that occur within 30-days after patient discharge is changing the calculus of reimbursement and has opened providers' eyes to the value of home healthcare technology like QoLT.

Interdisciplinary approach. Health-related practitioners and social scientists have insights into the human functions and human behaviors that most engineers lack. Their partnership elicits requirements and constraints, and enables evaluations and assessments over a continuum of time, that is essential in QoLT research. That interdisciplinary approach drives our education and outreach vision, which stems from recognition of the unique characteristics of QoLT: issues of everyday living, integration across multiple disciplines, and direct impact on diverse stakeholder groups. We aim to create a growing community of engineers, scientists, practitioners and consumers who are intellectually prepared and motivated to create, assess, and apply technology to benefit people with disabilities and older adults.

In collegiate and graduate school levels, the dialog stemming from QoLT systems development gives technologically oriented students clinical training and experiences to motivate and guide their work, and gives clinically oriented students technological training and experiences to help them understand how best to use technology. QoLT is unique because we train students in relevant social sciences and ethics and expose them to real end-use settings so they can make informed decisions about the implications of their work throughout their careers. At the pre-college level, QoLT provides familiar, real-life narratives that inspire young engineers-to-be. In informal learning environments, QoLT presents unique opportunities for the general public to interact with technologies that could affect their lives, to engage in conversational explorations of both technological change and attendant ethical issues, and to gain a sense of personal empowerment through technology understanding.

A significant paradigm shift is for people with disabilities to make major contributions to QoLT research, rather than only being beneficiaries of its outputs. Recognizing the distinct and invaluable perspectives that they offer, the QoLT Center has initiated educational programs to harness intellectual contributions from people with disabilities, especially Veterans with disabilities.

1.1.2 Barriers and How They Are Being Addressed

To realize our vision we need to overcome a number of technological, sociological and economic barriers or impediments to our progress and adoption. These barriers present challenges that drive the creation and organization of our research plan from the top. Below, we describe those barriers and how we are beginning to overcome them.

1. *Privacy Concerns.* Users can become troubled by numerous privacy-related issues that QoLT technology may present. These include the length of time that data are stored, the ability to remove individual identifiers, and the ability to designate who can and cannot view their data. From the technology provider's perspective, privacy issues can pose concerns, as well, such as: data abstraction, or the strength of anonymization techniques; unauthorized parties obtaining or viewing data, and the protection systems needed to guard against both possibilities; and the severity of potential legal or economic damage if privacy is compromised. *An emergent QoLT engineering principle, however, is that people will trade some sense of privacy for enhanced ability to gain information about their environment and situation, enabling them to live independently longer. This is evident in our First-Person Vision evaluation research, including the new Caregiving Study, and in Person and Society Thrust privacy research. We can overcome this barrier when a clear, understandable and genuine value proposition that can be conveyed to potential QoLT end-users.*

2. *Market Factors.* The greatest technology has little value if it cannot find its way into the marketplace. Many unique and difficult factors present barriers to QoLT technologies in this process. The first is reimbursement, i.e., determining how much of the cost will be covered by government agencies (OVR, Medicare, Medicaid, VA), government waiver programs, or private insurance. If there is no reimbursement model, price point is governed by amount consumers will pay themselves, production costs, acceptable mark-ups in the product space and prices of competing alternatives. It is also necessary to determine the appropriate regulatory requirements of government agencies and applicable standards posed by industry associations. *At the same time, many QoLT products do in fact have a consumer base extending well*

beyond our Center's primary target populations. Our QoLT Foundry vision statement, "Intelligent systems for everyone," reflects how people value convenience, productivity gains, entertainment and leisure. Business models for QoLT, however, are not often obvious. This barrier is overcome through exploration of related markets adjacent or complementary to target markets. For example, our Virtual Coaches aimed at physical therapy appear to have potential in sports training and sports medicine.

3. *User Acceptance.* Users need technology to be aesthetically pleasing, of demonstrable value and without stigma attached before they will agree to use it. Technology products must be reliable and durable, offering sustained service before needing to be replaced. Ease of use and quick mastery for effective usage contribute to the basic requirement that the technology creates a perceived benefit to the user. *Since clinicians and informal caregivers are in fact willing to configure and customize QoLT systems, this barrier can be reduced if QoLT developers make it convenient for them to do that. This is evident in our Seating Coach and Health Kiosk testbed systems. At the social level, humans have expectations about how robots should behave that are similar to their expectations about how other people should behave. This is evident in our QoLTbot Interaction Design project. People fundamentally prefer to do things without assistance from other people, even if it takes much more time. This is evident in the PerMMA project and in our Person & Society Thrust research.*

4. *Demonstrating Value.* For a technology to demonstrate its value, it must satisfy a number of demands. It must replace previous approaches at an acceptable cost. It must operate for a satisfactory length of time before it ceases to function. It must be used frequently, and must positively change how the user lives, works, and participates in society. Lastly, a technology must yield positive clinical outcomes regarding the user's health, physical/mental condition, functional status, medications, and healthcare utilization. *Many QoLT products do in fact have a consumer base extending well beyond our Center's primary target populations, as we found our prior QoLT Foundry efforts and more recently in dialogs with current industry Members of our consortium.*

5. *Safety Assurance.* Because QoLT systems, especially robots, interact directly with people, safety is a paramount concern. Effector motions must be controlled precisely, reliably, and, in the case of therapeutic robotics, clinically appropriate algorithms. Work in a multitude of diverse environments requires not only robust sensing, but manipulation, navigation, and locomotion algorithms that are robust to sensor errors and unexpected events. *For personal assistive robots like HERB, PerMMA and Strong Arm, safe physical interaction with people is achieved by simultaneous consideration of structural mechanics and control system designs that model and account for human elements such as reaction time and agility.*

6. *Robustness and Generalizability.* QoLT systems must perform reliably and produce the same results for the same task independent of variability in the environment. They must satisfy the same expectations whether the user is slight in stature or full-bodied. We approach this challenge with both universal design principles that enable application over a broad range of human performance, and adaptation mechanisms built into the computational intelligence and mechanical resiliency of our systems and devices. *In particular, our Perception and Awareness research emphasizes the use of machine learning and large amounts of training data to model wide variability of environments, objects, users, and human activities.*

7. *Interoperability*. In a free market, users and caregivers will seek products from alternative vendors for reasons of performance, cost or service. QoLT research outputs should be interoperable with one another and with other commercial products to share communication channels, exchange data, and enable subsystem replacement and upgrade. *Our modular approach, exemplified in the Virtual Coach system architecture, strives to make it possible to substitute software components. Integration to electronic medical records is a challenge we've recently encountered in the Health Kiosk project, specifically logistical difficulties of getting access to data exchange protocols used by UPMC's EMR vendor.*

8. *Multi-Disciplinary Collaboration Challenges.* Engineers working in isolation from stakeholders cannot be confident of adoption of new QoLT. The context in which QoLT systems are to be deployed consists of real-life experiences (the end-user, family, and other stakeholders), technical competence (engineering and design), clinical expertise (rehabilitation, geriatrics and other healthcare provisions), social-behavioral knowledge (social sciences and decision-making), industrial and market issues (economics, business,

and healthcare reimbursement), and government and law (public policy). These multi-faceted dimensions of context must be considered at the point of device conception and throughout its design, development and commercialization. *The challenge of getting engineers and clinicians to collaborate must (but can) be overcome for QoLT system development. This is particularly evident in the QoLT Handbook, which was published in late 2012. We can lower this barrier through sustained research support of cross-disciplinary teams who are willing to cross bridges.*

9. *Individual Differences and Unpredictability.* Individuals with widely different physical, cognitive and emotional characteristics will use QoLT systems. For a given system, the extent of the assistance that it delivers – and that the user is willing to accept – will certainly vary from person to person. It is also likely that assistance and the acceptance of it will vary from day to day for a given person. Variations across populations and variability of individuals are fundamental challenges for QoLT that we address through the intelligence and adaptability in our systems. *With machine learning techniques, it is possible and valuable to auto-tune user interactions with intelligent systems by incorporating contextual information that is gathered about the user herself, her environment and her situation. This is evident in our Learning, Personalized Social Coaching, Interaction Prediction and DriveCap Navigator projects.*

10. *Complex Interactions.* Traditional intelligent machines, e.g., factory automation, have focused on interactions of machines with the environment and paid little attention to direct interactions with people. In contrast, QoLT systems deal directly with people. They must provide for the complexity of person-to-person interactions, person-and-machine interactions, as well as the combination of those interacting with an uncertain environment. In robotics, truly unstructured interactions have rarely been addressed and most systems perform only a single task. QoLT systems must respond to changing environments and task contexts, and are expected to complete multiple tasks in a coordinated and graceful manner. *We have learned that knowledge about how humans interact with objects, and how they exchange them with each other, is instructive for designing human-robot interactions. This is evident in our Mobile Manipulation (particularly Push Grasping), Soft Interaction and HERB projects, which suggest that the barrier can be lowered through human-inspired design.*

11. *Model Noise and Uncertainty*. Any models we generate of human function, physiological and mental state and the components of the environment in which they are acting, remain limited and incomplete. Models can only be built from data that is available and states (as in a state-machine representation) that have been observed, both of which fall short of all possible values for all variables and all states. Thus models have "noise" in the outputs that they generate. We attempt to deal with this challenge over time through the application of heuristics that generate probabilistic outputs, and self-learning built into the QoLT systems to extend their real-world data and knowledge. *PAT's use of machine learning and models built on real data (rather than hardcoded models) helps lower this barrier.*

12. *Contextual Variability.* Just as we are challenged by person variability, we are challenged by the uncertainty of the context within which a task is being performed. The same task performed in different places or cultures may need to have the means of implementation modified to effect the same end result for the user. It includes such constraints as an environmentally appropriate user interface to following a different route home when it's dark out. *Our Personalized Social Coaching project demonstrates that learning techniques can be used to cope with contextual variability.*

1.2 *Value Added and Broader Impacts*

1.2.1 Broad Impacts

1.2.1.1 Research

Engineered Systems-level Approach and Advances

We have defined a new interdisciplinary approach to intelligent system development. By forcing consideration of non-technical issues in QoLT system design, *Person and Society* research brings health and social science to the forefront of advanced technology research. QoLT *Perception and Awareness* is creating sensing, recognition and learning solutions to reason about and predict human behavior from low-level motor actions to high-level cognition and planning. It creates capability for a computer to understand not just what people are doing, but how and why they act. QoLT *Mobility and Manipulation* creates hardware and software that are inherently safe for physical interaction of machines and people. It is producing robotic effectors that gently touch people, even while moving them, and, in the case of therapeutic robots, clinically appropriate algorithms. QoLT *Human System Interaction* research addresses the challenge of dynamically adjusting interfaces on the fly to account for changes in an individual over time. It also creates methods for support providers to modulate the level of compensation that QoLT systems provide in order to achieve therapeutic outcomes.

Through field deployments with practitioner members, we are not only integrating components and subsystems, but we are exploring how to appropriately integrate systems and people. We make extensive use of stakeholder focus groups, engaging hundreds of prospective end-users, clinicians, and professional and informal caregivers to gather input and feedback on systems. Through nationally representative surveys, our research includes collecting data on attitudes toward QoLT products and concerns about cost, conspicuousness, technological complexity and aesthetics. This knowledge will help guide technology development within this ERC and elsewhere and make important contributions to future policy changes. These knowledge bases are central to our system architecture and are valuable products for industry, future QoLT researchers and developers. Last year, we published the first QoLT Handbook, a resource for students, faculty and researchers in the social, engineering and computer sciences, the book provides methods and tools for identifying, developing, marketing and delivering technologies that enhance the quality of life.

We have defined a new form of engineering that explicitly accounts for human-technology interactions. Figure QoLT-Impact-1 defines the system architecture that provides the framework for all QoLT system development and integration. At the core of a QoLT System is a *Task Reasoning Engine*, which ascertains if the necessary resources for a task are available, invokes sequences of actions to perform the task, measures if and how the task is progressing, and reformulates action sequences accordingly. It is linked to a *Knowledge Base* that contains relevant general information, such as resource requirements and the nominal steps involved in preparing a meal, as well as installation-specific information, such as the user's food preferences, dietary instructions from her physician, the layout of her kitchen, the current contents of her refrigerator and pantry, and a log of her caloric intake for the past year. The other six modules of a QoLT System are used to interact with the user, caregivers (clinicians, other professionals, family members) and the environment. For each of these interactions, there is an *Interpretation* module that gathers information and an *Engagement* module that conveys information and/or effects physical changes. *Interpretation* of the user, for example, might range from simple keyboard input to picking up signs that she is hungry and collecting data about her eating habits; whereas *Interpretation* of her environment might include recognizing the handle of a frying pan, distinguishing the labels on canned goods and knowing the status of her cook top. The system's *Engagement* might be through appropriate menu suggestions, e.g., in a coaching system, or by actually feeding a person who has upper extremity paralysis. Likewise, *Engagement* of the environment might be as complex as a robot preparing a meal or as simple as shutting off the stove if it has been on too long.

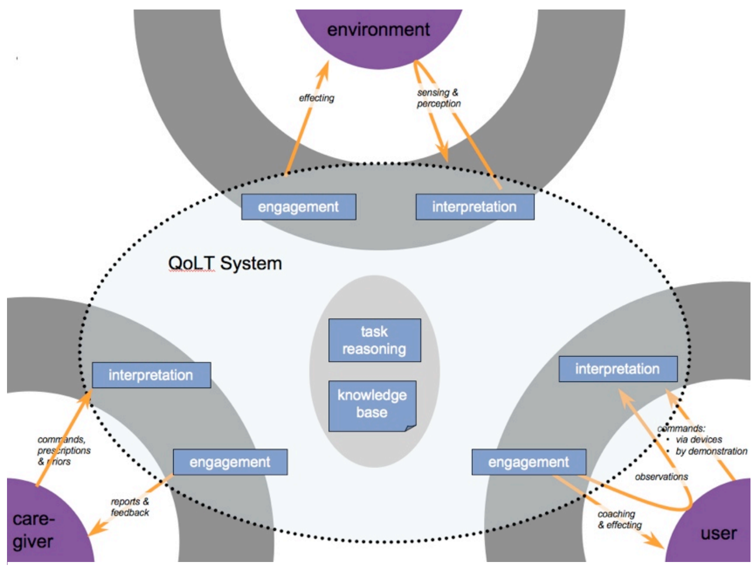


Figure QoLT-Impact-1: QoLT System interactions with use, caregiver and environment

The QoLT System Architecture adopts fundamental principles from software engineering: systems consist of modules with well-defined inputs, outputs and functionality, and a particular module does not need to understand the detailed inner workings of any other module. System designers can substitute one module for another as long as both are functionally equivalent and have the same I/O; module developers can make steady – or dramatic – changes without compromising the functionality of the whole system. Because of *interchangeability,* a particular QoLT System can be tailored to fit a number of users, situations and constraints. For example, we are developing multiple sensing and machine learning approaches to recognize meal preparation activities in the kitchen. Those include cameras attached to walls, wearable cameras, wearable inertial measurement units, and instrumented cabinets, drawers and appliances. Separately or in combination, all can be used to answer the question, "what is she cooking?" In real implementations, we expect to encounter some users who will not accept a surveillance camera, but are willing to don a wearable one. Similarly, circumstances may preclude use of some approaches (e.g., in some kitchen layouts it may not be possible to achieve useful camera vantage points; we can't count on a person with a mild cognitive disability to remember to wear his motion sensors). The important point is that the same dietary coaching system could be used in lots of kitchens, albeit with different modules for *User Interpretation* and *Environment Interpretation*.

Engineering a QoLT system requires consideration of task-level goals and attributes of the person who needs to achieve them. This is illustrated in Figure QoLT-Impact-2, which shows two different instantiations of the *Personal Mobility and Manipulation Appliance*. "User A," depicted in orange, has full use of his upper extremities hence can usually operate the robot with his joystick interface. On days that he requires more assistance, he can summon a remote expert user to help complete a task. "User B," depicted in blue, has Cerebral Palsy and depends on the computer to execute high-level directives that she issues via a touch screen. Elements common to both implementations include the robot manipulator and mobile base, cameras, force sensors, temperature sensors, and microphones to observe both the task and the user, and a reasoning engine that ensures safety.

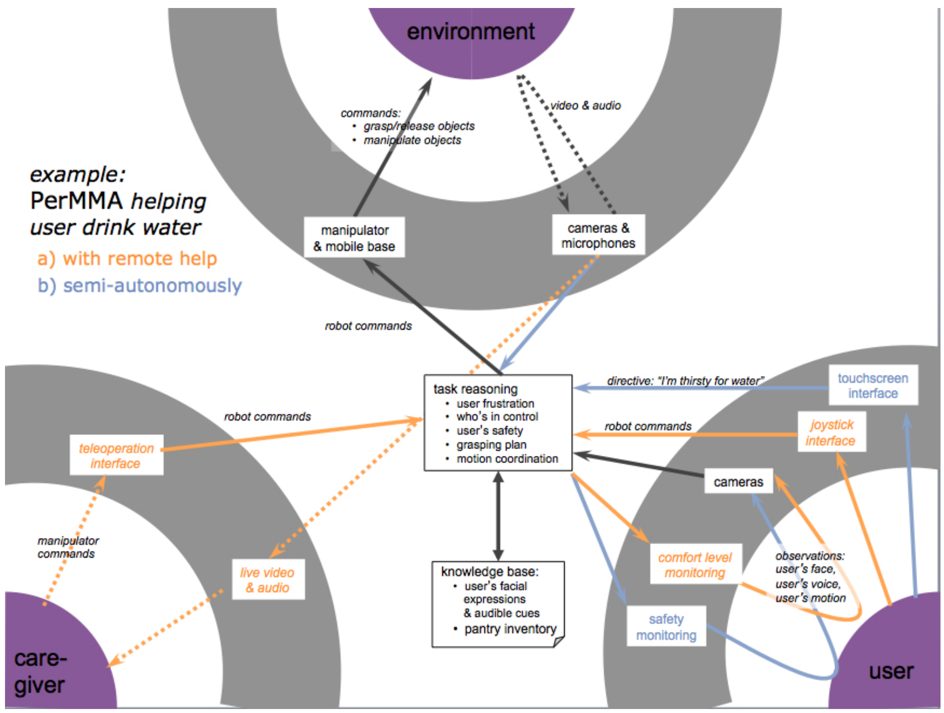


Figure QoLT-Impact-2: Two different operating modes of *PerMMA* that achieve the same task goal.

The two scenarios in Figure QoLT-Vision-2 also prescribe performance metrics, as in Table QoLT-Impact-1 below. While “User A” operates with direct control of *PerMMA* and “User B” relies on robot autonomy, for both the most important thing is that the task can be completed, i.e., he gets a drink of water. Hence the (top-level) human-symbiosis metrics for both scenarios are the same. This is a defining characteristic of QoLT: performance is measured in terms of an outcome for the user. In this case, performance would ultimately be judged by an occupational therapist. Differences in operating modes, however, translate into differences in subordinate performance metrics. Many performance metrics can be gleaned from the clinical literature and many are in terms of task performance relative to a human attendant.

Salient performance metrics for all our testbed systems are presented in the Strategic Research section.

Table QoLT-Impact-1: Performance metrics for two operating modes of *PerMMA*

		“User A” – Direct + remote control	“User B”- Autonomous Robot
human-system symbiosis			
task completion	reasonable time	within 2 minutes	
	reasonable cost	equipment cost less than cost of five years of human attendant	
	tolerable error rate	no more than 2x that of a human attendant	
	tolerable collateral damage	small amounts of spillage, dropping the water bottle away from the user, dropping a straw	
split of control	acceptable split of control	direct control modes endpoint control mode joint angle control mode	autonomous mode open/close doors manipulate objects present objects to user
	variability of split	local + remote operator	NA
	split auto-tunable or not	no	NA
safety of human/system interaction	nature & degree of risk to human	software failure resulting in unguarded motions that touch the user or impede her movement	
	tolerable error rate	less frequently than once per week	
user interaction			
user conveying intent to system	variety of modes	joystick, confirm/deny, halt, E-stop	gesture, pointing, voice command, halt, E-stop
	acceptable effort on user’s part	undivided attention	issue command
	tolerable error rate of machine’s interpretation of user intent	< 5%	
	acceptable latency of interpreting user commands	touchscreen: 3s joystick: 100ms	voice command: 2s
system providing directives, information, feedback to user	variety of modes	text message on screen, text-to-speech	
	acceptable latency of providing of feedback to user	1s	
	acceptable frequency	>1 Hz	
	tolerable error rate	5%	
general factors	tolerable invasiveness	cameras on the robot and in the home environment	
	acceptable user set up effort	drive wheelchair into kitchen	create library of objects kept in refrigerator

		"User A" – Direct + remote control	"User B"- Autonomous Robot
caregiver/clinician interaction			
set up	acceptable effort required to instruct the machine	train in remote operation for 1 week	pre-position water bottles in refrigerator and straws on kitchen counter
remote operation	acceptable effort required to control the machine	comparable to local control by user	NA
	acceptable latency of commands reaching the machine	200ms	NA
system (technology)			
perception of objects/environments	repertoire of objects that can be recognized	NA	refrigerator door handle, water bottle, other objects in refrigerator, bottle cap, straws, user's face, user's hand
	required accuracy	NA	80% recognition rate
	required speed	NA	whole scene in < 5 seconds
	tolerable error rate	NA	10%
awareness of user	repertoire of actions that can be recognized	NA	reaching to accept the drink; pointing at an object
	repertoire of states that can be recognized	body posture	choking; other discomfort
	required accuracy	90%	95%
	required latency	real-time	<1sec
	tolerable error rate	once per 10 operations	
planning / reasoning of actions	tolerable compute time	NA	30s
	tolerable error rate	NA	once per 20 operations
manipulation of objects/ environment	repertoire of actions		open/close refrigerator, reposition clutter, grasp bottle, move object with attitude constraint, open screw-top bottle, place straw in open container, hand-off to human, move bottle with straw near user's mouth
	repertoire of objects that can be moved		all refrigerated items in robot object library
	required grasping accuracy		0.5 cm
	applied force and kinetic energy regulation	max speed no greater than 15 cm/sec with full rated payload of 2.5kg	
	tolerable speed	no less than 1/3 human speed; no greater than 1.1x human speed	
	tolerable error rate		once per 10 actions

We have identified a number of QoLT principles:

- It is possible and valuable to auto-tune user interactions with intelligent systems by incorporating contextual information that is gathered about the user herself, her environment and her situation. This is evident in our *Learning, Personalized Social Coaching, Interaction Prediction, Active Intent Prediction* and *DriveCap Advisor* projects.
- Achieving safe physical interaction with people requires simultaneous consideration of structural mechanics and control system design. For the latter, one must model and account for human elements of the interaction such as intentions, dexterity and agility. We emphasize these principles in our *Soft Interaction* and *PerMMA* projects.

- People fundamentally prefer to do things without assistance from other people, even if it takes much more time. We confirmed this in the *PerMMA* project and in our *Person & Society Thrust* research.
- Knowledge about how humans interact with objects, and how they exchange them with each other, is instructive for designing human-robot interactions. We are creating and applying that knowledge in our *Mobile Manipulation, Soft Interaction* and *QoLTbot Interaction Design projects.*
- At the social level, humans have expectations about how robots should behave that are similar to their expectations about how other people should behave. We have made important discoveries along those lines in our *QoLTbot Interaction Design* project and in associated projects that focus on human-robot interaction.
- Perception techniques originally conceived to support robot autonomy can be directly applied to support human task performance. This is evident in our *Recognition* and *First-Person Vision* projects, as well as associated projects to develop aids for people with visual impairments.
- Models of some fundamental human movements such as walking, standing and lifting, are instructive for robot controller design. Once better understood, those models can also be instructive to people who have or are at risk for physical impairments. We are developing them in our *Understanding Humans* and *Strong Arm* project and in the future will apply them to Virtual Coaches for gait and human transfers.
- Clinicians and informal caregivers are in fact willing to configure and customize QoLT systems. QoLT developers need to make it convenient for them to do so. This is evident in our *Seating Coach, MemExerciser, eWatch* and *Health Kiosk* testbed systems.
- People will trade some sense of privacy for enhanced ability to gain information about their environment and situation. We have found this to be true in our *First-Person Vision* evaluation research and through large population surveys conducted by our *Person and Society Thrust*.
- Many prospective end-users' ability to provide meaningful input to the system development process is hindered by the difficulty most laypeople have to conceptualize a transformational QoLT. Techniques such as Wizard of Oz studies and other rich stimuli methods can help designers overcome this barrier. Other large-scale surveys conducted by the *Person and Society Thrust* and interactions with project-specific focus groups have borne this out.

1.2.1.2 Education

The QoLT Education, Outreach and Diversity (EOD) program continues to grow by receiving additional grants; we are now supported by 10 external grants from federal agencies, foundations, and other organizations We anticipate reaching sustainability through these and ongoing efforts to increase capacity. We facilitate 11 programs with approximately 90 participants per year. We also attend approximately 35 events per year, most of which are staffed by our QoLT Ambassadors, resulting in approximately 3,500 interactions per year that promote the QoLT EOD vision to create a growing community of engineers, scientists, practitioners, and consumers who are intellectually prepared and motivated to create and apply technology to benefit people with disabilities and older adults.

Culture

We have been infusing QoLT research into existing courses at both CMU and Pitt through class projects and discussion topics from QoLT research. We started a new course named 'QoLT Ethnography' to teach methodologies on gathering insight on the context in which a technology is to be introduced, and to introduce the *Person and Society* concepts and practices into the technology development process. We started a new undergraduate course entitled 'Human Robot Interaction' that focuses on the approaches and technologies needed for getting intelligent machines to interact naturally with people. The course was inspired by the issues seen frequently in QoLT, and teaches many of the techniques that have been found to be effective in QoLT applications.

We have defined a pedagogy that distinguishes QoLT from traditional engineering disciplines – and from related interdisciplinary health-technology pursuits (e.g., medical robotics and tissue engineering). It features 1) person-system symbiosis, 2) societal aspects of technology, 3) multi-disciplinary approaches to technology development, and 4) the complete life-cycle, systems-oriented approach to technology development. From those principles we have derived a set of core competencies for QoLT students. Our students develop them through a combination of pre-ERC courses that already fit our requirements, new courses that Center faculty have developed, and other established courses in which we have infused QoLT themes, principles and problem foci. In 2012 we instituted a tracking system to help students and their advisors chart their progress toward the core competencies.

We have encouraged our students to be entrepreneurial and several have been involved in start-up companies as well. Of the 13 companies that we have had some role in getting started, 8 include students as founders. Most recently, Nahom Beyene, who received his PhD in 2013, is starting a company called Navity and received a NSF I-Corps for his NAViSection work with the help of his mentor, Gary Miller, a former Executive in Residence with the Center. Another alumnus, Henry Kang (PhD 2012) co-founded the Pittsburgh Association of Chinese Entrepreneurs and started the company PeekaBuy to commercialize the results of his QoLT research. Other QoLT graduates are now plying their trades at Amazon, Philips Healthcare, Philips Research, Bayer Healthcare, Johnson & Johnson, Google, and Microsoft.

Our REU programs have been successful not only as rich and rewarding experiences for students, but as a mechanism for enhancing the diversity of the ERC as well. Our flagship QoLT REU Site was renewed for a third cycle with more than one reviewer suggesting that we have developed a model framework for others to follow to incorporate more students with disabilities and other underrepresented groups. Our efforts to help Veterans re-enter the pipeline have expanded through providing vocational training. We developed the Advanced Inclusive Manufacturing (AIM) program and received funding through Highmark. This program will be expanded to include all PWDs and is currently in review at NSF for an Advanced Technology Education grant to meet this goal.

Educational Exchanges with Industry

There is evidence that QoLT has emerged as a business sector: the leading robotics business conference, RoboBusiness started a track on Quality of Life Robotics in 2012
.
In February of 2011, we organized a 2-day workshop for Nissan in which we together explored future issues, trends and needs of automobile technology for older adults. We held a “Gaps Workshop” in February 2102 aimed at identifying needs for products to support aging in place. The QoLT Foundry held eight “Opportunity Meetings” in 2008-2011 in which Innovation Partners and QoLT personnel discussed specific commercialization opportunities. Our annual QoLT Summit, held in October, has research and innovation components on the agenda; in the past three years, over 30 attendees have been from industry or practitioner organizations.

Most recently, the Education team has been working with our Industry Liaison Officer to broker job shadowing, internships and full-time job placements between our students and Member (and prospective Member) firms. A system to facilitate the process is still in development, but the first iteration, which we conducted over email, generated moderate interest.

Pre-college and General Public Outreach

Many stakeholders can be directly impacted by the products resulting from QoLT, making QoLT a natural attractor to pre-college students. Our pre-college program aims to excite students and heighten awareness among teachers and parents about science and engineering in general and quality of life technology in particular. We also focus our efforts on the inclusion of students with disabilities in the pipeline and empowering them to be able to improve their own lives as engineers or technologists. As detailed in the Education and Outreach section of this report, we have identified the barriers for why both able-bodied students and students with disabilities do not engage in STEM disciplines and have formulated programs and activities that will address these issues.

Through our Tech-Link program (which is tied to FIRST Lego League), we have influenced the way students think about engineering and technology, especially in our target population of students with disabilities. Recently, we have attracted external funding to expand the program. Our new Elderbots program is a collaborative effort of QoLT, long-term care provider Members, and schools near them, is exploring novel ways to use our Romibo personal robot for educational and intergenerational purposes. Our new approach to Research Experiences for Teachers combines science and math teachers to create interdisciplinary units in the classroom. Instead of an in-person student design competition, we facilitated an online competition, which increased the number of participants and judges, and lowered costs.

1.2.1.3 Industry/Practitioner Collaboration & Innovation

As described further in Section 4, we recently reconstituted our consortium as an ecosystem of producers and consumers of QoLT products, and the numbers of Members of both types has grown substantially in the past 1½ years. Many Members are actively engaged in research projects and several are working with us on a Task Force that will figure in the Center's sustainability.

Figure QoLT-Impact-3 The QoLT consortium is an ecosystem.

We have secured six projects in aggregate from three rounds of the NSF Small-business ERC Collaboration Opportunity Program (SECO). Our general SECO strategy is to leverage QoLT Center outputs, giving priority to technology artifacts over knowledge that we have created, and simultaneously advance one or more QoLT Center goals. For small business partner, the objective is to generate a new product offering and/or enhance one of its existing products. The table below provides a thumbnail sketch of our translational research project portfolio; more details are in Section 4 of this volume and the individual project write-ups in Volume 2.

Table QoLT-Impact-3. Summary of our translational research grants

small business	status	benefits to company	benefits to QoLT Center
TravellingWave, Inc.	completed	significant usability improvement of its VoicePredict system over conventional text-input systems	integration of VoicePredict interface into the Seating Coach
Rehabtek LLC	completed	validation of electronic measurements as an alternative to the clinical gold standard of mechanical measurements of human joint range of motion; validation of visual feedback distortion as a clinically useful technique in physical therapy	pre-clinical evidence supporting the clinical value of Virtual Coaches for exercise and physical therapy
Barrett Technology, Inc.	completed	enhanced software library for their 3-fingered robotic hand	improved performance of the HERB testbed system
Anthrotronix, Inc.	completed	new product for in-home hand and finger physical therapy	clinician interface technologies for exercise coaches
Wicab, Inc.	completed	computer vision algorithms to enhance their Brainport vision prosthetic	new branch of R&D in vision prosthetics
Myomo, Inc	completed	new patient and clinician interfaces for their mPower neurobotic stroke rehabilitation device	new/enhanced user engagement technologies for exercise coaches

Innovation Award

The QoLT Foundry, our innovation program, was a major accomplishment. The Foundry was initially funded by CMU's Vice-President for Research and a grant from a local foundation. In December of 2009, QoLT was awarded an NSF EEC/ENG grant to continue and expand the program. In contrast to the conventional ground-up approach of waiting for researchers to form start-up companies, we take proactive steps to deliberately create new QoLT companies. The Foundry was staffed by Executives in Residence (EIRs), experienced entrepreneurs who have spent most of their professional careers in the private sector. Together with interns who are majoring in business, law and technology management, the EIRs develop business models for QoLT-related technology outputs following the general process illustrated in Figure QoLT-Impact-4. Since founding in 2008, the Foundry has been involved in formation of a dozen start-up companies, five of which are still in existence. *CMU's new university-wide Center of Innovation and Entrepreneurship Activities has incorporated the QoLT Foundry model as best practice.*

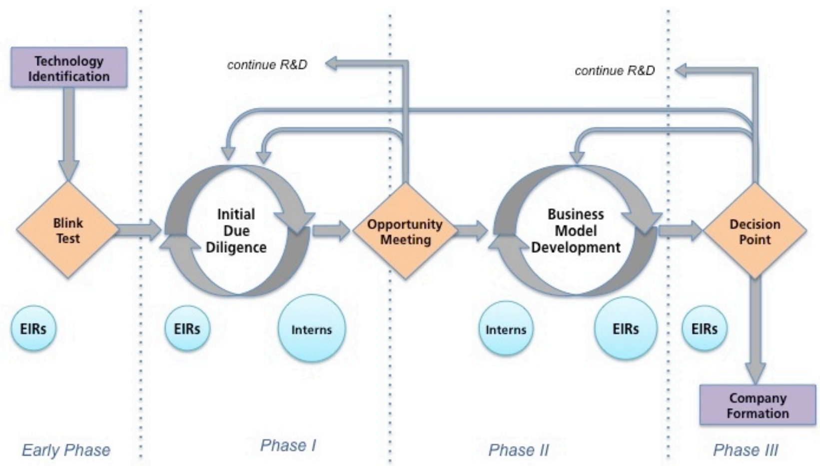


Figure QoLT-Impact-4: The QoLT Foundry process model

1.2.1.4 Team and Diversity

Interdisciplinary Makeup

We have made great strides to create collaborative working relationships among social psychologists, sociologists, gerontologists, policy experts, library scientists, and epidemiologists, physical and occupational therapists, nurses, physicians, rehabilitation engineers, computer and engineering scientists; and design faculty. This has been possible by the highly interdisciplinary composition of faculty that covers all of these areas, and the Center's explicit effort to bring them together for technology conception, development and evaluation. Our Scientific Advisory Board has pointed out that our interdisciplinary culture is one of our most important, transformative contributions to engineering research.

Some team members are technologically oriented while others have a clinical focus; some have some of both. and each participating university has a distinct organizational culture. Sharing the QoLT vision has proven to be a key in overcoming institutional differences and research interests. We all recognize that creating intelligent, human-oriented systems requires skill sets that no single institution, department or individual possesses alone. Our team members not only appreciate each other's complementary expertise, they actively and creatively seek ways to combine them. Indeed, by virtue of the connectivity it has instilled, this ERC has become a vehicle to accelerate and proliferate collaborative relationships.

Since the very earliest days of the Center, we have maintained strong participation of persons with disabilities (PWDs) and women, while we worked to improve our efforts to attract under-represented racial minorities and Hispanics. Our Diversity Plan focuses on four primary tactics: recruitment; educational programming to help propel diverse students forward at critical junctures; effective mentoring; and demonstration of strong leadership examples. A particular focus for QoLT's diversity-enhancement efforts is to reach out to students with disabilities and help integrate them into the mainstream of STEM education.

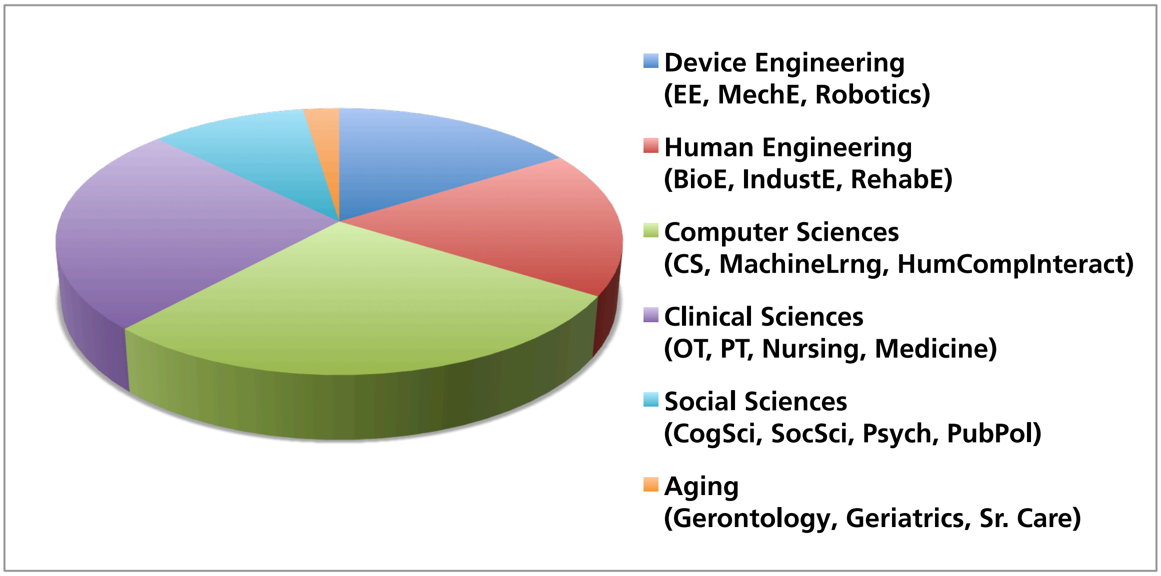


Figure QoLT-Impact-5: Interdisciplinary nature of the QoLT Center faculty

Diversity

One-third of the leadership team are women and over 20% have a disability. We aim to include underrepresented groups in all of our education initiatives across the pipeline. Our Tech-Link, REU, and ELeVATE programs enroll a majority of participants from underrepresented groups each year. The RET program targets recruitment of teachers from urban schools where the majority of students receive free and reduced lunch (i.e. low socio-economic status) and come from ethnic minority groups. We actively recruit and engage graduate students through our affiliation with AGEP, FGLSAMP and other HBCUs; the Workforce Recruitment program (for students with disabilities); and national societies and conferences (e.g. NSBE, SHPE, SACNAS). As a result of these efforts, we have recruited students to both our REU and graduate programs.

1.2.2 Impact in the Past Year

1.2.2.1 Accomplishments

Awards and Achievements

- Nahom Beyene was a Finalist in the Everyday Health Awards for “Innovation, Emerging Tech Category” presented by Living in Digital Times at the 2013 Consumer Electronics Show. The award honors individuals, companies or organizations that are utilizing technology to design and engineer innovative products or services that help people or patients with better health outcomes, every day. (See the Nugget below on his spin-off company, Navity.)
- Rory Cooper was given the VA Secretary of Veterans Affairs “Diversity and Inclusion Excellence Award” for his commitment to mentoring students with disabilities and to enabling the VA and the University of Pittsburgh to better support Veterans with disabilities. He also received the “ Outstanding Civilian Service Award” from the U.S. Army for his extraordinary and exceptional contributions to Veterans by leveraging science, clinical research, and advanced engineering technology to improve the tactical, operational, and strategic mobility of wounded and disabled Veterans.
- Rich Schulz received the “M. Powell Distinguished Contribution Award for Applied Gerontology” from the American Psychological Association. This award is presented in honor of the memory of M. Powell Lawton to recognize those whose contributions have improved the quality of life of older persons.
- Jodi Forlizzi was elected to the 2014 class of the CHI Academy, an honorary group of individuals who have made substantial contributions to the field of human-computer interaction. They are the principal leaders of the field, whose efforts have shaped the disciplines and/or industry, and led the research and/or innovation in human-computer interaction.
- The HERB team won “Most Innovative Technology “ at the 3rd Robot Film Festival in San Francisco
- Dan Siewiorek was named an Honorary Professor by Nanjing University of Post and Telecommunications, and Adjunct Professor for 2012-2016 at Harbin Institute of Technology.
- Rory Cooper received the Paralympic Scientific Award from the International Paralympics Committee, which is given to an academic researcher for his or her contributions to research in the field of sports for persons with an impairment, and it serves to promote and encourage further study in this area.
- Jodi Forlizzi, Min Kyung Lee, Bilge Mutlu Sara Kiesler, Carl DiSalvo, and Cristen Torrey and were given the 2013 Newell Research Award from Carnegie Mellon for elucidating the fundamental principles of human-robot interaction and its associated research methods.
- Elaine Houston received a Carnegie Science Award in the University/Post-Secondary Student category from the Carnegie Science Center. She was chosen by a committee of peers, recognize and promote outstanding science and technology achievements in western Pennsylvania.
- Anca Dragan received a graduate student fellowship from Intel.
- Hongwu Wang won a postdoctoral studies fellowship from the Craig Nielsen Foundation.

Notable Invited Talks

- Anca Dragan gave a keynote address at Carnegie Science Center’s SciTech Festival. She and alumna Portia Taylor were featured speakers at the Opportunities for Undergraduate Research in Computer Science (OurCS) Workshop

- Nahom Beyene spoke about his NAVisection technology at the California Association for Driver Rehabilitation Specialists (ADED) Chapter Meeting.
- Dan Fisher and Kristen Sabol were panelists for the American College of Healthcare Executives Chapter Discussion Program.
- Randy Eager was an Innovation Panelist at MedCity CONVERGE.
- Rory Cooper was a Guest Speaker at Interactivity 2013 - Reimagining Children's Museums
- Rich Schulz was an Invited Speaker for The Johns Hopkins Center on Aging and Health, and at the 2013 American Psychological Association Annual Convention
- Scott Beach and Karen Courtney organized a workshop on Evaluating Quality of Life for Health Information Technologies at the International Conference on Information Technology and Communications in Health (ITCH), Victoria, BC, Canada.
- Dan Siewiorek delivered three keynote addresses: Virtual Coaches in Healthcare: A vision of the Future, Mobile Voice Conference, San Francisco, CA; “Smart Environments”, Honors College, Harbin Institute of Technology, Harbin, People’s Republic of China, “Smart Environments”, Nanjing University of Posts and Telecommunication, Nanjing, People’s Republic of China.
- Jim Osborn was a panelist at the Louisville Innovation Summit.

QoLT in the Media

- HERB the robot was featured in an online OREO cookie commercial.
- Kitchenbot was featured in a WTAE TV-4 story during National Robotics Week.
- An IEEE Spectrum podcast on personal assistive robots included an interview with Jim Osborn, as did a story in the NY Times about the ethics of robots caring for the elderly.

Publication Record

In 2013, the QoLT Team authored 83 papers. 60 included student authors and 27 have both technical and non-technical specialists among the co-authors. One was nominated as best paper finalists. Please see Section 8 of this Volume for a complete listing of the 2013 QoLT Center publications, sorted by Cluster.

Grants Received in 2013

Table QoLT-Impact-2: New funding received

Title	Sponsor	Amount
iCorps Team NAVisection	NSF	$50k
Telerehabilitation Services	VA	$121k
Human Recognition	Samsung	$150k
Manipulation in Clutter	Toyota	$250k
Movement Detection for Parkinson’s Disease	Highmark	$300k
Real Time Observation Analysis for Healthcare Applications via Automatic Adaptation to Hardware Limitations	NSF	$460k
Self-Management Assistance Through Technology (SMART)- Virtual Coaches for Wheelchair Users	NIDRR	$2,373k
Disability and Rehabilitation Research Project on Inclusive Cloud and Web Computing	NIDRR	$3,742k
Rehabilitation Engineering Research Center on Physical Access and Transportation	NIDRR	$4,617k

IPAB Member Participation in Research

The following table summarizes industry and practitioner involvement in our research during 2013.

Table QoLT-Impact-4. Industry and practitioner involvement

Firm	Collaboration(s)	Status
Vincentian (member)	Student project, working to design and implement a process by which low skilled person can safely deliver medication in a skilled nursing facility	Ongoing
Grand Healthcare, Jewish Association on Aging, The Abramson Center for Jewish Life, MS World, and Vincentian (members)	This taskforce is working to write a position paper to facilitate the updating of long term care policy at the state level, to facilitate the use of QoLT technologies.	Ongoing
Henry Ford Medical Center (member)	Participating in a capstone engineering class where they are looking at improving the discharge process from an acute care hospital	Ongoing
Epson (member)	Moved from an associate to a Master level member and now has placed a visiting researcher at QoLT	Ongoing
GM (member)	Collaboration on DriveCap Advisor	Ongoing
Myomo (member)	Myomo was awarded a Small-Business/ ERC Collaborative Opportunity: (SECO) grant to continue the commercialization efforts around the stroke therapy coach.	Ongoing
Nissan (member)	Workshop about electric car; workshop on issues of older adults driving, sponsored project in autonomous driving	Ongoing
Presbyterian SeniorCare (member)	Access to facilities, staff and clients for QoLT researchers and QoLT industrial affiliates; collaboration on Health Kiosk project	Ongoing
PHRQL (former member)	Entrepreneurial capstone course and joint lab facilities established to investigate remote monitoring of data indicative of health and to create a personal health record for QoL.	Finished 2013
Pinney & Associates (member)	Collaboration on medication sorting evaluation	Finished 2012
Robert Bosch Corporation (member)	Collaboration on InForm Exercise Coach, Modeling Human Balance, and Grand Challenge projects	Finished 2013
TFH USA Ltd. (member)	Course project to develop a sensory room that can automatically adapt to the next patient. This is a joint project with TFH and Bosch, TFH is supplying the sensory equipment and Bosch is supplying the room sensors.	Finished 2013

Technology Transfer

In 2013, we filed nine invention disclosures bring the total disclosures to 63, submitted 4 provisional patent applications, and converted 1 provisional to a full patent application. An exclusive license for Seating Coach technology was negotiated with Permobil. We also launched one new company, Navity who is on the process of completing the license agreement for Drive Cap. We are currently negotiating commercial licenses with companies for two QoLT R&D products, Strong Arm and MEBot.

1.2.2.2 Highlights of Significant Achievement and Impact a.k.a. "Nuggets"

Research and Technology Advancements

Accurate Recognition of Emotion in Voice

Outcome/accomplishment

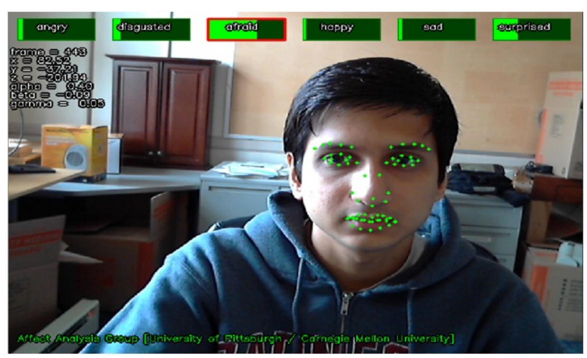
Just as our ability to sense and react to another person's emotional state is crucial for appropriate and meaningful interactions with other people, intelligent systems having that capability stand the chance to perform better and be more acceptable to humans than systems that don't. We have developed two different forms of emotion recognition, one based on voice and one based on facial expression, both of which have performance characteristics that rival – and sometimes exceed – humans'.

Impact/benefit

Quality of Life Technologies are by definition human interactive. In fact, their overall effectiveness often depends on their interplay with users. Virtual Coaches are intended to perform the same functions as human coaches in things like exercise, managing health and stepping through everyday tasks like fixing a meal. A good coach "reads" how his trainee is feeling at the moment and adjusts his coaching instructions and style accordingly. For the same reason, a Virtual Coach should be perceptive. That should translate to greater acceptance of the technology, increase user's sense of technology value, and lead to longer sustained use which essential in rehabilitation contexts. Emotion recognition is an important component of a Virtual Coach's perceptiveness. Similarly, personal assistive robots need to be aware of their user's emotions because we now know that people expect such robots to be social.

Explanation/background

We have built an emotion recognition system based on machine learning that uses the acoustic features (intensity, pitch, formant frequencies) in spoken syllables, words, and phrases for classifying the speaker's emotional state as anger, fear, happy, sad, disgust, or neutral. Each is recognized with over 75% accuracy. The system works in real time, meaning the system recognizes emotion immediately after the user has finished speaking. This approach has several advantages. First, it does not require the computer to understand *what* is spoken (i.e., for the computer to do natural language processing), only to understand *how* it was spoken. In general, this makes the system robust to location of the voice, as well as accents, inflections, etc. Because it is based on machine learning, it supports any new user and its performance improves over time. We have integrated audio-based emotion recognition into our Virtual Coach for Stroke Rehabilitation. An interactive dialog elicits responses from the user, and based on those responses, the system changes its behavior. For example, when determines that the user is angry, it advises him to 'take a rest'.



Facial expression is a rich source of emotional information as well and is robust against pose variations. Like our audio-based approach, this method also uses machine learning. We tested it on the 118 subjects in the Extended Cohn-Kanade (CK+) dataset. Emotions that present with relatively large facial feature distortions (e.g. disgust, happy, and surprise) get very high classification performance – over 97%. We have integrated this technology into our Health Kiosk, a system for acquiring basic health data such as blood pressure, weight and sleep quality aimed at older adults, especially those who are not computer users. Most subjects express neutral emotions when the Kiosk is working correctly, but express negative emotions, including surprise, frustration, and confusion, when instructions are unclear or a device is not working as expected.

Approaches to Recognizing Everyday Objects in Everyday Scenes

Outcome/accomplishment

Your house is neat as a pin, right? Everything is in its place and easy to find, isn't it? Of course not. But people have an amazing ability to discern and distinguish objects, even when they are cluttered and

randomly (dis)organized. Understanding the objects in a person’s environment is essential for many quality of life technology applications, especially robots that assist with acitivites of daily living and instrumental activities of daily living. In addition, recognizing the objects a person is dealing with at the moment helps the computer to recognize the activity she is engaged in, and understanding human activity is the basis for awareness: if, when and how an intelligent system should intervene or offer assistance. We have developed computer vision techniques that successfully recognize things associated with daily life with very high accuracy – 100% in some cases. Our techniques have been developed with QoLT scenarios in mind: they emphasize everyday objects and everyday environments, they literally learn about new objects, they work in a wide variety of observation conditions, and they minimize involvement of the user.

Impact/benefit
Recognizing specific object instances in images of natural scenes is crucial for many applications ranging from robotic manipulation to visual image search and augmented reality. In particular, many objects in daily living environments lack texture and are primarily defined by their shape (a plain white coffee mug is a good example). Even though many shape matching approaches work well when objects are un-occluded, their performance decreases rapidly in natural scenes where occlusions are common. This sensitivity to occlusions arises because those methods are either heavily dependent on repeatable contour extraction or only consider shape information very locally.

Explanation/background
Occlusions are common in real world scenes and are a major obstacle to robust object detection. Previous approaches primarily modeled local coherency of occlusions or attempted to learn the structure of occlusions from image data. Our approach explicitly models occlusions by reasoning about the spatial inter-relationships of objects. For a given environment, we compute physical statistics of objects in the scene and represent an “occluder” (an object that is occluding another object from view) as a probabilistic distribution of 3D blocks. These physical statistics need only be computed once for a particular environment and can be used to represent occlusions for many objects in the scene. By reasoning about occlusions in three dimensions, we effectively provide a unified occlusion model that accounts for different viewpoints and multiple objects in the scene. The model is concise, works for arbitrary viewpoints, captures global visibility relationships, and is computationally efficient.

Object recognition generally begins by building a database or library of object models: 2D and/or 3D images of objects that the system is trained to find in. Training data is acquired in favorable conditions, i.e., the object is isolated and illumination is conducive to acquiring high quality image data. In the real world, objects can be in any orientation and position, often significantly different from the images used to train the model. Accounting for all possible viewpoints is infeasible, yet a 3D recognition system must still recover the object pose given a finite set of training images. In the past, this has been addressed by using affine invariant features, affine invariant patches and view clustering. We take the approach of simulating novel viewpoints and adding features extracted from affine transformed training images to our model, effectively "imagining" how the object might appear. Similarly, our approach quantizes features on an object model and associates each with a descriptor and all of its possible locations on the model. At run time, the quantization allows us to associate a feature on a query image with multiple locations on a model. This body of work includes the PhD dissertation research of three QoLT students Alvaro Collet, Ed Hsaio, and Henry Kang.

Education and Outreach

Former QoLT REU Student Elected National Chairperson of the National Society of Black Engineers (NSBE)

Outcome/accomplishment:

Sossena Cherise Wood, a former student of the Quality of Life Technology Center's (QoLT) Research Experience for Undergraduates (REU) program and currently a doctoral candidate in the Department of Bioengineering at the University of Pittsburgh, will serve as National Chairperson of NSBE, the National Society of Black Engineers, for a one year term. She is only the sixth woman president since the organization's founding in the 1970s.

Wood states that her participation in the QoLT REU program helped inspire and support her pursuit of graduate studies in engineering at The University of Pittsburgh. At QoLT, Wood contributed to research on the Cueing Kitchen testbed system. Her work resulted in a second place award in the PhD category of the 35th Annual National GEM Consortium's Technical Research Exhibition –despite the fact that she had not yet started her own doctoral program studies. The following year, Wood went on to receive the 2012 GEM fellowship from the National Consortium for Graduate Degrees for Minorities in Engineering and Science. Each year only 100 students are chosen nationwide for this fellowship to further their studies in graduate education.

Impact/benefits:

As National Chairperson for NSBE, Wood serves as a role model and mentor for students from backgrounds underrepresented in science and engineering. She embodies the accomplishment potential of women in engineering while also working from an experiential learning perspective in QoLT that favors universal design as a means of optimizing the interactive relationships between engineered systems and the people of all ages or abilities who will use them. Her strong leadership skills, focus and confidence have been recognized; Wood sets challenging goals and works hard to achieve them.

Wood's service actively demonstrates a desire and determination to give back to the learning communities that have helped her excel. As National Chairperson, her objectives include improving NSBE members' visibility by showcasing their innovative accomplishments to business executives in the workforce and promotion of STEM careers among K-12 students through programs such as SEEK – a Summer Engineering Experience for Kids (SEEK) – which is a NSBE-run first all-girls engineering camp for students in grades 3-8 that features a parent orientation component to maximize success.

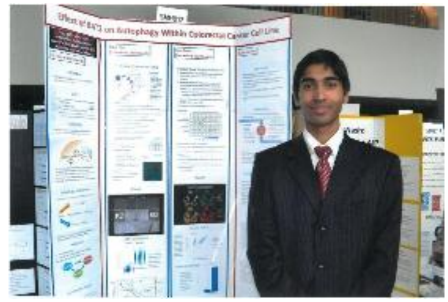
Ms. Wood and some of the SEEK participants

From Tech-Link to Harvard

Outcome/accomplishment

Ishan Chatterjee, a sophomore electrical engineering major at Harvard University, started his engineering experience with QoLT as a Tech-Link LEGO robotics student. Ishan was a Tech-Linker for several years and participated on many winning teams. Upon matriculation from the Tech-Link program at 14, Ishan returned as a junior coach and mentor. In 2011, Ishan won 1st place for his submission in the Pennsylvania Region Science Fair, continuing on to place 2nd in the national competition.

Impact/benefit



The Tech-Link program has been a vehicle for students with and without disabilities to explore engineering and computer science through LEGO robotics. The students engage in hands-on programming and robot design to create solutions for real-world problems, including those that support people with disabilities. Tech-Link and QoLT provided Ishan with experiential learning opportunities that connected STEM globally in a significant way – using engineering and technology to improve quality of life. Tech-Link continues to bring together students with diverse abilities to think, design, and build creative life solutions.

Explanation/background

Ishan's career path has been directed, in part, by his exposure to the diverse elements from his Tech-Link experience, particularly working collaboratively with students and faculty with disabilities. He is an electrical engineering major at Harvard University and is currently working on the Soft Exosuit project in Harvard's Biodesign Lab (http://wyss.harvard.edu/viewpage/456).

QoLT's Programs for Veterans Taking Off

Outcome/accomplishment

The QoLT EOD team is committed to serving Veterans with and without disabilities by helping them reintegrate and become successful in civilian society. Our network of partners has steadily grown, which will aid in scaling and replication of our programs at other institutions nationwide. In December 2013, the NSF recognized the program by inviting the ELeVATE team to participate in the pilot I-Corps for Learning program, which will aid in scaling and replicating ELeVATE.

USMC Veteran Matt Hannan, an ELeVATE student, sets up PERMMA for a demo

Impact/benefit

Since 2011, the QoLT EOD has grown its programs for Veterans to provide comprehensive training and transition assistance, not only to Veterans interested in pursuing higher education in engineering and technology, but also to those interested in manufacturing careers. By extending transition programs to more Veterans and ensuring the Veterans success on the path to education and career, QoLT EOD contributes to our country's economy by ensuring that more qualified professionals enter the STEM workforce.

Explanation/background

Since the establishment of ELeVATE in 2011, QoLT EOD has continued to pursue development of Veterans transition programs, focusing on Veterans with interests in alternative career tracks. Building on the success of ELeVATE, we established two brand-new programs, REV-T (Research Experience for Veterans and Teachers) and AIM Advancing Inclusive Manufacturing). REV-T is a part-time program that brings teachers and Veterans together as they work with individuals with disabilities in the community to design assistive technology products to accommodate their clients' needs and create innovative science and technology curricula based on their own experience. AIM is a comprehensive vocational training program for Service Members and Veterans with disabilities that teachs students how to design, develop, and evaluate their own product using established design principles.

One group of REV-T students worked on design and development of an adaptive device that allows a person using a power wheelchair to successfully participate in game hunting. The other group designed and developed a case that allows for easy attachment / detachment of a physical activity monitor to the user's manual wheelchair. The first cohort of AIM students began training in January 2014. Veterans with disabilities in the community as well as prospective funders have expressed much interest in the program, which is likely to expand to accommodate more participants.

Our network of partners continues to grow. In addition to strengthening our existing ties to regional and national Veteran services organizations, such as the Vocational Leadership Program and the Wounded Warrior Project, we have developed a partnership with Student Veterans of America's (SVA) national chapter and began reaching out to for-profits, such as Google. Google partnered with Student Veterans of America to offer intensive resume-building workshops for Veterans who are members of SVA chapters. Google Pittsburgh hosted a separate session for the 6 participants of ELeVATE, which was rated very highly by the students. The company will continue to offer the workshop to future ELeVATE cohorts. A member of Google VetNet, a group for Google employees who are Veterans, will serve as a community mentor to an ELeVATE student this summer.

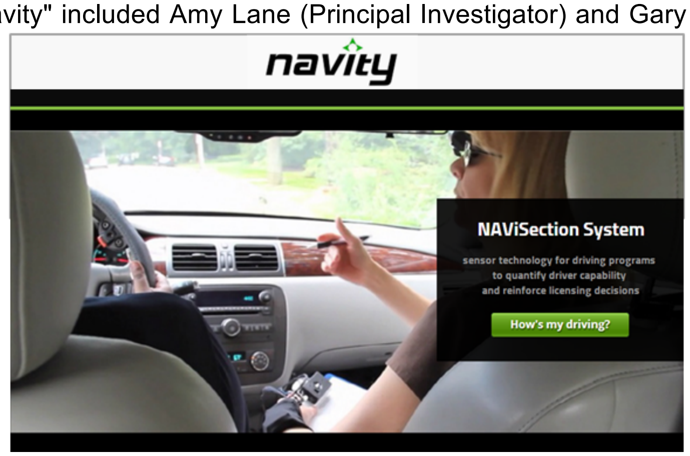
We are exploring additional avenues for partnering with Google and other technology companies on Veterans initiatives. In addition, several local manufacturing companies (e.g., Acutronics, Cygnus Manufacturing Company, Kerotest Manufacturing) have offered to provide on-the-job training to AIM students with the possibility of future employment. AIM has drawn attention of new funders, which lead to several successful proposals and new funding sources.

Technology Transfer

NAViSection Project Selected for NSF I-Corps Teams Award; University Spin-off Formed

Outcome/accomplishment

Nahom Beyene was the Entrepreneurial Lead for a National Science Foundation Innovation Corps (I-Corps) Teams Grant. The I-Corps Teams award supported commercialization of the NAViSection research project. Along with Nahom, "Team Navity" included Amy Lane (Principal Investigator) and Gary Miller (Business Mentor) in a rapid version of the Lean LaunchPad course developed by Steve Blank at Stanford University. Overall, the grant provided a six-month grant for $50,000. The NSF Teaching Team is backed by a number of venture capital firms. Their goal is to scout for prospective entrepreneurs who discover compelling business models to commercialize research. Funding from this NSF award allowed Nahom's team to conduct 111 customer discovery interviews in the first two months among driving evaluators, automotive manufacturers, auto insurance companies, and families facing driver licensing issues to name a few.



This I-Corps award was one of five affiliated with an NSF Engineering Research Center. Navity is the company formed to carry on commercialization efforts for the NAViSection system. Nahom has requests from the management of two driving programs to begin operations.

Impact/benefit
The QoLT Center provided the support and operating structure to bring members of Team Navity together. Amy Lane manages the driver rehabilitation program that facilitated research and development of the NAViSection system. During driving sessions, an evaluator (i.e. Amy Lane) protects against the crash risk of client's driving errors. The NAViSection system records these events to quantify insufficient driver capability for driving programs. Based on these programs, the commercial effort of Team Navity will introduce automotive testing to driver testing. Driver evaluation vehicles could record crash critical events continuously by adding sensor technologies. Then, sensors and software for collision avoidance technologies would receive real world physics and real scenarios towards simulation of the crash critical events they must detect and prevent.

The benefit from QoLT Center research to society is a safe, cost-effective, and highly visible testing protocol for advanced vehicle safety technologies. In a very personal way, the NAViSection system will introduce families to the promise of collision avoidance technologies. As these technologies are proven to be safe, the automotive companies may offer a safety feature that is "like having an expert driving teacher protecting your family wherever you go." This style of transparency in vehicle safety demonstrations would occur without the cost of paid expert drivers and with zero liability to automotive companies in the rare event of a crash.

Explanation/background
In recent years, Amy and Nahom conducted three studies on technology and driver rehabilitation practice. The original goal of NAViSection was to associate vehicle data to the evaluation process of a driver rehabilitation program. When Nahom completed validation of The NAViSection System, he connected with Gary for the opportunity to explore commercialization of the project through I-Corps. The QoLT Center helped to match Amy and Nahom with Gary based on his prior involvement as an Executive in Residence.

In addition to the I-Corps experience, Nahom has been recognized and awarded by multiple organizations in the Pittsburgh startup community. NAViSection was invited into the first class of the ThrillMill accelerator and participated in the business mentoring roundtable by TiE Pittsburgh. As a technology preview presenter, Nahom pitched at the AlphaLab demo day representing the University of Pittsburgh. On the national scale, he was also a finalist in the first Six-Minute Pitch competition at the Transportation Research Board conference.

Nahom has been selected as a finalist in the Wells Student HealthCare Entrepreneurship Competition and semi-finalist in the Randall Family Pitt Big Idea Competition at the University of Pittsburgh. Rooted in the study of medically impaired driving, the local chapter of Health 2.0 meetup provided him a robust community of Health IT professionals for networking and guidance. Most recently, the NAViSection System was selected as an emerging technology finalist in the Everyday Health Awards for Innovation. Finalists were recognized during an awards show in the Digital Health Summit at CES2014.

<u>Louisville Innovation Summit Patterns Healthcare Innovation Expo after QoLT Showcase</u>
Outcome/accomplishment
The QoLT Center was the anchor exhibitor at the Louisville Innovation Summit, held November 12-13, 2013, in the Kentucky Center for the Arts, Louisville, KY. The Summit brought together executives, entrepreneurs, and service providers from the aging-care sector to interact with roboticists, academics, and designers to explore new ideas for transforming our industry. QoLT Executive Director Jim Osborn was a panelist during the event's Opportunities for Innovation session.

Impact/benefit
Rather than the usual 10x10 booths laid out in rows, the Entrepreneurs Garage adopted an open format that encouraged attendees to move about freely. Organizer John Bradley says his inspiration for the layout was the QoLT Center's pavilion at the 2012 Consumer Electronics Show.

Explanation/background

In addition to a program loaded with industry heavyweights and cross-discipline mash-ups, attendees got hands-on time with inventions coming out of places like the QoLT Center, as well as MIT and Stanford – devices and systems that will help us take care of ourselves longer and help caregivers do their jobs better.

QoLT Center technologies featured in the Louisville Innovation Summit's "Entrepreneur's Garage" included: Romibo, a DIY social robot therapy kit featuring intergenerational community building elements; Stroke Therapy Coach, an integrated virtual-reality based therapeutic and rehabilitation training system; SPARK, an interactive visualization tool for self-monitoring activity levels; WorldKit - a system enabling ad hoc, custom design of touch-sensitive or gesture-driven interfaces on any surface; and Health Kiosk, an adaptive, multi-sensor telehealth system to monitor physical, physiological, cognitive and behavioral status. Videos of our personal assistive robots HERB, PerMMA and Strong Arm, were also shown.

2. Strategic Research Plan and Overall Research Program

2.1 *Strategic Research Plan*

The QoLT vision encompasses relating human physiological, physical, and cognitive function to the design of intelligent systems; creating technologies and systems that make measurable positive impact on quality of life; working closely with user groups throughout design, development, testing, and deployment phases for adoption, evaluation, and privacy concerns; and developing a curriculum to motivate students and inspire under-represented groups to pursue careers in QoLT.

2.1.1 QoLT System Testbeds and Research Thrusts

Our strategy is driven by four *QoLT Systems* that embody the QoLT vision, drive and align our engineering thrust research and development efforts. Our approach is to develop integrated prototype systems with progressively greater capability over the life span of the ERC, to evaluate the prototypes in the testbeds, and to feed findings back into the thrust research.

We have chosen four human activity domains and corresponding systems:

- Cognitive Reasoning and Perception – *Virtual Coach (VC)*
- Physical Assistance for Independent Living - *QoLTbots (QB)*
- Aging in Place / Independent Living – *Home and Community Health and Wellness (HCHW)*
- Independent Transportation – *Safe Driving (SD)*

and four research thrusts:

- *Human-System Interaction (HSIT)*
- *Mobility and Manipulation (MoMaT)*
- *Perception and Awareness (PAT)*
- *Person and Society (PST)*

At the beginning of Year 5, we combined the efforts previously focused on physical assistance and independent living to enable a greater synergy of their respective robots, *PerMMA* and *HERB* and added a new system, *Home and Community Health and Wellness*, to build on emerging technology from some then-existing projects and new ones focused on technology for safe personal care, treatment for chronic illness and prevention. Each of the systems corresponds to a particular class of needs and shares core technological features. Systems and research in the underlying thrusts to: 1) make genuine impact on important identified needs; and 2) maximize likelihood that new technologies will cut across multiple systems so that more impact can be made.

In our original vision, we selected systems to respond to needs expressed by target populations – people with disabilities, older adults, caregivers and healthcare professionals – that are supported by the scientific literature. We identified major barriers, assessed the current state-of-the-art, and considered our team's expertise in order to make those selections. The aperture of our vision has since widened to include the general population, partly because the work of our QoLT Foundry, our program to create viable spin-off companies based on QoLT R&D, indicates that there are much larger markets for QoLT and because, as pointed out by the Site Visit Team, there is great potential in connecting to companies that operate in those markets.

The systems that we have selected have the potential to affect millions of people, as illustrated by Table QoLT-Strategy-1. That table also illustrates opportunities to improve quality of life for even broader populations in mainstream markets. For example, the *InForm Exercise Coach*, while intended for osteoarthritis physical therapy, has applications in sports training.

Table QoLT-Strategy-1: system testbed characteristics

Systems	Examples	Key Functionalities	Targeted Populations (size)	Target Markets *(Adjacent Markets)*
Virtual Coach *Cognitive support in a variety of contexts*	Seating & Medical device usage coaches	provide appropriate guidance, feedback and reinforcement inform clinicians & patients	assistive technology users people with Mild Cognitive Impairment (>6M)	healthcare IT, durable medical equipment, medical devices, assistive technology *(sports training, personal health)*
	Stroke Therapy & Exercise coaches	recognize correct movements track performance inform clinicians & patients	survivors of stroke (2.5M) people with osteoarthritis (20M) people in post-acute rehab	
	Personal Health Informatics	monitor physical activity inform clinicians & patients	people with obesity (MM)	
Home & Community Health and Wellness *Monitoring of health and support in everyday tasks*	Cueing Kitchen	recognize kitchen activities provide cues for actions	people with TBI (5.3M) people with MCI (>6M)	home healthcare, long-term care, *(home security, consumer products, retail)*
	Health Kiosk	measure and record vital signs allow interaction with clinicians	older adults living alone (4M)	
	dWellSense	monitor of ADL & IADL tasks	older adults living alone (4M)	
QoLTbots *Physical assistance with everyday tasks*	Personal Mobility & Manipulation Appliance	manipulate objects for user assist with ADLs	wheelchair users with upper extremity impairment (0.2M)	assistive technology, home healthcare long-term care *(consumer products)*
	Strong Arm	assist with seating transfers	all wheelchair users (4M)	
	Home Exploring Robot Butler	retrieve and place objects prepare meals & do chores	people w/ mobility impairments (10M) frail elderly (4M)	
Safe Driving *Ways to maintain transportation independence*	DriveCap	assess a person's capability to drive a vehicle	drivers with low vision (>3M) people with MCI (>6M)	automotive industries, long-term care *(insurance industry, fleet operators)*
	DriveCap Advisor	provide feedback on driving performance & behaviors	older adult drivers (MM)	
	Virtual Valet	short-distance autonomous driving	drivers with mobility impairments	

2.1.2 3-Plane Chart

The chart reflects the alignment of our thrusts and systems, clarifies the role of each project, exemplifies our system architecture, and depicts the evolution and integration of basic research, enabling technologies and instantiated systems, interacting with the societal influences that both motivate and constrain them. Less obvious are some temporal characteristics that need to be recognized. The top level of the chart displays implemented functioning systems with capabilities to be realized after several years of effort. Each testbed system effort really both begins and ends there. We start with a needs assessment and analysis coming from end-user focus groups, health and rehabilitation clinicians and physicians, community leaders and social scientists, informed by means ranging from personal and professional experience to a plethora of statistics and research studies. These serve to define and set the goals of the QoLT systems that will ultimately emerge as the products of the fundamental research conducted and enabling technologies developed at the levels below. Whereas some particular QoLT systems may "bubble up" from the lower levels, the constituent projects of these levels are the result of a top-down analysis motivated from the QoLT system definitions at the top. The top level also illustrates the fact that data gathering for revealing unarticulated user needs and the evaluation study of QoLT systems' performance and acceptance, occurs in field deployments, and feeds back additional requirements to the technology base and basic research. We also evolve business cases at this level to better understand and speed the commercialization.

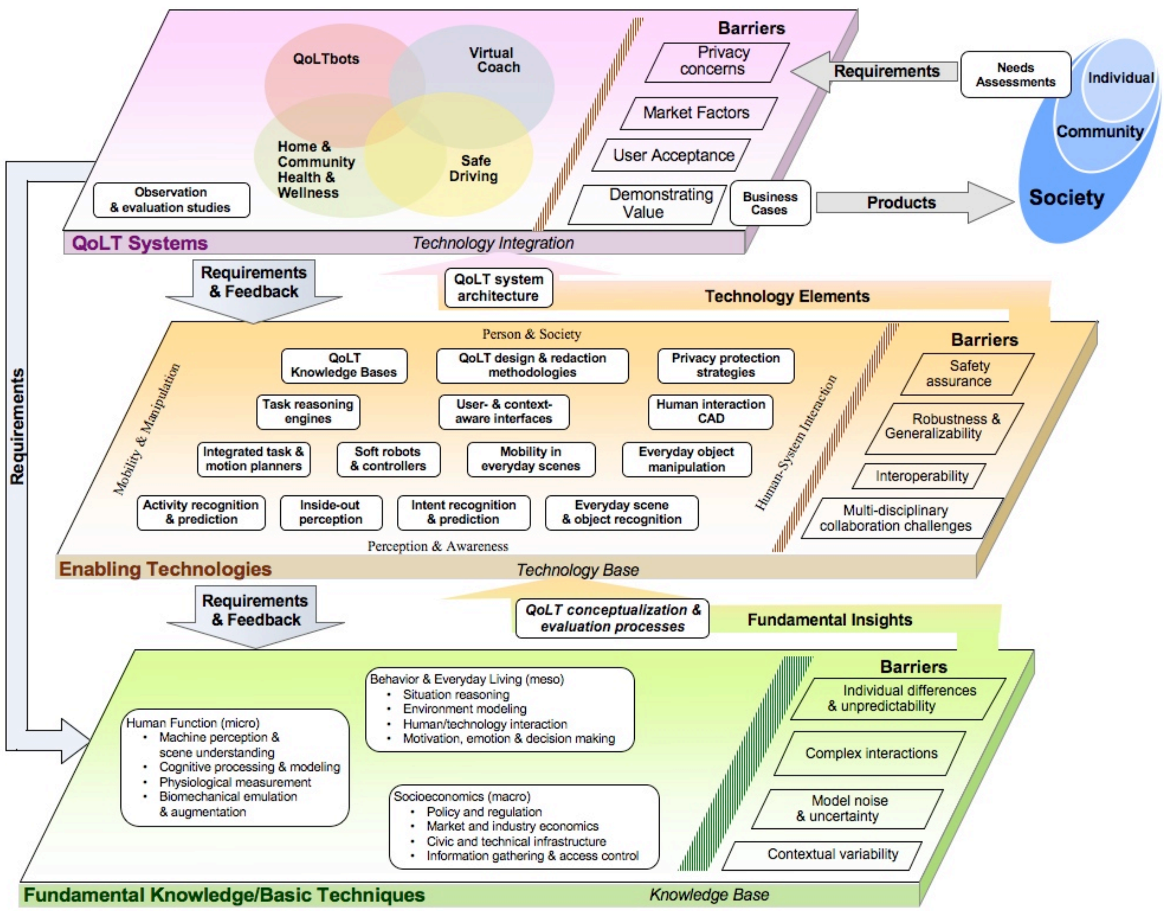


Figure QoLT-Strategy-1: our 3-plane chart

The middle level generates a technology base of modular components that provide necessary functions or capabilities to the multiple QoLT systems, tools to be used in designing and implementing such components, and knowledge and data bases to inform our work and that of our colleagues elsewhere. The technologies of the middle plane map to the modules of the QoLT System Architecture described earlier. For example, “user and context aware interfaces” and “soft robots” serve user engagement, whereas “task reasoning engines” may serve user interpretation. Caregiver engagement is served by “user and context aware interfaces” while his/her interpretation is augmented with “activity recognition and prediction”, “inside-out perception” and “intent recognition and prediction”. An interpretation of the environment is enabled by “everyday scene and object recognition”, and “inside-out perception” whereas “integrated task and motion planners” enables safe and complete task execution in the environment. The bottom level basic research increases fundamental knowledge to support the development of the technology base. We have categorized these as primarily focused on individual human function (the micro-level), behavior and interaction with the living environment (the meso-level), and the social and economic factors (the macro-level) that enables or constrains the outcomes of our work. The barriers that appear on the right side of each plane are discussed in Section 1.1 of this volume.

How each of the thrusts and systems contributes Fundamental Knowledge/Basic Techniques and Enabling Technologies to achieve our vision is presented in Table QoLT-Strategy-2a (“QF” stands for QoLT Foundry, considered as a thrust for the sake of this discussion). Table QoLT-Strategy-2b indicates which of the identified fundamental barriers are addressed by each thrust and system. Note that 1) several thrusts/systems address the same barrier and/or contribute to the same knowledge or technology base and 2) every thrust/system addresses multiple barriers and is making multiple contributions. This attests to the integrative – and necessarily collaborative nature of QoLT R&D. It is also worth noting that this matrix has evolved over the course of the ERC, particularly with more contributions from the systems.

Table QoLT-Strategy-2a: Contributions of thrusts and systems to elements on the 3-plane chart

	HSIT	PAT	PST	HCHW	QB	SD	VC	QF
Needs assessments			■	■	■	■	■	■
Business cases								■
Observation & evaluation studies			■	■	■	■		
QoLT system architecture							■	■
QoLT Knowledge Bases	■	■	■	■	■	■	■	■
QoLT design & redaction methodologies	■						■	■
Privacy protection strategies		■	■					
Task reasoning engines				■	■			
User- & context-aware interfaces	■			■	■	■	■	■
Human interaction CAD	■				■			
Integrated task & motion planners					■	■		
Soft robots & controllers					■			
Mobility in everyday scenes					■			
Everyday object manipulation					■			
Activity recognition & prediction	■	■		■	■	■	■	■
Inside-out perception		■	■	■				
Intent recognition & prediction	■				■			
Everyday scene & object recognition		■						
QoLT conceptualization & evaluation processes			■	■	■	■	■	■
Human Function	■	■		■	■	■	■	■
Behavior & Everyday Living	■	■		■	■	■	■	■
Socioeconomics			■					■

Table QoLT-Strategy-2b: Fundamental barriers addressed by thrusts and systems

	HSIT	PAT	PST	HCHW	QB	SD	VC	QF
Privacy concerns								
Market factors								
User acceptance								
Demonstrating value								
Safety assurance								
Robustness & generalizability								
Interoperability								
Multi-disciplinary collaboration challenges								
Individual differences & unpredictability								
Complex interactions								
Model noise & uncertainty								
Contextual variability								

2.1.3 System-driven Technology Development Roadmap

The Center's technology roadmap is shown in Figure QoLT-Strategy-2, which also shows each testbed has evolved as an integrated system of enabling technologies

We have defined performance metrics for QoLT systems and Enabling Technologies. An example for robotic assistance was presented in Table QoLT-Impact-1; Table QoLT-Strategy-3 captures progress made on the system specifications we deem most crucial.

Table QoLT-Strategy-4 presents milestones grouped by testbed systems and research thrusts. It distinguishes between milestones already achieved through 2013 and those expected to be achieved by the end of Year 8 (5/31/14). Some milestones originally targeted for Year 8 will be achieved in Year 9.

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Figure QoLT-Strategy-2: QoLT Research Roadmap

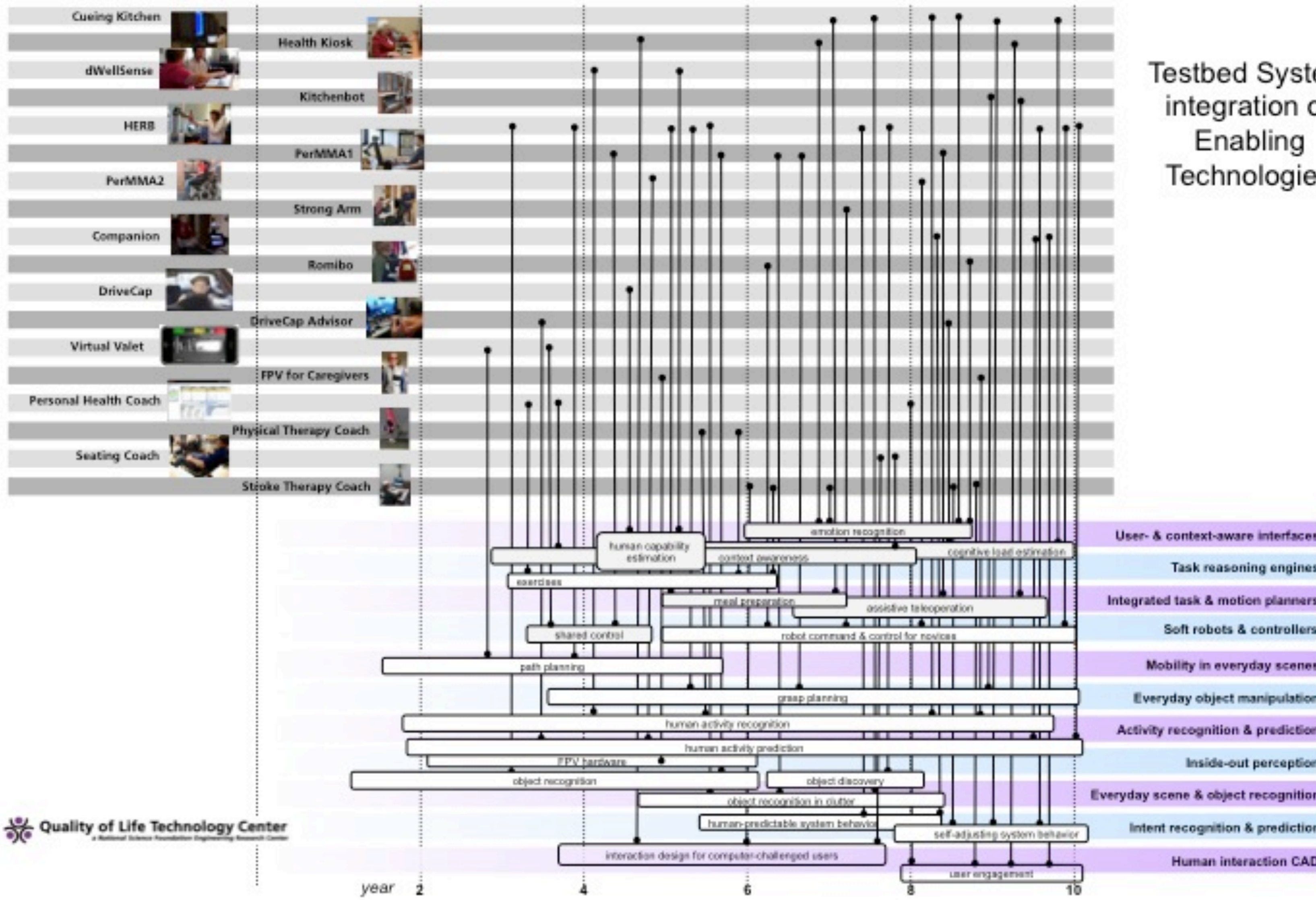

Table QoLT-Strategy-3: Testbed System Performance Metrics: Goals and Progress toward Achieving Them

	Specification type	Performance metric	Goal	Why crucial	Performance 1 year ago	Performance now
FPV for Caregivers	System (technology)	data capture reliability	fewer than one failure per 30 hours of operation	If device failures occur too frequently, we risk participants becoming frustrated and leaving the study.	All three units failed at least once per week	Three units, all collecting data for periods of up to 7 days.
	Caregiver interaction	tolerable burden during use	>80% of caregivers are comfortable wearing the unit for epochs of up to 4 hours	Utility of the system (as well as our preliminary data collection) requires the caregiver to wear it for extended time periods.	Some dissatisfaction with the vest design and initial unreliability	8 of 9 participants rate the wearable camera and support vest favorably in terms of comfort
	User interaction	perceived invasiveness	<20% of care recipients are distressed by the device	Rejection by the care recipient renders this approach useless.	Caregivers' wearing of the FPV device and vest prompted questions indicating curiosity but no distress	No care recipient distress has been reported (N=9)
Health Kiosk	System (technology)	data security	100% compliance with HITECH standards for electronic protected health information	Ensuring that personal health information gathered, transmitted, and stored electronically is adequately protected is required by law.	Privacy and security protections were partially implemented in our prototype kiosk.	Mechanisms for ensuring privacy and security of data have been fully integrated with the health kiosk, even as a formal HIT evaluation is being conducted that will result in formal policies and procedures for handling HITECH standards.
	User interaction	assistance required to use	95% of older adults capable of using the health kiosk independently after ≤2 training sessions	System is intended for self-monitoring and management of aspects of health and function.	Community-based usability testing showed that many older adults can learn to use the kiosk in a single session, but additional training support should be offered.	12-month deployment health kiosks at 3 congregate sites has commenced; training activities are currently being tracked.
HERB	User interaction	Intent-expressive legible motion	Observers predict the correct goal >90% of the time within the first 15% of the start of motion	Intent expressive motion is critical for seamless and coordinated human-robot collaboration.	Anecdotal data that legibility framework improved expressiveness	Familiarization to robot motion statistically significantly improved legibility (p=0.0035, 25 users) and trust (p=0.0031,16 users)
	System (technology)	robustness to uncertainty during grasping	Fewer than 5 failures per 100 grasping attempts	Grasp failures can be catastrophic and diminish trust	Grasping was open-loop stable but did not use sensor feedback	Grasping with feedback succeeds 84% of the time compared to 61% without feedback.

	Specification type	Performance metric	Goal	Why crucial	Performance 1 year ago	Performance now
PerMMA	System (technology)	object recognition accuracy	>80% accuracy on properly recognizing an object on the first attempt	Recognizing, estimating the pose of everyday objects and grasping objects is essential for robotic assistance with ADLs and IADLS	algorithms beginning to be ported from HERB to PerMMA	92% successful detection (n=62) within 1 second
	System (technology)	trajectory planning accuracy	>90% rate of calculating an acceptable path planning trajectory on the first attempt within 5 seconds		algorithms beginning to be ported from HERB to PerMMA	92.2% successful planning (n=5197) with 3 seconds on average
MEBot	Human-system symbiosis	acceptability	>95% of users find safety and ease of use to be acceptable	Enhanced mobility is the goal	Focus group provides data that is qualitatively positive	User testing to begin in Year 9
	System (technology)	curb climbing	climb curbs >5” in less than 30seconds	Climbing curbs is a challenge for most users of power wheelchairs.	(PerMMA-2) 3” curbs in 150 seconds	(MEBot) 8” curbs in 20 seconds
	System (technology)	self-leveling of seat	maintain level on side slopes of +/-15^o degrees and front/back slopes of +/-20^o	If the system does not detect the slope and react responsively, it will lead to user discomfort	Algorithm meets performance goal in simulation	Algorithms implemented on robot; testing on CAREN system to begin in late Year 8
Strong Arm	System (technology)	tip-over margin	safely transfer users weighing up to 250 lbs on 6 degree slope	If device is not stable during transfer, users will not trust it.	Mathematical prediction model verified	Algorithms implemented on robot; testing to begin in Year 9.
	Human-system symbiosis	required manpower	no greater than current standard practice (2 people)	Goal is to reduce labor costs	Clinical researcher on team able to assist with transfer by herself	Testing with practicing clinicians to begin in Year 9
	Human-system symbiosis	time to complete transfer	no greater than 3x the time using current standard practice (e.g., 160 sec. chair to bed using ceiling lift)	Wheelchair users will expect transfers to be at least as efficient as current practice, regardless of the manpower required	Wheelchair to sofa transfer in ½ time of standard practice (Hoyer lift) by research team	Testing with clinicians and prospective users to begin Year 9
Stroke Therapy Coach	Human-system symbiosis	acceptability	>90% of users find the coach acceptable	Rejection by the care recipient renders this approach useless.	not yet tested	95% of users satisfied with system performance
	User interaction	emotion recognition error rate	comparable to human coach	Emotion recognition is crucial to successful coaching and to user acceptance	not yet integrated	>75% accuracy

	Specification type	Performance metric	Goal	Why crucial	Performance 1 year ago	Performance now
QoLT CAD	System (technology)	# of independent movements measured simultaneously	10 (elbow x2, shoulder x2, knee x2, hip x2, trunk, neck)	These primitive widgets can serve as a foundation for recognizing numerous exercise movements corresponding to those joints.	One primitive widget was implemented: elbow.	Two primitive widgets have been implemented: elbow and shoulder.
	Caregiver Interaction	# of exercises authorable by PTs	at least 10	Cover large portions of established rehabilitation regimens.	Algorithms in development	2 representative exercises demonstrated with the tool
Cueing Kitchen	Human-system symbiosis	Improved independence and self-efficacy	20% less prompts needed, 30% reduction in perceived cognitive loads	This will affect if the system will be accepted and adopted by end-users	Developing the testing protocol and software system for human subject testing	Ready to test with human subjects and obtain data related to the metric goal
	Caregiver Interaction	effort to help set up and maintain the system	less than 3x time to create paper-based instructions	Caregivers need to setup the system for end-users to use the system	-	Testing to begin in Year 9
	System (Technology)	ease of installation in the field	Can be installed in a residential kitchen in less than one day	This will affect if the system can be realistically deployed in real world.	Developing a portable system	A portable prototype has been developed and is ready for testing.
	System (Technology)	reliability for everyday use	fewer than 1 system failure per 3 hour of operation	This will affect user interaction with the system and their satisfaction and acceptance of the system	Frequent wireless communication failures	Reliability qualitatively improved by through additional sensors and software upgrades
Kitchenbot	Human-system symbiosis	perceived usefulness and ease-of-use	80% of users find the KitchenBot easy-to-use and acceptable	This will affect if the system will be accepted and adopted by end-users	informal and anecdotal data only	Focus group evaluation showed 64% people considered Kitchenbot is easy to use, and 73% considered it is useful.
	Caregiver Interaction	Potential remote operation	Less than 3 times effort compared with assisting the task on site.	If it takes too long for a caregiver to operate the Kitchenbot remotely, caregivers will not accept such technology	informal and anecdotal data only	Testing to begin in Year 9
	System (technology)	track & carriage positioning accuracy	±1mm	Better positional accuracy will reduce computational demands on grasping control	Developing prototype track system	±1cm, but positioning errors increase with longer use
		track and carriage system reliability	fewer than 1 system break down for 10 hours of use	This will affect user interaction with the system and their satisfaction and acceptance	Developing prototype track system	Design still has trouble going through corners
DriveCap	Caregiver /clinician interaction	tolerable error rate in data interpretation	comparable to error rate of summary by observer of driving in real time	Accurately assessing whether a driver is safe has direct implications on both end user and bystander safety	Beginning to collect data	An on-road study with 16 participants showed perfect classification for driver pass/no-pass

	Specification type	Performance metric	Goal	Why crucial	Performance 1 year ago	Performance now
DriveCap Advisor	User interaction	tolerable burden during use	wearable sensors are comfortable, can be used while wearing winter clothing	Uncomfortable wearable sensors will lead to system abandonment.	Multiple body-worn sensors, including some that were rather cumbersome.	Body worn sensors have been considerably reduced in size.
	System (technology)	required accuracy	classification accuracy greater than human observer	Accurate detection of behaviors and activity are critical inputs when providing coaching.	Good progress towards detecting cognitive load. Limited progress towards detecting aggressive driving.	Model accuracies ranging from 81-90.5% for detecting aggressive driving.
Seating Coach	System (technology)	reliability of the app	zero failures for > one week of operation by a prospective user.	Reliability of the system will significantly affect user satisfaction and acceptance	System worked but reliability not yet tested	Zero failures for three weeks of operation by a prospective user
	System (technology)	Durability of the hardware	survives > one week of field use	Reliability of the system will significantly affect user satisfaction and acceptance	Not tested yet	Zero failures for three weeks of operation by a prospective user
	User interaction	understandability of information fed back to user	>75% of users easily understand information display on the smartphone version	Information visualization will affect perceived usefulness and satisfaction with the system	Clinicians affiliated with QoLT but not on development team felt display was understandable	All five participants of field trial found information was easy to understand

Table QoLT-Strategy-4: Milestones & Deliverables, achieved and future

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Home and Community Health & Wellness (HCHW)				
	• three generations of Health Kiosk prototype • laboratory study of Health Kiosk usability by older adults • Health Kiosk field usability study in four community settings with over 40 older adults • Health Kiosk enhancements based on usability studies • dWellSense instrumentation and software infrastructure • dWellSense data visualizations for clinician assessment and for client self-reflection • dWellSense deployment in approximately 12 households for at least 8 months • small scale Cueing Kitchen prototype • Cueing Kitchen usability study with 5-10 users/caregivers and 3-5 clinicians • Cueing Kitchen usability study protocol for use in full-size kitchen • (with PAT) feasibility study of vision-based activity recognition for use in Cueing Kitchen • refined dWellSense visualizations • determination if dWellSense data can provide clinical data about cognitive decline • administrator *and clinician* interfaces for Health Kiosk • improved Health Kiosk accessibility • business models of Health Kiosk for several deployment scenarios	Achieved already: • preliminary guidelines for selecting cueing methods based on user profiles and task characteristics • (with PAT) adaptation of First Person Vision for Cueing Kitchen • pilot-scale Health Kiosk intervention study with a healthcare provider (underway) by end of Year: • methods (automated, semi-automated, and manual) to step through cues for meal preparation task • full-size Cueing Kitchen software implementation • additional Health Kiosk screening functionality per clinician preferences and business models Dropped: • (with PST) adaptation of dWellSense into a tool for clinical use	Achieved Early (in Year 8): • prototype kitchen safety warning system • portable sensing and cueing components for field deployment Deferred from Year 8 to 9: • (with HSIT) techniques for inferring user intent and dynamically adjust cueing methods based on user response • pilot-scale Health Kiosk intervention study with a healthcare provider • (with PST) Health Kiosk interoperability with a standard PHR As Originally Planned: • (with PST) Health Kiosk interoperability with a standard EMR • evaluation of effectiveness of different cueing methods for different user groups	• field deployment of Cueing Kitchen • (with PST) study of user characteristics that affect Health Kiosk adoption, patterns of use, and effectiveness

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
QoLTbots (QB)				
	• HERB, PerMMA-1, PerMMA-2 testbeds • Strong Arm testbed (prototype transfer robot) • Constrained autonomous motion planning for real-world constraints like keeping objects upright and opening doors • OpenRAVE (open Real And Virtual Environment software architecture for testing, developing, and deploying motion planning algorithms) founded • (with PAT and MoMaT) perception, planning, and manipulation algorithms running on HERB to household object fetching tasks • Physics-based planning for autonomous manipulation in clutter and uncertainty • assistive teleoperation algorithms for HERB • Planning and control of human-robot collaboration during handover task • Prototype HERB user interface for meal preparation task • algorithms for mobile robot traction control on a variety of surfaces • PerMMA remote operator interface with thermal vision, stereo vision, 3D surface displays and force feedback • PerMMA teleoperation over the Internet • PerMMA-2 curb climbing and posture control • Intuitive Interaction scheme for Strong Arm • initial testing of Strong Arm by caregivers • planner to rearrange clutter in the way of primary task • with PAT and MoMaT) algorithms running on PerMMA to demonstrate opening door and retrieving a soda from a refrigerator • QoLTbot efficacy evaluation tool based Performance Assessment of Self-Care Skills (PASS) instrument • (with PAT and MoMaT) fully-autonomous frozen meal preparation demonstration • grasping tasks learned from experience	Achieved already: • loosely coupled human-robot cooperative manipulation tasks (like clearing a table) on HERB • ADL Task Board • HERB user interface on an Android tablet • Multi-stage manipulation planning for sequenced tasks like meal preparation. • legible motions learned by human demonstration • MEBot self-leveling • (was MoMaT) simplified system to economically provide the most important features of the intuitive interface system by end of Year: • field study evaluation of PerMMA interaction modes • QoLTbot user interface with gesture, haptic feedback, and speech	Achieved Early (in Year 8): • (with PAT) planning with partial observability due to occlusions in heavy clutter • tightly coupled human-robot cooperative manipulation tasks (like lifting a table) on HERB • (with PAT and MoMaT) loosely coupled cooperative tasks (like meal preparation) Deferred from Year 8 to 9: • initial testing of Strong Arm by end-users • planners for two-arm tasks • physics-based multi-arm behaviors • (with HSIT) techniques to predict human intent for assistive teleoperation /collaborative manipulation As Originally Planned: • PerMMA-3 testbed • QoLTbot tasks learned by human demonstration • tactile and force sensing incorporated into planning and control • reconfiguration planning and compliant planning and control for robust execution of complex tasks	• tightly coupled human-robot coordinated manipulation tasks (like preparing a meal) • (with PAT and MoMaT) autonomous and coordinated meal preparation in an unknown kitchen with minimal instrumentation • end-user studies of user interaction designs in the field • (was MoMaT) incorporation of limited autonomy into Intuitive Interface • (was MoMaT) demonstration of the simplified Intuitive Interface system in a test kitchen • (was MoMaT) coordination methods for a large library of mobile manipulator behaviors • (was MoMaT) planning methods for dynamic tasks and environments

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Safe Driving (SD)				
	• DriveCap data logger • driver cessation survey • algorithm to predict route based on historical routes • case studies in payment issues for vehicle modification, drive-by-wire vehicle modifications, novel interfaces for older drivers • stakeholder focus groups to identify valuable vehicle enhancements • techniques & interfaces to provide personalized route advice (also a spin-off company to commercialize them) • prototype Virtual Valet for use in private spaces • database of factors leading to driving cessation • prototype Virtual Valet • techniques to estimate cognitive load • on-line survey of end-users of Drive-by-Wire aids • integration of two Drive-by-Wire systems and a vehicle simulator to form one working system • observation and evaluation of the driving characteristics of 30 participants using the driving simulator • clinical guidelines for DriveCap use • additional methods for identifying differences in driving performance. • (with PST) prototype end-user interfaces and interactions for a DriveCap Advisor system • camera-based localization for Virtual Valet • field study using DriveCap	Achieved already: • business model for (and spin-off company to commercialize) DriveCap • naturalistic field data gathered for case study on Turning Assistance • evaluation of DriveCap Advisor Dropped: • improvements to the operator supervision components of Virtual Valet	Achieved Early (in Year 8): • empty parking spot detection for Virtual Valet Deferred from Year 8 to 9: • prototype Turning Assistance As Originally Planned: • start case study on One-handed Steering • field evaluation of DriveCap Advisor upgrade (addition of Year 7 PST identified features and components) • additional DriveCap Advisor algorithms	• business model for DriveCap Advisor • prototype One-handed Steering • technology enhancement of Turning Assistance • translation of new perception methods to Safe Driving projects (with PAT)

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Virtual Coach (VC)				
	• Physical Activity Coach (IMPACT) • Memory Coach (MemExerciser) • Computer Access Coach • propulsion coach for manual wheelchair users • two generations of Seating Coach for power wheelchair users • initial evaluation of Seating Coach for power wheelchair users • initial evaluation of psychosocial stress coach • prototype Exercise Coach • Personal Health Informatics • definition and demonstration of Virtual Coach software architecture • prototype HeadCoach and pilot study • prototype "Who's that?" coach • software architecture that supports multiple simultaneous virtual coaches • retrofit 10 wheelchairs for pilot study of Seating Coach • (with HSIT) Personalized Social Coaching integrated into Seating Coach • usability testing of physical therapist interfaces for HeadCoach • dashboard to track a variety of exercise activities • 8-week randomized control trial of Seating Coach (was planned for Year 8)	Achieved already: • expanded QoLT CAD component library (motion widgets) • motivational components for Exercise Coach and HeadCoach • emotion recognition integrated into Stroke Therapy Coach • emotion recognition integrated into Health Kiosk by end of Year: • tools to help clinicians to implement coach specifications • tools for specifying coach systems without programming Dropped: • deployment of Head Coach • automatic generation of classification elements for Virtual Coaches • clinician's remote interface for Head Coach • method to identify conflicting Coach rules and suggest changes to address the conflict	Deferred from Year 8 to 9: • deployment of Exercise Coach • business models for Exercise Coach • (with HSIT) field study of physical therapy coaching techniques As Originally Planned: • method to infer detailed coach functionality from high level specification rules • automatically generated classification models from user provided data sets • Stroke Therapy Coach full suite of games defined • user study of Stroke Therapy Coach	• prototype IADL coach • (with PST) prototype caregiver coach • prototype way finding coach • multi-purpose Virtual Coach Added: • hospital discharge coach

<table>
<tr><th></th><th>Achieved through Year 7</th><th>Planned for Year 8</th><th>Planned for Year 9</th><th>Planned for Year 10</th></tr>
<tr><td colspan="5">Human-System Interaction Thrust (HSIT)</td></tr>
<tr><td></td>
<td>• machine learning techniques that identify PC user's mousing performance
• designation interfaces based on machine learning
• activity recognition based on wearable location, biosignal & physical activity sensors
• techniques to infer user stress with wearable location, biosignal & physical activity sensors
• application of elements of game theory for motivating physical therapy
• clinician's "prescription" & feedback interface for EPW auxiliary seating function use
• field study of Lego robots for motivating AAC
• wearable electrocorticography hardware
• contextually aware smart-phone ringer adaptation app
• recognition of some emotions through audio analysis
• real-time data logging format and protocol for whole ERC
• algorithms for switching between interaction models based on inference of user's intent
• evaluation of active intent recognition algorithm in simulation and on real robot data
• Wizard of Oz study on physical therapy coach avatar
• analysis of user study on preferences for controlling robots
• competitive analysis of multi-user/multi-robot system (MURS) techniques
• pan & tilt camera head for HERB
• obstacle detection for HERB
• prototype user interfaces to HERB
• study of active intent recognition with human subjects
• expanded recognition of emotions through audio analysis
• autonomous responses for physical therapy coach
• pilot study of Romibo with children with disabilities</td>
<td>Achieved already:
• emotion recognition by facial expression analysis
• modulation of user interaction based on emotion recognition
• prototype of tactile system for MURS
• visual, auditory and haptic interfaces for MURS
• testing of MURS interface guidelines with several system designs

Added and Achieved:
• integration of emotion recognition into Stroke Therapy Coach and Health Kiosk
• method for automatic goal adjustment

by end of Year:
• (with VC) pilot study of personalized context learning on Seating Coach
• incorporation of semantic information in user interaction personalization
• (with PAT) incorporation of recognition algorithms into physical therapy coaching

Dropped:
• housing and docking station for HERB</td>
<td>Deferred from Year 8 to 9:
• implementation of intent recognition system on HERB and/or PerMMA
• evaluation of HERB user interfaces
• pilot study of Romibo with older adults
• user study of emotion recognition

As Originally Planned:
• definition of metrics of user engagement
• design guidelines for human interfaces to personal assistive robots
• evaluation of automatic goal adjustment in therapy coach

Modified:
• incorporation of emotion measurements (was stress measurements) into user interactions</td>
<td>• architecture for encoding interactions between an autonomous system and a user
• motivation techniques for personal safety coaching
• integration of emotion recognition into a VC and a QoLTbot
• incorporation of cognitive load measurements into user interactions
• algorithms for performing inference over the observed inputs from the sensors and the a priori interaction models

Added:
• user study of emotion recognition including use of personalization
• clinician interface to automatic goal adjustment</td></tr>
</table>

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Mobility & Manipulation Thrust (MoMaT) Note: this thrust was halted and it research agenda picked up by QoLTbots				
	• simultaneous collision-free path & grasping; constrained motion • direct manipulation control mode for object lifting & moving • manipulation planner for constrained motion • trajectory planner robust to noisy/incomplete data • trajectory planner for grasping deformable objects • trajectory planner for closed-chain kinematics & other complex constraints • trajectory planner 2 arm coordination (robot-robot, human-robot) • controller for two-arm lifting of heavy objects • compliant control demonstrated on 3 classes of robots • direct & teleoperation interfaces for heavy lifting • balance controller • prototype soft robot • prototype pressure sensing robot skin • user testing of Intuitive Interface • simulation of planar human walking, slipping, and tripping • incorporation of tactile and force feedback into physics-based actions • technique to automatically construct trajectory attributes from data • robot handoff behaviors to transfer objects to and from humans • planner to reveal unknown spaces occluded to the robot's sensors • integration of a variety of new and off-the-shelf sensors into our current soft arm prototype • feeding and wiping using our current soft arm prototype • modifications to Direct Interaction based on results of initial user testing • neuromuscular model of 3D human walking	Achieved already: • (in QoLTbots) design specifications for robot to do human transfers Achieved via Associated Projects: • gait testbed for transferring neuromuscular design and control of strategies to assistive devices Dropped: • incorporation of wrist, ceiling-based mount, and an alternative skin-based interface for the end-effector of Direct Interaction • field testing of the simplified Intuitive Interface system with individuals with chronic stroke • user testing of intrinsically soft robot in feeding and grooming tasks • models and simulations of how accidents happen • physics-based whole body behaviors for mobile manipulators		

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Perception & Awareness Thrust (PAT)				
	• First Person Vision prototype; initial evaluation by end-users • algorithms for everyday scene & object recognition: image indexing, learning to discriminate from clutter, predictive appearance, using temporal nature of video, geometric reconstruction of objects and architectural features • algorithms for everyday scene & object recognition: real-time predictive appearance • algorithms and systems for describing user's environment and cataloging possessions • algorithms for activity recognition: unsupervised image segmentation; (can recognize standing, sitting, pick up object, waving, pointing, eating, drinking) • algorithms for activity prediction: reinforcement learning , graphical models for learning tasks as aggregated motions • algorithms for activity recognition with near real-time performance • synchronization tools for merging multiple data sources • tools to support Grand Challenge in situ • Grand Challenge data collection initiated in multiple homes; data gathered in situ added to online library • Grand Challenge data/algorithms for household chores added to online library • human awareness algorithms and data sets in online repository • algorithms and systems for learning models of familiar objects and recognizing them in input data • algorithms for clustering, recognition, alignment on in-situ data on typical tasks • algorithms for forecasting sequences of human actions • (with PST) field evaluation of FPV • wearable face recognition system • wearable object recognition system	Achieved already: • field deployable object learning system • integration of system for human action recognition & prediction • field deployable object recognition and discovery system	Deferred from Year 8 to 9: • (with HSIT) incorporation of recognition algorithms into physical therapy coaching Associated Project: • recognition systems using cloud computing • building interior navigation system for people with visual or cognitive impairments As Originally Planned: • algorithms for activity recognition for - larger classes of actions -interactions between people • integrated object discovery, learning and recognition system	• in situ evaluation of object recognition and discovery • in situ evaluation of object model learning • in situ evaluation of integrated object discovery, learning and recognition system

	Achieved through Year 7	Planned for Year 8	Planned for Year 9	Planned for Year 10
Person & Society Thrust (PST)				
	• database of evaluation techniques and assessment strategies for QoLT • registries of IRB-approved study populations • protocol and researcher training for integrating clinician & end-user perspectives into QoLT designs • survey on attitudes towards the ERC's QoLT Systems and assessment strategies for QoLT • registries of IRB-approved study populations • computerized search system (QoLT Mine) for related QoLT products & research activities • survey on attitudes towards privacy, privacy trade-offs & QoLT Systems • guidelines related to privacy for QoLT engineers & designers • QoLT Handbook • (with HCHW) community-based usability testing of Health Kiosk • survey investigating various video masking strategies with a national representative sample of middle-aged and older adults with/without disability • qualitative follow-up study of video masking strategies with an online sample • analysis of health care providers' views of data trustworthiness of various types of health and functional status obtained from an array of technology and non-technology sources • statistical analyses of surveys using Rich Stimuli Data Collection techniques • (with PAT) community-based usability testing of First Person Vision with dementia sufferer / spouse dyads • repository for QoLT visual stimuli for use in survey and qualitative research • Rich Stimuli guidelines to aid engineers developing QoLTs • follow-up survey of QoLT Registry participants regarding reaction to rich visual stimuli depicting QoL technologies • survey exploring the patient/consumer perspective of trustworthiness of various types of health and functional status data from technology and non-technology sources • analysis of nationally representative sample of adults, detailing reactions to different video masking techniques	Achieved already: • development of cost/benefit and adoption of QoLT evaluation models that take into account quality of life • evaluation methodologies that use rich stimuli to enable assessment of user preferences for features and functionalities of QoLT systems • more refined, targeted, large sample rich stimuli studies of design features of QoLT systems • analysis of data trustworthiness survey data Added and will be by end of Year: • Policy case study and recommendations for Health Kiosk	Deferred from Year 8: • Integration of QoLT Handbook into QoLT training programs • design of large-scale evaluation studies that generate evidence of efficacy and effectiveness for QoLT systems • methods for overcoming adoption barriers due to privacy concerns with QoLT systems As Originally Planned: • Health Kiosk intervention study • analysis of theoretical and practical implications of video masking techniques • further exploration of technical and psychological reactions to video masking techniques and presentations	• extension of FPV system to other applications involving complex health related behaviors (e.g., self-management of complex medical treatments; difficult transfers) Modified: • guidelines for addressing data trustworthiness into features and functions • guidelines for integration of findings pertaining to privacy concerns into features and functions Added: • analysis of outcomes of FPV use by dementia caregivers • development of blueprints for technology development processes and associated methods and measures • caregiver preference and cost models for personal care and kitchen assistance technologies

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2.1.4 Strategic Planning

We use the tools presented above to plan projects. The review process that we now use started in late 2009 with a top-down directive from Director Takeo Kanade that the research projects should be categorized along four dimensions of synergy:

- Technology Trajectory – were the capabilities of the technology increasing (upward) or level
- Reuse/integration – could the technology be used in other projects, was the technology being integrated with other technologies to produce a more capable system
- Collaboration – was there collaboration with other projects and between organizations
- External engagement – was there engagement with partners and the public beyond the ERC

Near the end of each ERC year (early Spring), thrust and testbed system leaders grade current projects with respect to their Impact (Scientific, Commercial, Public, Educational), Relevance/Synergy (technical/scientific, interdisciplinary, and external), and Execution Quality. In addition, they craft brief proposals for the next year's research portfolio. Each project is assigned to specific members of our SAB and IPAB for review. In this process we get feedback from them individually through a phone call (we also get input on appropriateness of research directions at the Center, system, thrust and project levels at their annual meeting in the Fall). With all of those inputs in mind, the Center leadership drafts the next year's project portfolio scope and budget, striving to balance progress down the roadmap with contributions to our technology and knowledge bases. The Center Director makes final determination.

2.1.4.1 Budget Plan

One major change for Year 8 was to dismantle *MoMaT* as a thrust; most of its components were picked up by QoLTbots. A budgeting challenge was a cap on Year 8 spending at 67% of the nominal, expected amount. The effects of that are discussed in section 5.3.3.

2.1.4.2 Integration of Education and Research (including REU Program)

QoLT's Research Experience for Undergraduates program affords approximately 10-14 undergraduate students per summer an opportunity to engage in QoLT research. Students often work on projects that have components at both universities, such as the *Virtual Coach* or *PerMMA*, affording them opportunities to learn from faculty and graduate student mentors across many disciplines. Accompanying activities expose students to the research across the center through tours, field trips to industry partner sites, and workshops led by QoLT faculty. A culminating symposium allows students to practice presenting and disseminating research results and serves as an event to bring together and update researchers and interested parties across both universities on the QoLT center's activities. The outcomes of the REU program are assessed by the Person and Society Thrust which have indicated that it serves as a powerful intervention in which to raise students' self-efficacy in succeeding in STEM programs and pursuing advanced degrees. Four alumni of the QoLT Center REU, plus one student who participated in our Bridge Program with the PROMISE AGEP, are now QoLT graduate students.

QoLT serves as the client in several capstone design and other classes. Recent examples include:

- Rapid Prototyping of Embedded Systems. This is an advanced research and survey course with 25% credit in a project component. During the Spring of 2012, students designed and architected three virtual coaching systems using QoLT CAD techniques (see project write-up in Volume 2).
- Graduate Course in Mobile and Pervasive Computing. This is an advanced research and survey course with 25% credit in a project component. During the fall of 2012, students designed and architected two mobile applications ; using First Person Vision to recognize faces and provide names to the user in a heads up display, and measuring the impact of latency (as induced by shipping computations off to the cloud) on user performance.
- Engineering Product Design. In an interdisciplinary project course offered by the CMU school of engineering, also taken by business and design majors, upper classmen undergraduates work in

teams of 5-7 students to develop a complete solution for a new or revised product for a real client in the Pittsburgh area (besides the QoLT Center, other clients have included Westinghouse Nuclear, Calgon and Bombardier). QoLT has been a popular theme for the past six semesters and has yielded. a Kitchen Inventory Tracker; a fitness encouragement system, a new rollator design, a sensor to encourage proper use of a walker, an iPhone app to encourage healthy eating, a more accessible kitchen, and a combination cane/grabber. One team prototyped a motorized lift chair with better ergonomics than products currently on the market. They have since formed a start-up company to commercialize their design.

2.1.4.3 Translational Research & Innovation Grants

We have secured six projects in aggregate from three rounds of the NSF Small-business ERC Collaboration Opportunity Program (SECO). Our general SECO strategy is to leverage QoLT Center outputs, giving priority to technology artifacts over knowledge that we have created, and simultaneously advance one or more QoLT Center goals. For small business partner, the objective is to generate a new product offering and/or enhance one of its existing products.

The first three awards were made to small businesses, which subcontracted the QoLT Center. All have been completed.

Robust Speech to Text Messaging
(with TravellingWave, Inc.)
This project addressed some shortcomings of the existing input interfaces for mobile devices, such as 9-digit keypad, miniature keyboards and more recently touch-based inputs. Such interfaces are being used by mobile users to enter text into applications like email, messaging, or internet browsing. It is widely acknowledged that these low-level input methods are unintuitive and lack the speed, accuracy, and user-friendliness of a full-size keyboard. To address these problems, this project incorporated a "predictive speech-to-text" prototype as a new user interface paradigm into first iteration of TravellingWave's VoicePredict product, which is one of the first multimodal mobile user experiences. Voice prediction technology has the potential to become a ubiquitous interface for a variety of computing platforms including personal computers, embedded and assistive technologies.

The project resulted in significant usability improvement of its VoicePredict system over conventional text-input systems. For novice users, VoicePredict is 27% faster than a 9-digit keypad and needs 63.5% fewer keystrokes than 9-digit keypad. For experienced users, VoicePredict is 44% faster and needs 84% fewer keystrokes then 9-digit keypad. For users' familiarity with a virtual keyboard, VoicePredict is 29% slower for novice users, but still needed 32.5% fewer keystrokes then a virtual keyboard. For experienced user, VoicePredict is 3.6% faster and needs 70% fewer keystrokes then a virtual keyboard. This project enabled integration of VoicePredict into QoLT's Seating Coach, extending and enhancing its usability.

Telerehabilitation System for Intelligent Stretching & Remote Assessment of Arm Joints
(with Rehabtek, LLC)
This project evaluated the potential of a *Virtual Coach*ing paradigm, visual feedback distortion (VFD), to enhance physical therapy regimens that incorporate Rehabtek's IntelliStretch device. IntelliStretch is designed for stroke survivors who experience difficulty performing everyday activities due to hemiparesis (weakness on one side of the body). One specific aim of this study was to investigate the effect of VFD on wrist and elbow range of motion (ROM) as measured by the IntelliStretch. Angular displacement measurements were displayed on a PC and gradually distorted by increments imperceptible to users. This induced the users to reach greater ROM to achieve the same level of feedback on the screen, thus encouraging improved performance. This is akin to a track and field coach "raising the bar" in order to get her athletes to jump higher. The other specific aim was to assess the ROM measurement accuracy of IntelliStretch relative to goniometry, the current gold standard.

We verified that IntelliStretch ROM measurements are valid relative to traditional goniometry, an important pre-clinical result. It also validated VFD as a clinically useful technique in physical therapy.

Rehabtek is incorporating it into their companion software for IntelliStretch. For the QoLT Center, this is an important step forward in our line of *Virtual Coaches* for rehabilitation, exercise and personal health.

Methodology for Applying Haptic Robotics to Agile Manufacturing (with Barrett Technology, Inc.)

The goal of this collaboration was an unprecedented robotic hand with the speed and intelligence needed for dynamic grasping. Barrett's goal of enabling human-robot collaboration in factories complements the QoLT Center's goal for robots to assist people in their everyday lives. In each case people are not only allowed but encouraged to interact with robots that necessarily must be much more aware of those real-time interactions than conventional robots. Through development of an advanced robotic-hand platform that can respond in real-time, this awareness will be able to span the entire robotic arm + hand combination. Barrett is a leader in dexterous robot hands that are light enough to mount on the end of human-friendly (i.e. lightweight) robotic arms. In order keep bulk, weight, and power consumption down, this hand was originally designed with 8-bit processor technology. The improved Barrett Hand incorporates novel motor drivers (Barrett's Puck technology) and 32-bit processor intelligence in order to support responsive grasping and manipulation. Both bulk and power consumption dropped significantly. The project had four (4) objectives: enabling high-speed communications, supporting high-speed sensor feedback, implementing advanced controls, and creating user interfaces.

We developed Robot Operating System (ROS) drivers for the Whole Arm Manipulator (WAM) arm and Barrett Hand that estimate control torques based on a dynamic model of all links, provides ROS services for motion control and ROS messages for feedback, and are compatible with OpenRAVE plugins to allow for autonomous planning and execution of manipulation tasks. We developed plugins for OpenRAVE that allow for the sensing and command of the WAM arm and Barrett hand via an OpenRAVE robot model and randomized path planning of collision-free arm and hand trajectories. Finally, we developed example scripts for OpenRAVE that demonstrate identifying, grasping, manipulating, and releasing objects in both simulation and in reality.

This project helped move robotics a step closer to both ultimate goals of (1) robotic assistants in homes and public places, and (2) human-robot collaborations in factories. Robotic assistants will allow the aging and people with disabilities to remain independent longer, reducing an enormous and growing pressure on society and improving individual dignity and quality of life. This project also aims to improve the quantity and quality of jobs in the US. Human-robot collaboration promotes in-shoring: not only keeping jobs in the US but also raising the level of skill (and pay) of those jobs. Ultimately, a whole new field will emerge to build and service the technology that supports human-robot collaboration.

Late in 2010, we received two SECO grants for ERC-initiated collaborations with small businesses. Those projects will be completed in 2012.

Computer Vision Processing for Assistive Navigation and Recognition (with Wicab, Inc.)

This project focuses on using computer vision algorithms to process video into easily interpretable information for low-vision and blind individuals. Effort will be devoted to enhancing the BrainPort Vision Device, a wearable sensory substitution device designed for the blind. It enables perception of visual information using the tongue and a camera system as a paired substitute for the eye. Visual information is collected from a video camera and translated into gentle electrical stimulation patterns on the surface of the tongue. With training, users can perceive gross shape, size, location, and motion of objects in their environment. The aim of the project is to enhance the BrainPort with computer vision algorithms to enable perception of detailed scene information. These algorithms will ultimately be broadly applicable to all artificial vision devices (i.e. retinal implants) that incorporate camera technology to capture a visual scene. The application of computer vision to aid low-vision and blind individuals has tremendous symbiotic potential: computer vision techniques have matured enough to reliably execute low-level tasks like stabilization, salient feature detection, and 3D reconstruction, while blind individuals bring the power of high-level human inference to interpret the output of computer processing. The particular focus will be in developing compact representations of video that facilitate navigation and recognition functions in individuals with low-vision and blindness. CMU will modify existing algorithms and/or develop new algorithms for the purpose of enhancing a blind users experience with the BrainPort. Wicab will provide hardware (the BrainPort Vision Device, the BrainPort Development Workstation, and the BrainPort API) and will integrate CMU-developed software, as appropriate, for future user testing.

We produced vision-based systems for object-recognition, face recognition, and edge enhancement. The object recognition and face recognition algorithms have been transitioned for a follow-on user study at the University of Pittsburgh. The edge enhancement algorithm has been deployed in the BrainPort system. In addition, we began investigating the use of wearable 3D depth sensors for head-level accident avoidance in real-time, to aid in navigation.

Use of an Instrumented Glove for In-Home Hand Therapy (with Anthrotronix, Inc.)

The objective of this project was to develop a home-based physical rehabilitation system to improve hand function and finger coordination in individuals with chronic brain injury, such as due to stroke. Hand function is particularly important for self-care; in particular, fine motor control and finger coordination are critical for many Activities of Daily Living. The goal will be to use a new technology developed by Anthrotronix (The AcceleGlove) to quantify hand movements and a new technique developed by faculty at the QoLT ERC (Visual feedback manipulation) to improve hand function in elderly patients. Leveraging Anthrotronix's existing technology development experience and the ERC innovative research, we expect that a new home-based therapy product will be released by the end of the project. There are two objectives. 1) Collect and analyze data to develop and validate clinical guidance with regards to the use of an instrumented glove for hand assessment. In particular, we will determine the validity of the AcceleGlove relative to goniometry and standard tests of hand function. 2) Develop a new rehabilitation intervention for hand function. Our rehabilitation systems will focus on promoting coordinated movements of the hand and the ability to move each finger independently of the others.

We took advantage of availability of the Microsoft Kinect, a cost effective RGBD sensor, system that requires minimal setup, and expanded the project objectives in early 2012 to include development of the novel Home Arm Movement Stroke Training Environment for Rehabilitation (HAMSTER). This system is designed to train various arm movements that are commonly impaired after stroke with a motivational game-like interface. These games include a bowling game targeting isolated movements of the shoulder and a table tennis game targeting isolated movement of the elbow. Users also train coordinated movements of the shoulder and elbow in a pick and place game and a darts game. Anthrotronix's redesigned AcceleGlove has been incorporated into the HAMSTER system to detect grasp of virtual object for training functional reach. Additionally, the HandSOME device was integrated with the HAMSTER. HandSOME is a light-weight device designed to assist with finger extension, which is commonly impaired after stroke.

Initial evaluation of the HAMSTER system by clinicians has been completed. Twelve clinicians (OTs and PTs) with experience treating individuals with chronic stroke were recruited. Only two of the clinicians had any familiarity with the Kinect and they had each only used the device once. After testing each game for 2 minutes, the clinicians reported generally good usability across all of the programs. All of the clinicians reported that they felt the system would be useful for home-based therapy after stroke. The results of this data collection have been accepted for presentation at the International Conference on Human Computer Interactions in July 2013.

Late in 2011 we received another SECO grant.

Virtual Coach for Home-based Neuro-robotic Therapy (with Myomo, Inc.)

The goal of the proposed collaboration is to enable therapists to provide support to their patients in a virtual sense, i.e., without actually being present, through the use of computer-based surrogates. Specifically, we propose to implement *Virtual Coach* technology in the context of home-based physical therapy for recovery from stroke and other neuromuscular impairments. This *Virtual Coach* will complement another promising approach, neuro-robotic therapy that helps patients re-learn how to move partially paralyzed (hemi-paretic) arms using their own muscle signals.

This project has two objectives. The translational research objective is to specialize QoLT *Virtual Coach* technology to realize a neuro-robotic therapy monitoring and reporting capability. Myomo will commercialize the resulting *Virtual Coach* prototype, thereby broadening its product line to include valued companion software for its new line of *mPower* hardware devices. The exploratory research objective is to make that *Virtual Coach* more automatic, i.e., to have it behave more like a human therapist through functions like self-adjusting the therapeutic regimen and responding to non-verbal cues from the patient during exercise sessions.

The new product that will result from this project will alleviate some of the need for face-to-face therapy sessions. This project's outputs respond to other trends in the US healthcare system, including the dwindling supply of qualified care providers and the movement toward electronic medical records. *The ultimate goal of our Virtual Coach technology is to provide human-equivalent care at substantially lower cost*.

This *Virtual Coach* is composed of a tablet for clinician programming, a Kinect for monitoring motion, and a machine learning model to evaluate the quality of the exercise. Based on a set of rehabilitation exercises in a Myomo video (e.g. bring a cup up to the mouth, lift an object from the floor and chair, one/two arm stand up and sit back, walking, etc.) and multiple discussions with Myomo therapists, we established the correct and most typical erroneous exercise postures and movements for three exercises. A normalized Hidden Markov Model (HMM) was trained to recognize correct and erroneous postures and exercise movements. Parameters for the HMM were selected to be normalized to height and distance between joints as measured in an exercise session calibration phase. Feedback for typical problems with each exercise (e.g. go faster, lift higher, keep your posture straight, repetitions are too slow/fast) was solicited from the therapists and built into the audio feedback to the patient. Graphical representation of the patient progress and exercise history is presented on the tablet computer. The clinician and patient view of the user interface have been built. Encouragement and corrections to techniques are provided by audio and textual feedback, as well as summaries of performance and progress that can be easily interpreted by clinicians and patients. Some automatic adjustments techniques have been explored. For example, having the virtual coach recognize patient's specific condition, such as fatigue, and suggesting a rest period. A game was developed based on one exercise motion (wiping motion) to control a virtual reality hang glider. By positioning targets different sequences of motion could be encouraged. The goal of the game was not only to make routine exercises more fun thereby increasing exercise duration but also practice coordinated motion between the two hands.

We had several interactive sessions with physical therapists/clinicians during the design and implementation of the coach. We demonstrated the Myomo Virtual Coach for clinicians at the Vincentian Rehabilitation Center in Pittsburgh. We also run an in-service session for about 35 clinicians / therapists at the UPMC Mercy Rehabilitation Institute, and Rehabilitation Hospital in Sewickley, Pennsylvania. The physical therapists expressed very positive feedback about the system's capabilities and our summary performance reports/diagrams, such as exercise duration for different sessions, minimum and maximum angle for each repetition, bar graphs of successful repetitions during each exercise.

2.1.4.4 Actions taken in response to 2012 Site Visit report SWOT analysis

The actions we have taken in response to specific weaknesses and threats are presented in the Executive Summary. Below are the responses to the list of action items we included in our response to the Site Visit report

- *In future annual reports, we will provide more thorough analyses of competing products and research efforts, more thorough explanations about how we 1) identify critical technical and adoption barriers and 2) how we decide which ones to tackle, especially for PAT research.* Status: 1) see the volume 2 write-ups of our core projects, 2) see Table QoLT-Strategy-3 earlier in this section which presents progress toward performance goals and metrics and explains why we have been working on them

- *We will target gaps in in the QoLT product value chain, particularly robotics firms, in IPAB Member recruitment.*
  Status: We made significant progress by adding iRobot and Henry Ford Health System.
- *We will assist students in obtaining QoLT and disability-oriented employment (full time as well as internships).*
  Status: We have a process in place to facilitate this.
- *We will continue to address more specific privacy issues in our in situ evaluation studies of QoLT systems.*
  Status: Health Kiosk and FPC for Dementia Caregivers are both addressing privacy.
- *We will bring more policy expertise to bear on QoLT.*
  Status: We created a new project QoLT Policy and Adoption Analysis that is doing just that.
- *We will hire support staff for the front office (comprised of ILO, Communications & Media Director, Administrative Director and Executive Director).*
  Status: Done.
- *We will make better use of existing university resources (technology transfer offices, CMU Center for Innovation and Entrepreneurship, CMU Corporate Relations, CMU and Pitt Foundation Relations, CMU and Pitt Alumni Relations) to support the ILO.*
  Status: All of those groups have been better engaged, Corporate Relations in particular as a Member recruiting ally.
- *We will explore secondary outcomes of Health Kiosk deployment impact such as patterns for primary care services, emergency room visits, and hospitalizations as well as health care providers' perceptions of the value of kiosk data for clinical decision-making and patient self-management.*
  Status: The Health Kiosk field implementation study is just now getting underway.
- *We will find a way to afford students access to the QoLT Handbook.*
  Status: We have made electronic versions of the pre-print chapter drafts available.
- *We will strive to more directly assess user acceptance, individual differences, and issues of privacy in HSIT research. We will identify specific outcome measures for HSIT projects.*
  Status: This is a work in progress.
- *We will reach out to behavioral scientists and communications/marketing experts to augment our expertise.*
  Status: We have not made much progress on this yet.
- *We will explore three avenues of exploration to further/continue dWellSense.*
  Status: We have had some discussions with our Members about this. There is not sufficient interest to pursue it further.
- *We will conduct studies that evaluate additional dimensions of human-QoLTbot performance.*
  Status: the QoLTbots group made significant strides in evaluating user interactions (see vol1, section 2.3.2 and vol2, sections 2.4.2 and 2.5).
- *We will target payers, payer foundations and self-insured companies for IPAB membership.*
  Status: We have begun this, but have much more to do. Highmark, which has formed a strategic partnership with CMU, is an asset for connecting to such prospects because it actually manages self-insurability for many companies.
- *We will cultivate relationships with state and local leaders.*
  Status: Together with several of our Affiliated Provider Members, we have begun dialog with the Commonwealth on QoLT being an investment to offset future Medicaid expenditures.
- *We will continue to refine our membership sales and marketing efforts and materials, and will explore greater use of webinars and online video content.*
  Status: We constantly improve our marcomm collateral.

- *We will make great use of analytics in our membership sales process.*
  Status: The ILO and ED use our Zoho CRM extensively (see vol1, section 4).
- *We will involve students more in recruiting and retention of IPAB Members.*
  Status: Student projects are a benefit that many new Members are availing themselves of.
  Students are more engaged than in years past at Member meetings.
- *We will revise our Membership structure and agreement.*
  Status: Done.
- *We will increase the frequency of internal news dissemination.*
  Status: We could still improve on this.

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2.2 *Research Thrusts*

2.2.1 Human-System Interaction thrust (HSIT)

Jodi Forlizzi (leader)	CMU	Human-Computer Interaction; Design
Jeff Bigham	CMU	Human-Computer Interaction
Jennifer Collinger	Pitt	Physical Medicine & Rehabilitation
Rory Cooper	Pitt	Rehabilitation Science & Technology
Anind Dey	CMU	Human-Computer Interaction
Brad Dicianno	Pitt	Rehabilitation Science & Technology
Steven Dow	CMU	Human-Computer Interaction
Chris Harrison	CMU	Human-Computer Interaction
Jason Hong	CMU	Human-Computer Interaction
Amy Hurst	UMBC	Human Centered Computing
Jen Mankoff	CMU	Human-Computer Interaction
Aubrey Shick	CMU	Robotics
Reid Simmons	CMU	Robotics
Rich Simpson	Pitt	Rehabilitation Science & Technology
Asim Smailagic	CMU	Electrical & Computer Engineering
John Zimmerman	CMU	Human-Computer Interaction

2.2.1.1 Motivation and Rationale

The *Human Systems and Interaction Thrust (HSIT)* seeks to understand how humans should best interact with semi-autonomous technology. Specifically, our research seeks to understand how humans should play a role in human-system interaction, and how systems should best adapt and personalize to human needs. With this understanding, we can then design systems that engage people, sustain their use over time, and improve QoL for everyone. We seek to generalize findings from *HSIT* research and subsequently demonstrated it on other QoLT systems.

QoLT *HSIT* research addresses several of the QoLT Barriers.

- *User Acceptance:* Our work greatly supports the adoption and long-term use of QoLT systems. The results of our research can be applied to make systems that better support the needs of individuals and groups. For example, our research on *Adaptive Intent Recognition* ensures that people's intentions and potential activities are taken into account in the interaction between people and technology. Our research on *Personalization* ensures that clear goals in system use can be articulated in a user-driven, system driven, or user and system-driven model and that these goals can be revisited as technology use evolves over time.
- *Demonstrating Value:* Our work helps to demonstrate the value of long-term use of QoLT systems. It will result in systems that are used frequently and remain relevant over time. For example, our work on *Engaging Experience with Personal Informatics* systems revealed barriers to long-term product use that we can address in subsequent designs.
- *Market Factors:* Our work contributes to a robust set of market factors for QoLT systems. For example, our work on *How Systems Should Personalize* ensures that systems can be created that address not just one individual's needs, but the needs of many different individuals.

HSIT research supports our strategy to develop products that are attractive to markets beyond older adults and people with disabilities. Products that adapt, personalize, and offer engaging experiences are compelling for everyone. For example, if we understand how to effectively motivate people toward healthy behaviors, such as proper diet and physical activity, we can benefit broad segments of the general population. Developing systems that adapt and respond to the needs of their users results in less product rejection.

In terms of the strategic 3-plane chart, *HSIT* is creating fundamental knowledge in *Human Function* and in *Behavior & Everyday Living*; it is developing enabling technologies of *User- & context-aware interfaces, Human interaction CAD, Activity recognition & prediction, Intent recognition & prediction* and *Privacy protection strategies*.

2.2.1.2 Relation to other Research Clusters

HSIT provides component technologies and generates knowledge that is incorporated in QoLT Systems. Studies of these systems are performed, and resulting knowledge is then applied to other QoLT thrusts and systems. For example, the results of our emotion recognition research have been applied to the Health Kiosk to better improve interaction between system and user. The system can respond to emotion sensed in a person's voice and adjust processes and procedures accordingly. The results of our personalization research can also be applied to therapy systems and coaches that people use for long periods of time. A system could personalize and provide social chat to patients who prefer relational technology. It could help to clarify one's goals in using a personal informatics system by asking a set of goal-oriented questions about what it means to have an active, healthy lifestyle. These approaches in turn will reveal more design and research opportunities for reflective and adaptive personalization in systems that improve QoL.

HSIT research helps to understand and define the function, form, and behavior of our *QoLTbots* – and how they should relate to people. We are developing technologies where the mode of the feedback (e.g., verbal, audio, visual) from a QoLT system is conditioned on both the context of the current situation and the user's personal preferences. Both the relevant contexts and preferences will be learned from sensor data and the user's responses, thus personalizing the system to the user.

2.2.1.3 Achievements

In prior years, we developed a software infrastructure to capture real world human-system interaction performance data (specifically a person with disability's interactions with a computer) and to detect if/what difficulties the person has with the interaction. We used that information to 1) adapt to that person's ability by automatically deploying computer access aids and 2) develop guidelines for selecting and configuring input devices to maximize the combined person-machine performance. We developed a contextually-optimized system that can reduce the driver's perceptual load significantly. From it, we created design guidelines for user attention management in the context of information presentation. We conducted a large-scale survey of users of personal tracking and informatics websites, and derived a model for collection of, use of, and reflection upon tracked data. This gave us insights on the benefits and drawbacks of user-driven vs. system driven interaction. We developed algorithms to sense, learn and predict patterns of human activity using data from low-cost wearable sensors. That work culminated in a set of techniques that could learn models of human activity from large training sets. We developed an emotion recognition system that can detect emotional content in real-time utterances.

The following are highlights of *HSIT*'s achievements in the past year:

- We developed techniques to help people better adhere to the directives of Virtual Coaches. Learning is done through a combination of sensors, user inputs, and different stimuli. These techniques were originally developed in the inContext iPhone app, and have since been applied to the Virtual Seating Coach and the Walking Assistant Coach.
- We developed techniques to automatically determine a patient's current ability and to progressively set higher goals as the patient's ability improves. The algorithms use a game suite to assist in self-calibration, and input can also be adjusted by a clinician. These techniques have been applied in the Virtual Coach and Stroke Rehabilitation systems. These techniques have been used in short-term field studies at several local hospitals.
- We developed knowledge about two common ways to tailor and personalize technology-based services: user-driven methods and system driven methods. We built a planning tool for the Fitbit Activity Tracker to compare these two strategies. We learned that contrary to goal-setting theory, when users could create their own plans and reflect on their goals, they accomplished 123% of their goals as compared to only 84% of the system-created goals.

- We developed a robust set of emotion recognition techniques that have been integrated into existing QoLT systems. These can be instantiated in a model of human behavior per individual that has been applied to a number of QoLT systems, including the Health Kiosk and the Stroke Therapy Coach.

2.2.1.4 Future Work

In the next five years, there will be increased and focused effort to formalize our knowledge into metrics that can be used to extend our existing systems and to design and develop new adaptive, personalized systems that respond to an individual's dynamic needs.

We see several potential future approaches in human-systems interaction design for QoLT systems.

- Use a variety of inputs to create tailored systems. Systems should rely on information from sensors, user profiles, and when applicable, family and clinician inputs to make sure they are designed to best meet an individual's needs. In addition, contextual information such as the physical and social norms of the place where the system will be used can feed into how a system operates. For example, an elder is more likely to adopt assistive technology in the privacy of the home than in a public place — simple principles like these can be used to create better human-system interaction.
- Help people to make sure their goals are the optimal ones. A second approach is to design systems that help people to understand their current situation as they adopt new technology. A system could implement algorithms that link common misconceptions and problems with optimal solutions so that people could have personalized means of interacting with systems. In the *Romibo* example, a client may believe she has low technology readiness; by assessing her goals in using the *Romibo* system, she can be made to understand that she is facile with technology, thus drastically increasing her inclination to engage with the system.
- Incorporating decision criteria in developing adaptive systems. For example, a system could show a checklist of criteria related to one's goals in using it. People could then check off different criteria as they go through the options. Data could then be mined to automatically update these guidelines.

2.2.1.5 Team

The HSIT team is composed of members with diverse backgrounds. Rehabilitation experts and clinicians (R.A. Cooper, J. Matthews) provide expertise in accommodation to compensate for capabilities, requirements synthesized through interaction with user populations, and access to those users. Human-Computer Interaction specialists (J. Forlizzi, J. Mankoff, S. Hudson, A. Dey, R. Simmons) merge the latest interaction and evaluation techniques with machine learning to create novel user interactions. Forlizzi also brings to bear expertise and experience in Industrial Design. Electrical and software engineers (A. Smailagic, D. Siewiorek) integrate components into complete prototype systems suitable for pilot evaluation. Close collaboration with the PST identifies end user populations and conducts focus groups to provide feedback on technology concepts and prototypes. Multidisciplinary teams of undergraduate and graduate students build many of these systems as part of an engineering capstone design course or as independent research studies.

2.2.1.6 Peer-reviewed Publications

Fisher, R., T. Kollar, and R. Simmons. Building and Learning from a Contextual Knowledge Base for a Personalized Physical Therapy Coach. Workshop on Robot Learning. IEEE International Conference on Machine Learning (ICML). Atlanta, June 2013.

Forlizzi, J.; Pohlmeyer, A.; and Desmet, P. eds. International Journal of Design Special Issue on Design for Subjective Well-Being. December 2013. www.ijdesign.org

Hurst, A. and Kane, S. "Making 'Making' Accessible". In Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13). ACM, New York, NY, 635-638

Jeni, L., Girard, J., Cohn, J., et. al. (2013). Continuous AU Intensity Estimation using Localized, Sparse Facial Feature Space, Proceedings of the 2nd International Workshop on Emotion Representation, Analysis and Synthesis in Continuous Time and Space (EmoSPACE), 2013

Lee, Min Kyung. PhD Dissertation, Carnegie Mellon University, September 2013.

Smailagic, A., Siewiorek, D.P., Chakravarthula, S., Kar, A., Jagdale, N., Gautam, S., Vijayaraghavan, R., Jagtap, S., “Emotion Recognition Modulating the Behavior of Intelligent Systems”, IEEE International Symposium on Multimedia, Anaheim, CA, December 9-11, 2013.

2.2.2 Perception and Awareness thrust (PAT)

Martial Hebert (leader)	CMU	Robotics
James Bagnell	CMU	Robotics
Fernando de la Torre	CMU	Robotics
Alex Hauptmann	CMU	Computer Science
Takeo Kanade	CMU	Robotics Institute
Kris Kitani	CMU	Robotics Institute
Judith Matthews	Pitt	Nursing; Urban & Social Research
Yaser Sheikh	CMU	Robotics, Mechanical Engineering

2.2.2.1 Motivation and Rationale

The objective of the Perception and Awareness Thrust (*PAT*) is to provide fundamental perception tools to sense and understand the environment in order to maintain awareness of the user's actions and surroundings. Our general approach to perception is to liberate application systems as much as possible from infrastructure constraints. We emphasize user-wearable sensing solutions and data-driven techniques to understand the user's environment and behavior from sensor data.

We have structured the thrust as three broad projects that address the key barriers and challenges facing the development of perception systems and solve inter-related problems. New devices better adapted to the needs of the QoLT systems must be designed, and their acceptance by the client population must be assessed. This is addressed in our *Sensing* project that includes exploring new sensing modalities and user studies in close collaboration with *PST*. A second challenge is to learn models from very large and multi-modal datasets. In our *Learning* project, we address this challenge by developing machine learning techniques that are designed for dealing with large amounts of data, for generating predictive models, and for combining noisy data from multiple modalities. Thirdly, understanding the user's environment by identifying objects and 3D structure is difficult because of the variability of the real world data, which we address by developing new perception techniques in our *Recognition* project. Across all three projects, a major research obstacle is the availability of relevant ground truth data, which we address through a sustained effort in collecting increasingly realistic data over increasingly broader selections of scenarios and subjects. Although we focus on vision (images, 3D, and video) as the main sensing modality in the *Recognition* project, we incorporate other, non-vision, sensing modalities such as motion profiles from IMUs (inertial measurement units) in all the other projects.

The *PAT* research program addresses directly many of the key barriers identified in the top-level QoLT strategic plan. By developing perception systems that are trained on data from users' and users' environments, our work on recognition addresses the need to adapt to and to be robust with respect to the high degree of variability between different users, environments, and tasks. We address directly the issue of measurement noise by developing techniques trained on sensor data consistent with that used at execution time. For example, models used in recognition are built from real, noisy data rather than being hardcoded. The machine learning techniques developed in *PAT* address the barrier of robustness to noise and variability, by relying on large training sets of sensor data, and the need for adapting to the user's specificity, by using sophisticated forecasting techniques.

Our *Sensing* project, in collaboration with *PST*, addresses directly the acceptance barrier: we get feedback from the client population on acceptance through user studies and implement responses to that. The use of data intensive techniques was identified early in the project as central to dealing with the large variability in subjects and environments. Our effort in data collection and analysis continues to be responsive to the key barriers identified for the QoLT vision. Broad-based data sets acquired in-situ with the client population ensures that the variability across subjects and tasks is captured, and that other projects have access to high quality data for modeling that variability (*Learning* in particular). Similarly, data acquisition using a variety of sensors addresses the need to deal with observation uncertainty due to sensor noise. Finally, our work on acquiring – automatically and without supervision – models of the user's environment addresses directly the usability barrier. Indeed, our systems need to be usable without expert knowledge and, preferably, without user intervention.

In terms of the strategic 3-plane chart, PAT is creating fundamental knowledge in *Human Function* and in *Behavior & Everyday Living*; it is developing enabling technologies of *Everyday scene and object recognition, Activity recognition & prediction, Intent recognition & prediction, Inside-out perception* and *Privacy protection strategies*.

2.2.2.2 Relation to other Research Clusters

PAT's products support other QoLT thrusts and systems. *PAT* provides technology to support *QoLTbot* interaction with household objects and its products have been now integrated in several generations of systems. It provides techniques for understanding of the user's status and activities for more informed intervention by Virtual Coaches, and it motivates the development of machine learning techniques used in *Safe Driving* and *HSIT*. Last year we started closer collaboration with *HCHW*, in confusion detection from visual signals and using the instrumented kitchen to test techniques for automatic analysis of user/objects interactions. These applications have expanded this year, especially in the work on motion tracking and understanding in the *Learning* project. Understanding the acceptance, usability, and relevance of the *PAT* technology to client populations and practitioners is central to the success of *PAT*'s research. This is addressed by continuing strong collaborations with *PST* in the form of users studies, and joint projects.

All *PAT* projects generate scientific contributions beyond the QoLT applications. Our work in sensing provides new insight into the best use of sensor data and the interaction of user's with different modes of sensing. In the areas of learning and recognition, we continue to generate contributions in fundamental advances in the theory and algorithms for general problems in Machine Learning and Computer Vision, published in the top-tier conferences and journals of both communities. The underlying algorithms have been used for advancing fundamental research in scene analysis and in several areas of imitation learning and reinforcement learning. This aspect of *PAT*'s scientific impact is evidenced by the continued awarding of new research grants based on research initiated in QoLT's *PAT*. We view the continuation of this activity of creation of partner projects as confirmation of our sustainability effort started last year.

2.2.2.3 Achievements

Learning

A central theme of the perception plan is the use of data-driven approaches that rely on machine learning tools. The goal of the project is for a computer to be able to learn models of people's activities from training data that can subsequently be used to predict actions and behaviors. Our work in the *Learning* project this year was organized around two main axis 1) learning techniques for detection and tracking for behavior analysis; and 2) fundamental data analysis techniques and applications. In (1), we focus on techniques for robust, i.e., highly adaptive, techniques for detecting, tracking, and analyzing motion in first-person video data, thus enabling behavior analysis tools. In (2), we have been investigating techniques for matching, in the form of new graph matching techniques, and for time series analysis. In the area of time series analysis, we reported a number of contributions over the past few years leading to a mature body of techniques now applied to a broad range of important problems such as measuring Parkinson's disease symptoms.

<u>Detection and tracking for behavior analysis.</u> Robust detection, tracking, and analysis of hand motion are invaluable in recognizing and predicting behavior, in particular in terms of interaction with objects in the environment. We addressed all the aspects of this problem. First, we addressed the task of pixel-level hand detection in the context of ego-centric cameras. To quantify the challenges and performance in this new domain, we presented a fully labeled indoor/outdoor ego-centric hand detection benchmark dataset containing over 200 million labeled pixels, which contains hand images taken under various illumination conditions. Using both our dataset and a publicly available ego-centric indoors dataset, we gave extensive analysis of detection performance using a wide range of local appearance features. In particular, we proposed a novel approach based on model recommendation techniques which allow for adaptation to changing observation conditions, and generalization to new scenarios and across multiple users. Second, we continued exploring the problem of understanding the interaction between hand and objects in the scene, with the aim is to learn a discrete hand interaction vocabulary over the space of hand shapes. In particular, the project explores video-based data-driven methods for grouping common

grasps and discovering hand grasp taxonomies. In addition to elucidating the space of human hand manipulation, the resulting hand interaction vocabulary and taxonomies will also be useful representations for such tasks as understanding object functionality, motor skill analysis and neuromuscular rehabilitation. For example, we started applying our pixel-wise hand detection algorithm in the context of neuromuscular rehabilitation, in which our objective is to develop a low-cost single camera solution for in-home monitoring applications. This project, joint with Emory and Arizona State, will bring together rehabilitation specialists, mixed-reality engineers and computer vision researchers to develop a comprehensive rehabilitation system to quantify the progress of therapy.

Data analysis techniques. We made important progress in two broad classes of data analysis techniques, graph matching and time series analysis. Graph matching is a fundamental problem in computer science, and it plays a central role to solve correspondence problems in computer vision, in particular in establishing correspondence between data samples for clustering, alignment, and learning functions in QoLT. Although widely used, solving the correspondence problem through graph matching has two main challenges: (1) the corresponding mathematical problem is NP-hard and difficult to approximate; (2) algorithms do not incorporate geometric and temporal constraints that are natural in learning and computer vision tasks. We completed the development of a novel class of approaches started last year, in which the matching problem is decomposed into smaller matching subtasks in a systematic manner. This new class of approaches has a number of unique advantages such as computational efficiency, a unified framework that subsumes the other approaches, and a natural approach to incorporating the spatial and temporal constraints that are common in practical tasks. For example, our new approach to graph matching will enable us to perform pose detection in video input, a key enabling technology for many QoLT-related tasks, without relying extensively on supervised techniques that require copious amounts of labeled training data. We are currently working on use of motion capture data to automatically detect people's poses in video.

Time series analysis involves general techniques for manipulating, comparing, and interpreting time-varying signals, such as videos or readings from wearable inertial measurement units. We have continued this effort this year. In the fundamentals, we focused on the development of weakly-supervised learning techniques which are designed for minimizing the amount of labeled data in the training data. For examples, we showed that techniques based on multiple instance learning were able to find patterns that differentiate two diagnostic categories in a weakly-supervised manner. That is, given two sets of time series (say, hand movements measured by accelerometers) and a weak label for each of the time series (e.g., normal motion vs. tremor) our technique localizes the segments that are most discriminative. In addition to continued research on the fundamentals, we have greatly expanded the range of applications of time series analysis tools which have matured over the years of QoLT research. For example, we have started using these techniques in a new project with Allegheny Health Network on assessing the severity of Parkinson's disease symptoms. The effort proposes the development / optimization of a wearable system consisting of a set of low-cost wearable accelerometers to detect and quantitatively assess the severity of motor symptoms resulting from movement disorders like Parkinson's disease. The system will be used in everyday living environments and collect data during normal daily routines.

Applications. The learning techniques developed in QoLT have reached a sufficient level of maturity to be spun-off to separate research to support the sustainability of the center. The *Learning* project continues to be productive in proposing new initiatives. For example, the work on detection and tracking to new concepts for active the concept learning from demonstration with applications to robotics (NSF), to the development of a low-cost, camera-based solution to neuromuscular rehabilitation (with ASU and Emory), city modeling from first person views (with IBM), skill level characterization in Endotracheal Intubation, a life-saving medical procedure performed on critically ill patients (with UPMC), development of a web-based system for trauma assessment (with Univ. Pittsburgh and Colorado).

Recognition

The *Recognition* project is develops techniques for understanding the user's environment based on sensor data. Our approach includes techniques for localizing the user, identifying specific objects in the environment, and learning models of important objects and features in the user's environment. In the *Recognition* project, we continued the work started in the previous work in robust recognition of difficult objects common in daily living environments and in unsupervised discovery of object models. In the previous years, we emphasized the need for recognition techniques tailored to objects with little distinctive visual content (e.g., plain stoneware and flatware) and high degrees of clutter (say, a kitchen counter after a dinner party). This year, we completed this work by augmenting our work on shape-based recognition, occlusion modeling, and dealing with uniform regions, with a new approach for increased performance through better representation of shape information. Our results show significant improvement in shape matching and object detection on a difficult dataset of texture-less objects in natural scenes with severe clutter and occlusions.

In the previous years, we had developed state-of-the-art techniques for discovering object models in unsupervised data (images + depth). We showed how data fragments can be clusters into groups corresponding to individual objects and how models that can be used for recognition can be generated from these groups. In 2013 we explored further the question of automatically building 3-D models from the views. This will enable the use of the models for 3D reasoning, such as correctly planning 3D grasps. We are integrating our volumetric view of objects on real sensor data, and integrate it with the full system to enable HERB to grasp unknown objects. Our insights into the probabilistic nature of object volumes also opens up the door to new ways of accurately modeling objects from fewer scans.

Sensing
The goal of the project is to explore novel approaches to sensing, in which the system senses the environment and the user's behavior from the user's point of view, to facilitate the analysis of her behavior and intentions. This year, the project focused primarily on improving the robustness of the gaze tracking algorithm in real-world usage circumstances and in designing for specific applications, namely human computer interaction. We increased the robustness of the device in realistic user situations, in particular in improving and maintaining calibration. This is a critical technical limitation of all wearable vision devices, which must maintain calibration if the user's head moves with relation to the device or if the device is taken off. In particular, we developed new calibration algorithms and technologies that improve the robustness of the gaze tracker while minimizing device setup. Specifically, our novel method removed key limitations.

We investigated novel applications of our sensing concepts. For example, in collaboration with Shiwei Cheng and Anind Dey of the Human Computer Interaction Institute, we have developed a method of gaze transfer between multiple reading devices. The method works by detecting which screen the user is looking at and updating it to present the document that the user is currently reading. Further, the method tracks the user's gaze on the document. When the user looks to another screen, the location where the user was previously gazing is briefly highlighted to facilitate reading and comprehension.

2.2.2.4 Future Work
We plan to expand our work in fundamental learning tools in particular in the areas of matching and semi-(un-)supervised tools for time series analysis and increase the range of applications to QoLT tasks. We plan to complete and demonstrate our system on automatic building of object models, and to continue to increase the QoLT tasks in which products of our *Recognition* project are integrated. Finally, we plan to develop more sophisticated modes of interaction using the tools developed in our *Sensing* project. Specific technical items include:

- Grasp recognition and grasp trajectory analysis for neuromuscular rehabilitation
- Understanding and modeling human interactions through simulation by applying inverse optimal control to high dimensional features of human interactions.
- Visual verification for robotic manipulation tasks
- Extend graph matching for pose detection and activity recognition in video.
- Support applications of time series analysis and clustering to the QoLT projects and related projects.
- In the next year, we hope to have a complete software system which 1) segments objects from the scene, 2) reconstructs them from volumetric information, 3) matches them to an object database to infer their semantic properties.

- We will continue to integrate the recognition tools with the applications to *QoLTBots, Virtual Coach,* and the applications developed in the *Learning* project.
- Use our sensing approach to confirm user intent with external input, such as voice commands
- Use gaze to predict intent in environment where robots are also present (to prevent robot and user grabbing the same object, etc…)
- Use gaze to automatically detect objects of interest in scene (for users with impairment)

2.2.2.5 Team

The *PAT* team is comprised of researchers in computer vision, primarily Profs. de la Torre, Hebert, and Kanade, who are involved in the three core projects. In addition, Prof. Bagnell contributes to the *Learning* projects. In addition, *PAT* collaborates with *HSIT* (Anind Dey), for application of the learning technology, HERB (Siddharta Srinivasa), for the integration with robotics system (two graduate students are shared between the teams), and *Safe Driving* for some of the learning and vision components. In addition, *PAT* collaborated most closely with *PST* (Scott Beach and Judith Matthews) and *HCHW* (Dan Ding) for all aspects of evaluation of the perception technology and users studies. This team includes a mix of expertise in state of the art technologies in machine perception and machine learning, and expertise (through *PST* and *HCHW*) on integration of the technologies with client populations, caregivers, and practitioners.

2.2.2.6 Peer-Reviewed Publications

W.S. Chu, F. De la Torre, and J. Cohn. “Selective Transfer Machine for Personalized Facial Action Unit Detection,” Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Portland, June 2013.

A. Collet, B. Xiong, C.Gurau, M.Hebert, and S.Srinivasa. Exploiting Domain Knowledge for Object Discovery. IEEE International Conference on Robotics and Automation (ICRA), May, 2013.

X. Ding, W.-S. Chu, F. De la Torre, J. F. Cohn, and Q. Wang. Facial Action Unit Event Detection by Cascade of Tasks. International Conference on Computer Vision (ICCV), 2013.

E. Hsiao and M.Hebert. Gradient Networks: Explicit Shape Matching Without Extracting Edges. AAAI Conference on Artificial Intelligence (AAAI), July, 2013.

E. Hsiao and M.Hebert. Shape-Based Instance Detection Under Arbitrary Viewpoint. Shape Perception in Human and Computer Vision: An Interdisciplinary Perspective, Sven Dickinson and Zygmunt Pizlo, ed., Springer, 2013.

C. Li and K.M. Kitani. “Model Recommendation with Virtual Probes for Ego-Centric Hand Detection” International Conference on Computer Vision (ICCV 2013). December, 2013.

C. Li and K.M. Kitani. “Pixel-level Hand Detection for Ego-centric Videos.” Conference on Computer Vision and Pattern Recognition (CVPR 2013). June, 2013.

B.R. Pires, Myung Hwangbo, Michael Devyver, Takeo Kanade, “Visible-Spectrum Gaze Tracking for Sports", 1st IEEE International Workshop on Computer Vision in Sports, (CVPR'13 Workshop), Portland OR, USA, June 2013.

B.R.Pires, Michael Devyver, Akihiro Tsukada, Takeo Kanade, “Unwrapping the Eye for Visible-Spectrum Gaze Tracking on Wearable Devices", IEEE Workshop on the Applications of Computer Vision WACV'13, Florida, Jan 2013.

X. Xiong and F. De la Torre, “Supervised Descent Method and its applications to Face Alignment”, Proc. IEEE Conf. on Computer Vision and Pattern Recognition (CVPR), Portland, June 2013.

F. Zhou and F. De la Torre. Deformable Graph Matching. IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2013.

2.2.3 Person and Society thrust (PST)

Richard Schulz (leader)	Pitt	Institute on Aging
Scott Beach	Pitt	Urban & Social Research
Michael Boninger	Pitt	Physical Medicine and Rehabilitation
Rosemarie Cooper	Pitt	Rehabilitation Science & Technology
Karen Courtney	UVBC	Health Information Science
Annette DeVito Dabbs	Pitt	School of Nursing
Julie Downs	CMU	Social & Decision Sciences
Martial Hebert	CMU	Robotics Institute
Annmarie Kelleher	Pitt	Rehabilitation Science & Technology
Alicia Koontz	Pitt	Rehabilitation Science & Technology
Judith Matthews	Pitt	Nursing; Urban & Social Research
Larissa Myaskovsky	Pitt	Medicine
Jonathan Pearlman	Pitt	Rehabilitation Science & Technology
Laurel Person-Mecca	Pitt	Urban & Social Research
Kate Seelman	Pitt	Rehabilitation Science & Technology
Pamela Toto	Pitt	Occupational Therapy

2.2.3.1 Motivation and Rationale

The *Person and Society Thrust (PST)* has four primary goals: 1) implement models of participatory action design and infusion to assure end-user, clinician, and policy input into the conceptualization, design, and evaluation of QoLT; 2) promote a complementary scientific agenda aimed at developing and implementing evaluation methodologies for assessing the needs and preferences for QoLT, and acceptability and impact of QoLT; 3) provide core services critical to the success of the technical thrusts and engineering applications of the Center; and 4) support the educational mission of the ERC by developing training materials (e.g., QoLT Handbook) aimed at educating the next generation of QoLT engineers, health professionals, and policy experts. Achieving these goals requires that we work closely with the engineering thrusts on the development, design and evaluation of technologies being developed by the Center.

The successful introduction of technology depends on the interplay of three important factors: characteristics, needs, and preferences of the end user; features of the technology; and societal factors including social and health policy and the regulatory environment. From day one of the ERC, the role of *PST* has been to assure that end-users and the policy and regulatory perspectives heighten technology design and development from inception to commercialization. To this end, *PST* has worked closely with engineers to target populations and identify needs with high potential for societal impact. In addition, PST has attempted to identify enablers and barriers to technology acceptance at both the individual and societal level and design strategies appropriate for each stage of the technology development process. The cornerstone of our approach has been an iterative participatory design process that involves potential end users and other stakeholders early and often throughout development of a specific technology. This perspective is illustrated in Figure ?? below, which describes the development process from inception to commercial product with associated evaluation strategies and measurement approaches. This model has been so strongly infused into the culture of the Center that it has become second nature to the students and faculty involved in this enterprise. This seamless infusion of *PST* perspectives and expertise ultimately helps position the Center for self-sufficiency.

PST continues to provide consultation and support for all of the research inititiatives of the Center, participates in the educational programs through training and resource development (e.g., the Qolt Handbook), and serves as a critical resource for the IPAB by addressing policy and economic issues of interest. For example, data collected over the last two years regarding end users and caregivers' willingness to pay for technology has been a major interest of the IPAB, and their input continues to guide our on-going data collection efforts. In addition, *PST* has focused on three core research projects during the current year: 1) health kiosk deployment and evaluation in three community settings, 2) continued evaluation of the first person vision system (FPV) applied to dementia caregiving, and 3) large sample populations studies of consumer attiutudes and preferences regarding Qolt technologies (Rich Stimuli Data Collection initiative).

After extensive laboratory and small sample field studies we are now prepared to launch a pilot study with Version IV of the *Health Kiosk* which includes a much broader range of functions and addresses multiple fundamental researcher barriers. These barriers include *privacy concerns, user acceptance, robustness and generalizability, Interoperatiblity, utility or value,* and *adaptability to individual differences*. Details regarding each of these challenges and how they are being addressed are provided in Volume II. An ongoing assessment of the health kiosk also includes evaluating the universal design, privacy and security, and policy/regulatory implications for commercialization. A significant challenge during the current year was obtaining IRB approval from the two Universities for the deployment of the Health Kiosk for a large sample community study. Although a lengthy process at both universities, obtaining IRB approval has helped us to clarify how sensitive health data are the importance of maintaining securely and confidentially.

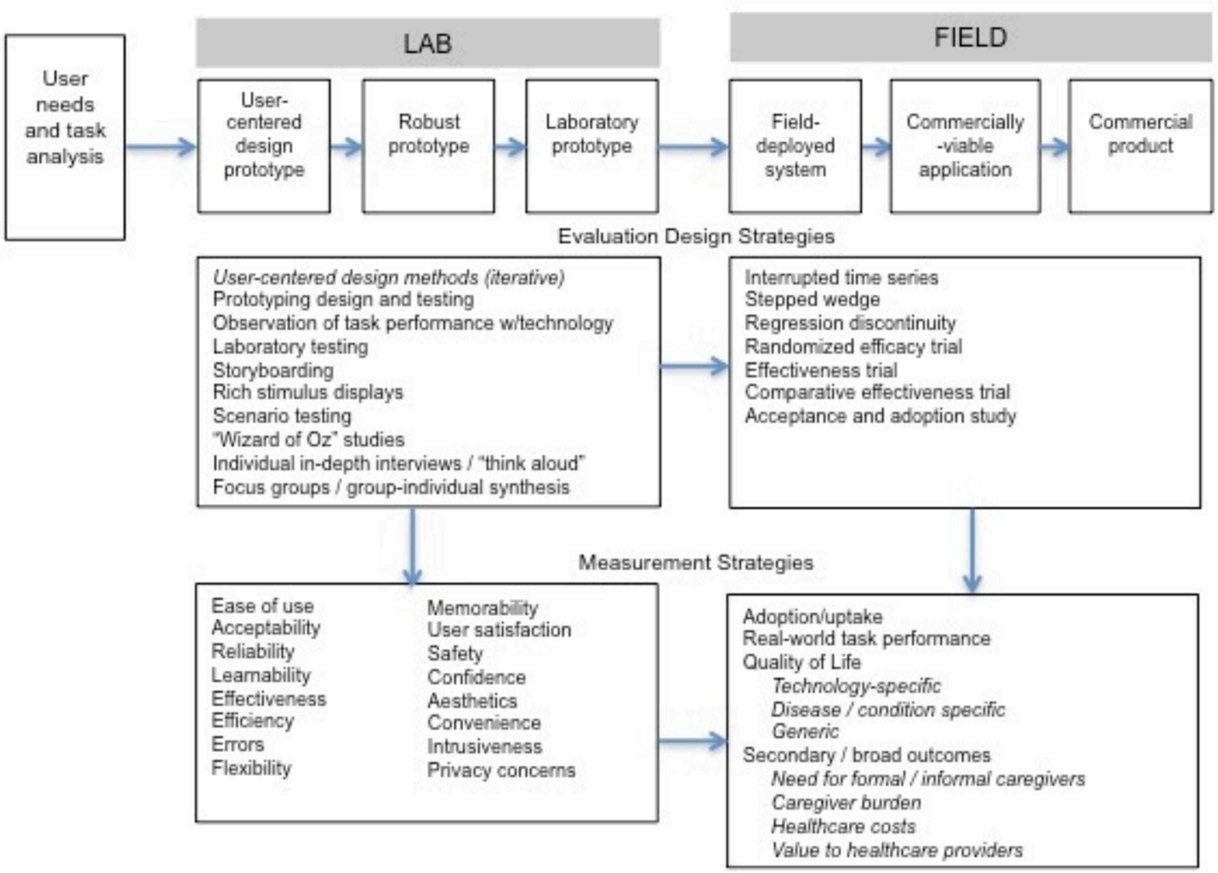

Figure PST-1. Technology Development and Evaluation Process

Although the Health Kiosk was originally envisioned as a health assessment and intervention delivery system for older individuals and persons with disability, we have widened the target population to include all adults over the age of 21. Just as health kiosks with more limited features and functionalities have become commonplace in many different commercial settings (e.g., pharmacies, grocery stores, discount stores), our kiosk has the potential of serving any adults who regularly frequent these venues.

The FPV system for the dementia family caregiving study has continued to be refined to address technical difficulties with the FPV device. We now have three functioning systems enabling us to increase our recruitment efforts. Key barriers addressed with this system include *privacy concerns, user* *acceptance, demonstrating value,* and *adaptability to individual differences*. Although our application of FPV to the context of dementia caregiving is highly specialized, if we are able to overcome the barriers and develop an effective system in this context, it should be highly generalizable to many situations requiring the detailed understanding of one-on-one human interaction (e.g., patient-physician encounters, client-provider interactions).

Our third project, the Rich Stimuli Data initiative, is an on-going research program designed to generate population-level feedback for QoLT technologies. In addition we hope to develop new methods for eliciting feedback from large samples of prospective end-users and stakeholders so they can provide valid, meaningful feedback to developers. In 2011, we conducted two nationally representative web-based surveys that included video stimuli. One survey obtained potential user reactions to written scenarios describing kitchen, personal care, and safe driving technologies, along with videos depicting "soft" robots and the Virtual Valet Safe Driving system. The second survey involved a randomized experiment comparing four versions of a video involving an older adult falling in a kitchen setting. In 2012, we conducted detailed statistical analyses of the data from the surveys and have published two manuscripts with a third currently under review.

In 2013, we conducted a national *web-based survey of informal family caregivers* (n=512) age 18-64 sampled from an internet panel provided by Survey Sampling International (SSI). The majority of the sample were adult children caring for an ill or disabled parent. Over half lived with the care recipient and most of the remainder lived within a 20-minute drive. The care recipients had a variety of disabling conditions (23% had Alzheimer's or dementia), and over half the sample reported spending at least 20 hours per week providing care. The survey covered current use of technology in caregiving, more general use of technology, general attitudes towards technology, and the health of the caregiver. The key outcomes in the survey were likelihood of use, perceived acceptance by the care recipient, and willingness to pay out-of-pocket for six categories of QoLT. It is estimated that there are 56 million informal caregivers in the US making this target population an important market for quality of life technologies.

This research program is specifically designed to address barriers related to privacy concerns, market factors, user acceptance and multi-disciplinary collaboration challenges. It has become a major contributor to the literature on population attitudes toward and acceptance of QoLTs.

2.2.3.2 Relation to other Research Clusters

PST is fully integrated into all systems development projects. Because many of our technologies have advanced to the point where human testing and *in situ* evaluation are key requisites to further development, *PST* is increasingly called upon to assist with IRB applications, end-user recruitment, negotiating facility access, and data collection. The three core projects of PST are highly interdisciplinary involving both universities, faculty from engineering, computer science, clinical sciences, the social and behavioral sciences as well as input from our IPAB and Scientific Advisory Board.

2.2.3.3 Achievements

The ***Health Kiosk*** continues to be refined with increased functionality and greater ease of use. Preparing to launch this pilot study has prompted us to address the many logistical and human factors concerns that arise when a novel technology is moved from the relatively protected environment of the laboratory. In addition we had to address the shift of the Kiosk from a community setting, supervised by the research team, to an environment where the technology is used without supervision or with minimal assistance from on-site personnel. These considerations are particularly salient because our technology involves collection, display, and transmission of personal health information. This challenge is increased particularly for older adults whose dexterity, experience with technology, physical abilities may vary widely, and whose ability to understand and execute instructions may be limited. We have decided to delay further discussion about potential integration of *Health Kiosk* data with electronic medical records at University of Pittsburgh Medical Center (UPMC) until we have substantial amounts of data from our pilot study participants' patterns of use. Likewise, we are delaying development of a health intervention module focused on mood, as we want to observe users' responsiveness to the other six modules first. As planned, we submitted an AHRQ grant in June 2013 that was positively reviewed, though not at a fundable level, and we will revise and resubmit this application in March 2014. The proposal has increased the disciplinary diversity of our team, with new members whose domain expertise ranges from healthy diet and physical activity to sleep quality, mobility and balance, bladder health, and depression prevention.

Based on recommendations of the review committee from last year, we conducted a case study of the Health Kiosk to address policy and commercialization issues relevant to its deployment. Prof. Kate Seelman led this effort in collaboration with several graduate students and QoLT affiliated faculty. The case study involved literature and web-based reviews of competing products, interviews with the designers of the kiosk and members of our industry advisory board, and consultation with policy experts with knowledge about HIPPA, FDA, and section 508 of the ADA Rehabilitation Act. Details regarding this work are provided in Vol II, QoLT Policy Analysis.

Since last year we have enrolled an additional 9 caregiving dyads, for a total of 10 dyads, in our FPV dementia caregiving study, and have collected over 760 GB of *FPV* data from 9 dyads whose family caregivers have worn our device and vest during two 3 to 7-day periods, for a total of 70 days. Approximately 75% of the screened and annotated video from this trove of *FPV* data capture is now available for application of machine learning and computer vision analysis. Eight of the 9 family caregivers who have worn our *FPV* device and vest have rated them favorably for comfort and utility. They have reported no evident distress in their family member with dementia attributable to what they are wearing. Using video clips from the caregiver's own *FPV* data capture as a springboard for discussion during face-to-face intervention has been very well received. Salient dementia-related problem behaviors and other manifestations of dementia captured with our *FPV* system have included resisting efforts to assist with personal hygiene, excessive daytime sleeping, repetitive questioning, compulsive walking indoors and outside, perseverative counting, rummaging, painful grimacing in response to manipulation during bathing (in a person with severe contractures), incontinence, and unprovoked emotional outbursts. Examples of tailored interventions have included suggestions to create distraction, simplify instructions, anticipate threats to safety, accept or increase respite from other family members or community agencies, and pre-medicate with short-acting analgesics to prevent or reduce activity-induced pain (i.e., during bathing and range of motion exercises).

While the detailed statistical analysis of the survey of family caregivers (Rich Stimuli Data initiative) is ongoing, some of the key findings to date include:

- Caregiver acceptance of kitchen, personal care, and safe driving technologies was fairly high, with more than half of caregivers saying they would be "somewhat" or "very" likely to use them to help provide care.
- Caregivers were slightly less accepting of wearable cameras, handheld / smartphone tracking, and the *Health Kiosk* (40-50% somewhat or very likely to use); they also perceived it less likely that the care recipient would agree to use these technologies
- In multivariate statistical analyses, younger caregivers, caregivers caring for someone with Alzheimer's disease, those with more positive attitudes towards technology in general, and those currently using the internet and other available technologies for caregiving were more accepting of kitchen QoLT.
- Caregivers were willing to allow technology to provide a large portion of the help with kitchen and personal care tasks, with more than 40% preferring "most" or "all" of the help from technology; an additional 25-30% preferred to "work with the technology."
- Caregivers were much more willing to allow technology to aid with caregiving than baby boomers were to cede control to technology to receive personal help with kitchen and personal care tasks (see Figure PST-2).
- Approximately 20% of caregivers were not willing to pay anything out-of-pocket for kitchen, personal care and safe driving technologies.
- Among those willing to pay at lease something, the mean monthly amount ranged from $50 to $75 depending on type and functionality of the technology.

- Compared to baby boomers asked about willingness to pay out-of-pocket for kitchen and personal care technology for personal assistance, caregivers were much more willing to pay for these technologies to aid caregiving.
- Multivariate statistical analyses showed that older caregivers (age 55-64), those with more positive general attitudes towards technology, those who currently use more common everyday technologies (smartphone, iPod, GPS), and those spending more hours per week caregiving were willing to pay more monthly out-of-pocket for kitchen QoLT.
- Multivariate analyses also showed that caregivers with more positive general attitudes towards technology, those who currently use more common everyday technologies and those currently using the internet as a resource for caregiving were willing to pay more monthly out-of-pocket for personal care QoLT.

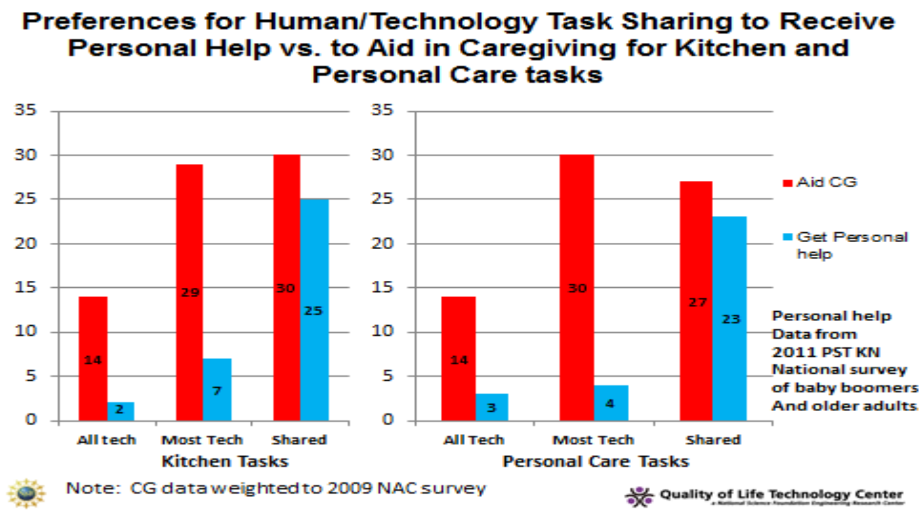

Figure PST-2 Our national survey indicates that caregivers are more accepting of technology than care recipients

2.2.3.4 Future Work

All three core projects of PST will continue into the next year. Important milestones in the coming year for the *Health Kiosk* include achieving our target sample of 200 and successfully collecting *Health Kiosk* data as planned in the longitudinal pilot study, achieving the metrics we have set forth, and re-initiating dialogue with the UPMC health information technology group regarding integrating data from personal health record information gathered at the *Health Kiosk* with individuals' electronic medical records. We are preparing to resubmit the AHRQ grant in March, to secure ongoing funding for our team that will support this project beyond Year 9 and beyond NSF funding for the QoLT ERC. Finally, we intend to develop at least two manuscripts: one describing our methods for implementing a fairly large-scale, multi-site pilot study with the *Health Kiosk* in congregate settings serving older adults, and the other describing privacy and security issues that we have addressed.

During the upcoming year, we plan to continue recruitment of at least 10 additional dyads for the FPV dementia family caregiving study, in order to amass sufficient FPV data to inform development of algorithms that could automate identification of dementia-related behaviors. Such progress would encourage us to pursue additional grant funding to support the use of FPV technology in advance of initial clinical evaluation of persons with dementia or other neurologic disorders.

Within the Rich Stimuli Data initiative, detailed statistical analysis of the family caregiver survey data will continue next year with the aim of publishing three manuscripts on findings from the survey. We also plan to pursue new studies in this area. In collaboration with engineers/designers we will design and carry out new rich stimuli studies to evaluate end-user / stakeholder acceptance of *PerMMA / Strong Arm* using a national wheelchair registry, and further evaluations of the *Health Kiosk* with both older adults and healthcare providers. Finally, our IPAB has recommended that we explore the possibility of doing an industry survey on attitudes toward and preferences for QoLT.

In addition, PST members have developed collaborative working relationships with other national and international centers focused on technology and aging, notably the Center on Aging at the University of Heidelberg and the Center for Research and Technology Education (CREATE) at the University of Miami. The first product of this collaboration is a review paper on technology and aging submitted to the Forum section of the Gerontologist. Joint research and writing projects will be pursued in the coming year.

2.2.3.5 Team

The *PST* team includes gerontologists, nurses, sociologists, roboticists, rehabilitation engineers, physical therapists, occupational therapists, computer scientists, business professionals, health economists, and public policy experts. This interdisciplinary team allows *PST* to be fully integrated into all systems development projects and contribute the social, behavioral, policy, and clinical expertise needed pursue the research and development agenda of the Center.

2.2.3.6 Peer-Reviewed Publications

Beach, S.R., Schulz, R., Matthews, J.T., Courtney, K., & DeVito Dabbs, A. (in press; early online, November 2013). Preferences for technology versus human assistance and control over technology in the performance of kitchen and personal care tasks in baby boomers and older adults. Disability and Rehabilitation: Assistive Technology.

Courtney, K. L., Jiang, Y., Beach, S. R., Matthews, J. T., & Schulz, R. (2013). “Clinician variations in data trust and use.” Studies in Health Technology and Informatics*,* 183, 189-194. IOS Press Ebooks.

Czaja, S.J., Beach, S., Charness, N., & Schulz, R. (2013). “Older adults and adoption of healthcare technology: Opportunities and challenges”. In A. Sixsmith & G. Gutman (Eds.), Technologies for Active Aging (pp. 27-46). International Perspectives on Aging, Vol. 9. New York, NY: Springer.

DeVito Dabbs, A.J., Song, M.Y., De Geest, S. & Davidson, P.M. (2013). “Promoting Patient and Caregiver Engagement in Self-Management of Chronic Illness”. Nursing, Research and Practice. http://dx.doi.org/10.1155/2013/180757

DeVito Dabbs, A.J., Song, M.K., Myers, B.M., Hawkins, R.P., Aubrecht, J., Begey A., Connolly, M., Li, R., Pilewski, J.M., Bermudez, C.A. & Dew, M.A. (2013). “Clinical Trials of Health IT Interventions Intended for Patient Use: Unique Issues and Considerations”. Clinical Trials: Journal of the Society for Clinical Trials. 10(6):896-906. [PMID: 23867222. PMCID: PMC3808467]

Doswell, W., Braxter, B., DeVito Dabbs, A.J., Nilsen, W., Klem, M.L. (2013). “mHealth: Technology for Nursing Practice, Education, and Research”. Journal of Nursing Education and Practice. 3(10): 99-109. DOI: 10.5430/jnep.v3n10p99.

McMillan, J. M., Courtney, K. L., Matthews, J. T., Smailagic, A., & Siewiorek, D. (2013). Designing the community multi-user health kiosk. Studies in Health Technology and Informatics, 183, pp. 79-83. IOS Press Ebooks. DOI: 10.3233/978-1-61499-203-5-79.

Schulz, R., Beach, S.R., Matthews, J.T., Courtney, K., Devito Dabbs, A., Person Mecca, L., & Sankey, S. (in press; early online, July 2013). “Willingness to Pay for Quality of Life Technologies to Enhance Independent Functioning Among Baby Boomers and the Elderly.” The Gerontologist.

2.3 *Testbed Systems*

2.3.1 Home and Community Health and Wellness (HCHW)

Dan Ding (leader)	Pitt	Rehabilitation Science & Technology
Rory Cooper	Pitt	Rehabilitation Science & Technology
Rosemarie Cooper	Pitt	Rehabilitation Science & Technology
Karen Courtney	UVBC	Health Information Science
Anind Dey	CMU	Human-Computer Interaction
Fernando de la Torre	CMU	Robotics
Alex Hauptmann	CMU	Computer Science
Scott Hudson	CMU	Human-Computer Interaction
Michael McCue	Pitt	Rehabilitation Science & Technology
Mark Schmeler	Pitt	Rehabilitation Science & Technology

2.3.1.1 Motivation and Rationale

The goal of the HCHW testbed system is to create and evaluate home and community-based solutions for assessing and informing health and functional status of people with disability and older adults, and providing appropriate assistance to aid everyday task completion. Ultimately, this should afford them with greater independence and safety in their home and community. Our approach is to equip existing built environments and objects/appliances with sensors and devise intuitive ways to provide feedback or assistance. There are two core projects in HCHW.

- *Cueing Kitchen*: This project enhances existing home environment by integrating sensing and prompting components to assist persons with cognitive impairments in initiation and completion of common kitchen tasks.
- *KitchenBot*: This project enhances existing home environment by embedding a robotic manipulator in the kitchen to assist person with upper extremity impairments in completion of common kitchen tasks.

In terms of the strategic 3-plane chart, HCHW is in the top plane. HCHW research is creating fundamental knowledge in *Human Function,* and *Behavior and Everyday Living;* it is developing enabling technologies of *Task reasoning engines, User- and context-aware interfaces,* and *Activity recognition & prediction;* it generates new knowledge through *Observation & evaluation studies.* Our HCHW systems directly address fundamental barriers of *User acceptance*, *Individual differences & unpredictability, Complex interactions, Interoperability, Multi-disciplinary collaboration challenges* and *Demonstrating value*.

"There is no place like home". Research has consistently shown that daily activities are predominantly performed in the home and its close surroundings, and people choose to live in their homes despite declines in physical and mental health. Thus, it is important to know how the home environment can be designed or enhanced to help assess and/or improve health conditions and daily functioning of its residents, especially those with reduced capacities due to aging or disability. Although such knowledge has been gathered in recent decades, the evidence is fragmented and scattered, especially on the appropriateness and effectiveness of technological solutions for the home (e.g., smart home technology). With technological advances continuing to enable sophisticated solutions for the home, there is a need to incorporate design principles that take into consideration of stakeholder needs and preferences into the development process of such technology.

HCHW was created to address this need. Two projects address the cognitive and physical challenges people with disability and older adults may face in a domestic kitchen environment.

- *Cueing Kitchen*: This project enhances existing home environment by integrating sensing and prompting components to assist persons with cognitive impairments in initiation and completion of common kitchen tasks.

- *KitchenBot:* This project enhances existing home environment by integrating a track-based robotic manipulator in the kitchen to assist person with physical impairments in completion of common kitchen tasks.

Each project team consists of one or more PST members with expertise in relevant fields such as occupational therapy and neuropsychology, which helps ensure that the problems are tackled in a clinically meaningful way. We completed a pilot usability study with the *Cueing Kitchen* on cueing components and an interview study with people having traumatic brain injury on their challenges in the kitchen. The project continues with a field study where we observe users with cognitive impairments to prepare a meal following paper-based and iPad-based user-controlled recipes, and a laboratory-based study where we evaluate cueing strategies with a goal to understand if and to what extent an instrumented environment is useful, for whom, and under what circumstance. The project moves towards developing a portable solution that facilitate quick and easy deployment of sensing and cueing components in the cuing kitchen to clinic and residential settings. *Kitchenbot* is a new project which employs a Participatory Action Design (PAD) approach and encourages frequent interaction with end-users and numerous design revisions. Two focus groups have been conducted on evaluating the conceptual design and the 1st prototype, respectively. The project moves towards refining the prototype and developing user control interfaces for pilot user testing.

2.3.1.2 Relation to other Research Clusters

HCHW closely interacts with other technical thrusts/systems (e.g., PAT, HSIT, and QoLTBot) to understand the application of various algorithms (e.g., activity classification, user intent analysis, new interfaces etc.) on our projects. For example, we collaborated with HSIT WorldKit project to develop a novel interactive kitchen surface based on WorldKit technology [Xiao 13] using a bundled Kinect Sensor and a standard projector this past year. HCHW also closely interacts with the PST thrust to plan user studies to better understand their needs and involve users throughout the development process.

2.3.1.3 Achievements

The main achievements over the past year for cueing kitchen are as follows. More details can be found in the volumn 2 project descriptions.

- A user study was conducted in the residential kitchen of 6 individuals with TBI where they prepared a meal following a step-by-step user-controlled recipe on an iPad mini vs a paper-based recipe. The user-controlled method using an iPad showed potentials to improve efficiency, but was not as helpful to improve safety and reduce stress. The observations support the needs of integrating sensing and prompting to guide these individuals through meal preparation tasks.
- We refine the cueing kitchen testbed by adding a kinect sensor to detect user locations and further developing the context-aware prompter (CAP) software to interactively guide users in completing a list of steps during meal preparation.
- We obtained both the VA and Pitt IRB approval and iteratively tested and revised the hardware and software system for subject testing. The testing will evaluate two prompting strategies that require progressively more machine intelligence: 1) a user-controlled method where the person informs the system to move on to the next step by clicking a button on the computer screen and 2) a context-aware method where the sensors in the cueing kitchen will estimate the completion of an expected step and gives out following prompts automatically.
- We collaborated with HSIT WorldKit project to develop a novel interactive kitchen surface based on WorldKit technology using a bundled Kinect Sensor and a standard projector. The interactive touch-based kitchen surfaces can give intuitive prompts (text, audio, and visual) to assist users in completing multi-step cooking tasks and detect their responses. We also integrated the kitchen inventory system into this application, making the system easy to adjust for different recipes and track kitchen storage.

- We developed a rough proof-of-concept prototype of the “cueing kitchen in a box” toolkit that facilitates quick and easy deployment of the cueing kitchen sensing and prompting components in clinics and residential homes.

The main achievements over the past year for kitchenbot are as follows. More details can be found in the volumn 2 project descriptions.

- Several focus groups with potential users evaluated the conceptual design of the kitchenbot and generated design criteria for the kitchenbot.
- Based on the design criteria, a working prototype of the kitchenbot consisting of an overhead track and a robotic manipulator was constructed and installed in the research kitchen at the Human Engineering Research Laboratories at Pitt. Control software of the prototype was made to allow for input from a column-mounted joystick for manual control or from a computer’s serial interface to move the manipulator to a given X, Y position within 0.1 inches.
- Several focus groups with potential users evaluated the kitchenbot prototopye and generated the design priorities for next stage of development including implementing autonomous features and enhancing safety features.
- Various types of alternative user interface were developed including a clickable virtual kitchen interface on a touchpad, voice control, and kinect-based autonomous control.

2.3.1.4 Future Work

We will continue improving the technical aspects of HCHW by incorporating high-level sensing such as vision and algorithms (e.g., activity classification and intention prediction etc.) developed in the technical thrusts into the projects. We expect the subject testing with the cueing kitchen will inform the further development of the cueing kitchen testbed. We will refine the current prototype of kitchenbot based on the focus group feedback and suggestions, implement software algorithm for autonomous control by applying perceptual computing technologies and programmed automation to significant increase the efficiency in performing routine kitchen tasks, and deveop a test protocol for conducting empirical evaluations with target users. We envision HCHW will become a platform to support a variety of research studies on advancing health and wellness of older adults and people with disabilities through technology. The testbed system could facilitate studies that address questions: To what extent these new technologies useful? For whom are these technologies beneficial? How user characteristics (e.g., age, gender, socioeconomic status, race/ethnicity, cognitive and physical capabilities, health status, and motivations) and contexts (e.g., support systems) mediate the adoption, patterns of use, and effectiveness of these technologies? How caregiving practice will be impacted by these technologies? Will training (amount and delivery) be necessary to help improve the use of these new technologies? We consider NIH Program Project could be an option for us to continue our research in this area.

2.3.1.5 Team

The project team has expertise in electrical engineering, rehabilitation engineering, computer science, human-computer interaction, robotics, occupational therapy, and neuropsychology. We have also included clinicians and prospective end-users from the outset of the project.

2.3.1.6 Peer-Reviewed Publications

Telson, J., Ding, D., McCartney, M., & Cooper, R. Preliminary design of an overhead kitchen robot appliance. RESNA Annual Conference, Seattle, Washington, 2013.

Wang, J., Ding, D., Mahajan, H.P., Filippone, A.B., Toto, P.E., and McCue, M.P., Evaluating different types of prompts in guiding kitchen tasks for people with traumatic brain injury: a pilot study. RESNA Annual Conference, Seattle, Washington, 2013.

Mahajan, H., Ding, D., Wang, J., Ni, S. X., & Telson, J. Towards Developing A “Cueing Kitchen” For People With Traumatic Brain Injury. RESNA Annual Conference. Seattle, Washington, 2013.

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2.3.2 QoLTbots (QB)

Rory Cooper (leader)	Pitt	Rehabilitation Science & Engineering
Michael Boninger	Pitt	Physical Medicine and Rehabilitation
Emmanuel Collins	FSU	Robotics; Human-Computer Interaction
Rosemarie Cooper	Pitt	Rehabilitation Science & Technology
Dan Ding	Pitt	Rehabilitation Science & Engineering
Jodi Forlizzi	CMU	Human-Computer Interaction
Annmarie Kelleher	Pitt	Rehabilitation Science & Technology
Alicia Koontz	Pitt	Rehabilitation Science & Technology
Jonathan Pearlman	Pitt	Rehabilitation Science & Technology
Motoki Shino	CMU	Robotics
Sidd Srinivasa	CMU	Robotics
Pamela Toto	Pitt	Rehabilitation Science & Technology

2.3.2.1 Motivation and Rationale

As the world's older adult population and individuals who require assistance with activities of daily living (ADLs) continues to grow, so does the need for technologies that assist mobility and manipulation. The goal of the QoLTbots testbeds is to advance manipulation and mobility assistance devices that support independent living. QoLTbots is focused on four robotic systems: the *Home Exploring Robot Butler (HERB),* the *Personal Mobility and Manipulation Appliance (PerMMA),* the *Mobility Enhancement Robotic Wheelchair (MEBot),* and the *Strong Arm*. The goal of QoLTbots is not to reduce human interaction, but to free people to achieve greater autonomy and quality of life. The tasks that we have focused on are driven by this goal. The typical older adult or person with a severe disability typically has access to about 4 to 6 hours of caregiver assistance per day. This time is split between a few hours each morning and each evening. In the morning, the caregiver assists with getting up from bed, dressing, grooming, and breakfast. The middle of the day is spent largely without assistance, except perhaps from a work/school colleague, neighbor, or friend/family-member. This leads to a regimented lifestyle for many. The process is repeated in the evening, with dinner, grooming, and preparing for bed. With the guidance of end-users and caregivers, we have focused on the activities that people wish to perform during the middle of the day when little or no assistance is readily available. Hence, we have focused on tasks such as re-heating food, preparing a simple meal, or having something to drink. Further, retrieving a dropped book or remote control or taking items from a shelf, cabinet or closet at home or in the community are feasible tasks that could have a significant positive impact. Being able to do these tasks with the assistance of HERB, PerMMA will improve the quality of life of our target end-user population. Likewise, MEBot and Strong Arm facilitate mobility and thereby support greater participation in the community and society.

Our key challenges are building user-acceptable, safe, and easily operated systems that can effectively and reliably perform common tasks in both home and community environments. Those tasks should include 1) manipulating objects such as picking up dropped items, reaching items high on shelves, carrying items such as groceries, and retrieving mail from a mailbox; 2) performing everyday activities such as opening doors, preparing food and cooking tasks including making sandwiches and heating soup, and controlling appliances such as TV, telephone, electric bed, music system, nurse call, etc. 3) transferring to/from wheelchair to bed or shower 4) engaging in recreational activities such as operating a PS3 game controller (for a gamer who has use of one hand) or gardening tasks, and 5) assisting caregiver (nurse and therapist) tasks such as using the Strong Arm to assist transferring. QoLTbot research includes the full range of robot control modes, spanning autonomous operation to human-robot collaboration to teleoperation, so that we can better understand the appropriateness and quality of life impact of robots assisting people in everyday life. We are evaluating each of these operational modes with end-users using new outcome measurement tools co-developed with clinicians. Teleoperation with intelligent and customizable interfaces for *HERB* and *PerMMA* makes robots easy to use. Allowing for efficient, touch based localization increases and enables tasks of fine manipulation, such as grasping delicate objects, pushing small buttons, and minute actions such as inserting a key into a keyhole. By introducing new algorithms we help facilitate robots in searching for and manipulating these objects in order to work in more natural environments.

Our primary target populations are older adults and people with disabilities including spinal cord injury, amputation, spinal bifida, cerebral palsy, muscular dystrophy, stroke, and multiple sclerosis. This population often requires assistance to conduct mobility activities and activities of daily life (IADLs and ADLs). The secondary target populations include people with chronic diseases and patients undergoing rehabilitation post-hospitalization. Our long-term vision is that QoLTbot technology will benefit the general population.

In terms of the strategic 3-plane chart, QoLTbots are testbed systems in the top plane. QoLTbot research includes enabling technologies of *Everyday object manipulation, Mobility in everyday scenes, Integrated task & motion planners, Task reasoning engines,* and *Human interaction CAD;* it generates new knowledge through *Observation & evaluation studies.* Our QoLTbot systems directly address fundamental barriers of *User acceptance*, *Individual differences & unpredictability, Complex interactions, Contextual variability, Safety concerns, Robustness & generalizability, Multi-disciplinary collaboration challenges,* and *Demonstrating value*. Commercialization courses focused on QoLTbots are building *Business Cases* that also address the *Demonstrating value* barrier as well as the barrier of *Market factors*. *User acceptance* is being addressed by incorporating user, clinician, and caregiver feedback into the design and development of QoLTbot systems. Multiple control modes and interfaces are available for different users, and predictability of robot motion algorithms are being developed to address *Individual differences & unpredictability*. Autonomous operation has been spanned to human-robot collaboration teleoperation with an intelligent and customizable interface to address *Complex interactions,* e.g. assistive teleoperation control is accomplished by integrating HERB's autonomous control algorithm to PerMMA's local control user interface. Human-robot interactions are tuned using contextual information about the environment and the user for *Contextual variability*. Multiple layers of safety mechanisms have been implemented to address *Safety concerns*. Algorithms have been developed to enable robots to be robust to environmental uncertainties and can approach any environment to enhance *Robustness & generalizability*. The QoLTbots team includes members in robotics, rehabilitation engineering, computer science, mechanical engineering, design, human-computer interaction, social science, occupational therapy, and physical therapy to address *Multi-disciplinary collaboration challenges*.

2.3.2.2 Relation to other Research Clusters

QoLTbots are a platform technology that allows robots to work symbiotically with people. There is a sharing of technology and data between HERB and PerMMA, such as human-robot collaboration, teleoperation with intelligent and customizable interfaces, robotic manipulation in cluttered human environments, human interface, and subject test database. In addition, QoLTbots relates closely with other clusters throughout the center. For example, we integrate work on computer vision and object recognition with PAT to address how we can dynamically adjust our system and optimize performance of the symbiotic person-system dyad. We work closely with HSIT to improve human robot interaction of our robotic systems. The Strong Arm is designed to allow for the integration of several thrust level technologies such as the Intuitive Interaction (MoMaT) and learning algorithms (PAT). As a testbed for robots, we focus on improving the quality of life of the users, collaborating with clinicians and social scientists in PST, In addition, QoLTbots collaborates with PST on general user studies and the entire user testing data for QoLTbots are contributing to PST database. QoLTbots is a key platform for engaging clinicians and prospective users in the technology development process.

2.3.2.3 Achievements

HERB

HERB was developed to provide manipulation assistance to the user around the home. In practice, this will require the ability to enable tasks of fine manipulation, such as grasping delicate objects, pushing small buttons, and inserting a key into a keyhole; to enable more efficient and easy-to-use way of controlling assistive robotic arms; to enable seamless human-robot collaboration; and to enable the acceptance of robots working in roles which require human interaction, particularly in personal settings such as the home.

Figure QB-1: HERB MICO arm performs equivalent task of pouring a glass of water

For a robot to be able to function in uncertain human environments, it must often perform information gathering actions. Consider, for example, the scenario of reaching into a shelf to extract a mug. In our work last year, we developed an adaptive submodular formulation we call Hypothesis Pruning. Given a set of information-gathering motions, like reaching into the shelf at various places for example, our algorithm uses an efficient information-theoretic metric to quickly select most promising actions. We showed that this method had good theoretical properties for that task, and performs well compared to other state of the art metrics. This year, we extended our algorithm to address region uncertainty. Now, each of our motions would succeed for a subset of hypotheses – we call each of these subsets a decision region. The goal is to select actions to quickly reduce the uncertainty to a single decision region, enabling us to accomplish the task successfully. We developed a general-purpose algorithm with strong theoretical guarantees, applicable to non-robot examples like the Netflix recommender system as well, and show it outperforms out original Hypothesis Pruning approach. This work was done in collaboration with ETH Zurich.

Our prior work on assistive teleoperation showed that the preferred amount of autonomous assistance depends on both the difficulty of the task and the particular user. This shows a clear need for customization of the amount of assistance provided. Most of the time since taking delivery of the new MICO system (November 2013) has been spent interfacing the robot with our planning and perception infrastructure (Figure QB-1). Since we are developing on the first delivered MICO arm, there has been much collaboration between ourselves and Kinova Robotics to obtain the type of joint controls needed to execute the outputs from the autonomous planning algorithms. In parallel to the technical development of the MICO platform, individual interviews are being performed with JACO arm users and Kinova Robotics employees who worked on the JACO interface design and user training sessions.

In the past year, we have tested the idea of familiarizing users to the robot's motion in order to address the challenge of modeling the user's expectations --- instead of learning what users expect, we investigated whether users can familiarize themselves with the robot's way of moving. We have continued our efforts on producing intent-expressive legible robot motion. In addition, we have also extended our framework this year to deceptive motion, where a robot attempts to deceive a user about its intentions. Our key reason to explore and quantify deception is to make sure that our robot does not deceive unintentionally. In some of our prior user studies, participants attributed qualities to our robot's motion, like smart, thoughtful, and arrogant, unintentionally. Our goal was to develop a mathematical model for intent to control this behavior.

We want HERB to work in human environments. For the robot to be accepted, the user must have confidence in the robot's abilities. However, if a user overestimates what the robot is capable of, the robot will likely disappoint the user. We have explored this framework through two user studies looking at how robot speed and speech affect users' perceptions of the robot's capability. Through these studies we were able to develop a metric for measuring perceived physical capability and perceived social capability. The initial results of these studies were published as Late Breaking Reports at HRI 2013 and HRI 2014. A full publication will be submitted to RSS 2014. We have also investigated this idea with children, looking at how first impressions of robots affect their future attitudes towards robots. This initial exploration will be published as a Late Breaking Report at HRI 2014.

PerMMA

User's found the interfaces to PerMMA to be awkward and too slow for their liking; therefore, we implemented a new touch screen interface and voice control interface for PerMMA. Last year we tested both the touchscreen and voice control interfaces with a total of 5 subjects. We noticed two trends among PerMMA users: cognitive impairment increases task completion time and increased task completion times with voice control as compared to touch screen control.

After having updated PerMMA to a Linux-ROS based platform and implemented MOPED and CBiRRT (developed by the HERB project) in 2012, we have further updated the software architecture to task state control in 2013 (Figure QB-2). The task state control is essential when performing complex tasks with a series of procedures. We evaluated the reliability of the task state integrated with one of the most frequent self-care activity of daily living – drinking (ICF code: d560). The entire drinking task includes detection, holding a drink, bringing the drink to the mouth, and putting the drink back. The PerMMA system has been tested both with path planning simulation and real performance. We have performed the drinking task state with over 1000 different drink and PerMMA locations. Overall, the simulation results show a very high success rate (> 92%). In the pickup state, starting from under the table shows more random failures than starting from above the table. Most failures occurred when the drink was located close to the limit of the workspace. Similarly, in the drinking state, most of the failures were found at the edge of the iARM workspace. There were no failures found on the right side of the iARM.

We have conducted a user study to evaluate the assistive robotic manipulator control interfaces in performing common ADLs using the portable ADL task board developed in 2012, a questionnaire developed by PST, and an adapted Wolf Motor Function Test. Testing tasks include pushing buttons, flipping switches, turning knobs, turning keys, and picking up drinks, shopping baskets, or mouth sticks. The IRB has been approved and testing is in progress. Twenty-five subjects have already been recruited and have completed the testing. The subject testing result will be presented during the site visit.

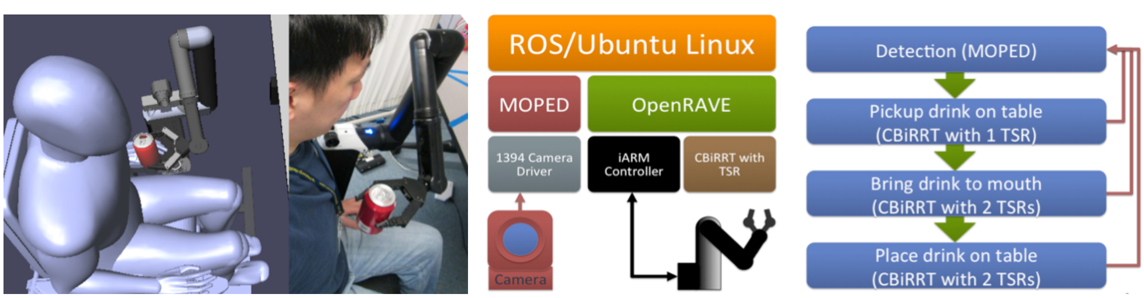

Figure QB-2: The updated PerMMA platform and task state control

MEBot

Multiple issues from PerMMA Generation II have been addressed in the current design of MEBot (Figure QB-3), including camber in the driving wheels, limited range of motion in the vertical and horizontal positioning of the wheels, high air consumption, high seat height, and wiring issues. Additionally, the components used in the first prototype limited the mobility applications due to the prototype's size and slow movements. As a result, addressing these issues while improving the mobility capabilities were the focus of the new generation.

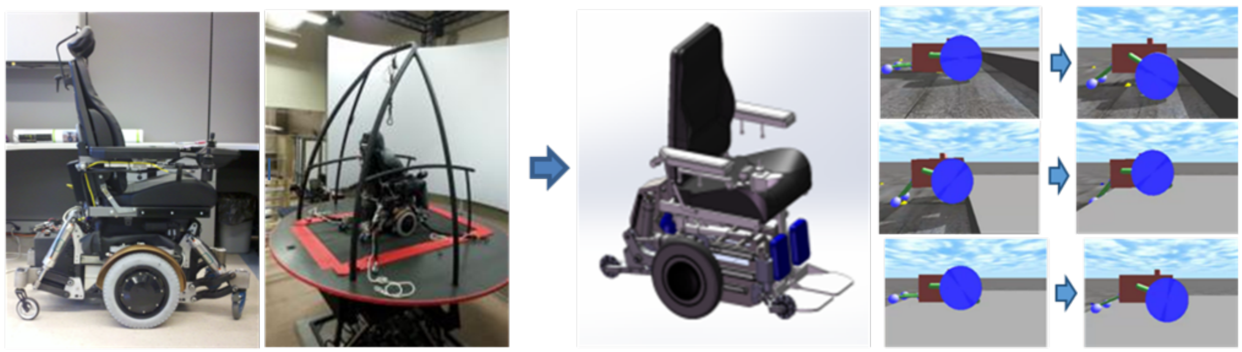

Figure QB-3: The PerMMA Gen II prototype was designed/developed and tested with the CAREN system and focus group studies. Limitations of the prototype are being addressed in MEBOT.

PerMMA Gen II demonstrated two main outdoor mobility applications: curb climbing and a self-leveling seat. The curb climbing application was successfully shown in the previous year; yet we addressed the long time sequence and limitations in the range of motion for climbing higher curbs. The self-leveling seat application was developed and applied in PerMMA Generation II in order to maintain a level seat leveled while driving on uneven surfaces. This was tested using the Computer Assisted Rehabilitation ENviroment (CAREN) dynamic platform to simulate driving at different slopes and angle surface change. We addressed the self-leveling and drive wheel movement limitations by increasing the range of motion of the driving wheels and rear casters. These increases allow MEBot to traverse steeper slopes than the current PerMMA Gen II and other motor wheelchairs while performing self-leveling to maintain the desired seating position. .

Strong Arm

Strong Arm accomplishments for the past year include focus group studies on usability and design, stability analysis of the system (Figure QB-4), and initial development of a graphical user interface. In order to obtain qualitative feedback regarding the design and usability of the Strong Arm, a focus group was conducted with 18 participants who use some type of wheeled mobility as their primary means of mobility. For safety concerns, a stability model of Strong Arm when different loads are applied and at different positions was developed. Figure QB-4, top right displays part of the results of the predictive stability model. The dotted parallelogram indicates the reflective markers on the base of the wheelchair, representing our stability margin. The curves inside the dotted line represent how the system's center of gravity changes over 3 trials along with the prediction model using 50kg. The bottom right shows the results how the end effector and the COM changes simultaneously while transferring the 185lb mannequin. Data was collected using Vicon System with reflective markers (as shown in the left of Figure QB-4) to measure movements of Strong Arm and force plates to measure the system's center of gravity and during a transfer using a 185lb mannequin. Figure QB-4 middle shows the start and end position of Strong Arm during a transfer with the 185lb mannequin. In the area of commercialization, we have been in discussions with RE2 Inc. about bringing Strong Arm to the market. Preliminary market analysis has been done, and plans have been made in regard to which features to include in a commercial version and how to comply with regulatory statutes. We also have an SBIR proposal recommended for funding.

Figure QB-4: Strong Arm stability test and safe zone for operation: The Strong-Arm system was tested using a force plate and VICON system for the stability during the transfer. Based on the test results, a safe operation zone was created to prevent tip-over during the transfer.

In summary, over the past year we:

- Developed an algorithm to reduce uncertainty during performing a task
- Developed models for assistive robotic manipulators such as JACO and MICO
- Investigated whether users can familiarize themselves with the robot's way of moving
- Explored the framework to enable the adoption and acceptance of robots that can assist users in everyday tasks by two user studies
- Tested the touchscreen user interface and voice control interface with 5 subjects
- Tested the ADL task performance evaluation tool with 24 subjects
- Developed and tested the task state control for PerMMA assistive teleoperation
- Designed the new MEBot
- Developed and tested self-leveling control using CAREN system
- Developed a slip-reduction control for MEBot
- Developed and tested the stability model of Strong Arm
- Designed and developed a graphic user interface for Strong Arm

2.3.2.4 Future Work

Summary of plans for the next year:

- Better modeling of objects and optimizing computation complex toward human-robot collaboration
- Continue to work towards approximation methods for reducing computational burden
- Continue developing this framework by exploring how modification and customization of the robot's behavior can improve acceptance
- Upgrade PerMMA manipulators to JACO arms and implement the assistive teleoperation control interface
- Continue to work on cross-platform (PerMMA and HERB) compatibility
- Continue to collect user data for the ADL task performance evaluation board
- RGBD sensors and assistive interface control will be integrated to improve task efficiency
- Develop user studies to evaluate the user interfaces with shared autonomy
- Continue to develop the standardized assistive robotic manipulator evaluation tool
- Further develop and test reliability, validity, usability of the outcome measurement tool
- Manufacture MEBot and implement the self-leveling algorithm on MEBot, test using

CAREN system and the built driving course
- Continue to develop Strong Arm user interface and control
- License MEBot and Strong Arm to HSTAR Inc. and RE2 Inc. respectively, to continue the commercialization process.

Future research will improve the overall autonomy, efficiency and robustness of QoLTbots performing real-life tasks. QoLTbots is a focus for integrative activities and a driver for better manipulation, perception, and interface technologies. An emphasis for new manipulation algorithms is “knowing less in advance” (having less prior knowledge) and “knowing less currently” (having less exact sensing and less knowledge of world geometry such as hinge axis for cabinet doors). An emphasis for perception is greater robustness and also less need for prior knowledge. We will develop algorithms that handle both known and unknown objects and people simultaneously.

2.3.2.5 Team

The QoLTbots team is comprised of faculty, staff, and students in robotics, rehabilitation engineering, computer science, mechanical engineering, design, human computer interaction, social science, occupational therapy, and physical therapy.

2.3.2.6 Peer-Reviewed Publications

Cha, E., Dragan, A., Srinivasa, Siddhartha, “Effects of Robot Capability on User Acceptance”, Late Breaking Report Proceedings of Human Robot Interaction 2013, 2013.

Chung, C., Wang, H., Kelleher, A., & Cooper, R. A. (2013). Development of a Standardized Performance Evaluation ADL Task Board for Assistive Robotic Manipulators. In Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference. Seattle, WA.

Chung, C., Wang, H., & Cooper, R. A. (2013a). Functional assessment and performance evaluation for assistive robotic manipulators: Literature review. The journal of spinal cord medicine, 36(4), 273–89. doi:10.1179/2045772313Y.0000000132

Chung, C.-S., Wang, H., & Cooper, R. A. (2013b). Autonomous function of wheelchair-mounted robotic manipulators to perform daily activities. IEEE ... International Conference on Rehabilitation Robotics : [proceedings], 2013, 1–6. doi:10.1109/ICORR.2013.6650378

A. Collet, B. Xiong, C. Gurau, M. Hebert, S. S. Srinivasa. “Exploiting Domain Knowledge for Object Discovery” in IEEE International Conference on Robotics and Automation. IEEE. 2013.

Cooper RA, Cooper RM, Wang H, Grindle GG, Houston E, Chung C, Kelleher AR, Candiotti J, Human-Robot Cohabitation: The Future of Assistive Robots, Association for the Advancement of Assistive Technology in Europe Conference, Vilamoura, Algarve, Portugal, September 19-22, 2013.

Daveler B, Candiotti J, Grindle GG, Cooper RA, Wang H, Design and Development of a Caster Wheel Lock Mechanism for a Robotic Power Chair, Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Seattle, WA, June 20-24, 2013.

Anca Dragan and Siddhartha Srinivasa, “Generating Legible Motion”. Robotics: Science and Systems. (best paper finalist)

Dogar, M., Koval, M., Tallavajhula, A., Srinivasa, S., "Object Search by Manipulation", IEEE International Conference on Robotics and Automation, May, 2013.

Hintzman Z, Candiotti J, Wang H, Chuy O, Implementation of a Slip Reduction Algorithm for Electric Powered Wheelchairs, SACNAS National Conference, San Antonio TX, October 3-6, 2013.

Javdani, S., Klingensmith, M., Bagnell, J. A., Pollard, N., Srinivasa, S. “Efficient Touch Based Localization through Submodularity” ICRA 2013

Jeannis H, Grindle GG, Kelleher AR, Wang H, Brewer B, Cooper RA, Initial Development of Direct Interaction for a Transfer Robotic Arm System for Caregivers, Rehabilitation Robotics (ICORR), 2013 IEEE International Conference on, 24-26 June 2013

Wang H, Xu J, Kelleher AR, Ding D, Grindle GG, Vazquez J, Salatin B, Cooper RA, Performance Evaluation of the Personal Mobility and Manipulation Appliance(PerMMA), Medical Engineering and Physics, pp. 1613-1619, Vol. 35, No. 11, November 2013.

Wang H, Chung C, Candiotti J, Grindle GG, Ding D, Cooper RA, User Participatory Design: Lessons Learned from PerMMA Development, Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Seattle, WA, June 20-24, 2013.

Wang H, Candiotti J, Motoki S, Chung CS, Grindle GG, Ding D, Cooper RA, Development of an Advanced Mobile Base for Personal Mobility and Manipulation Appliance Generation II Robotic Wheelchair, Journal of Spinal Cord Medicine, pp. 333-346, Vol. 36, No. 4, 2013.

Zhang L, Grindle GG, Cooper RA, Determining Range of Motion of Strongarm Transfer Technology, 27th National Conference on Undergraduate Research, La Crosse WI, April 11-13, 2013.

2.3.3 Safe Driving (SD)

Aaron Steinfeld (leader)	CMU	Robotics
Rory Cooper	Pitt	Rehabilitation Science & Technology
Anind Dey	CMU	Human-Computer Interaction
Patricia Karg	Pitt	Rehabilitation Science & Technology
SeungJun Kim	CMU	Human-Computer Interaction
Amy Lane	Pitt	Rehabilitation Science & Technology
Ashli Molinero	Pitt	Rehabilitation Science & Technology
Linda van Roosmalen	Pitt	Rehabilitation Science & Technology
Anthony Tomasic	CMU	Institute for Software Research
John Zimmerman	CMU	Human-Computer Interaction

2.3.3.1 Motivation and Rationale

Transportation is currently a barrier to social participation and, particularly, employment. More than half a million people with disabilities cannot leave their homes because of transportation difficulties [NOD 04]. Even when they are able to leave their home, one-third of people with disabilities have inadequate access to transportation [NCD 05]. Consequently, four times as many people with disabilities as people with no disabilities lack suitable transportation options to meet their daily mobility needs [NOD 00].

Such difficulty has importantconsequences. According to one study, 46% of people with disabilities, compared to 23% of people without disabilities, reported feeling isolated from their communities [NOD 00]. Individuals with disabilities were five times more likely to report dissatisfaction with their lives than were their non-disabled counterparts, and a majority of those surveyed said that lack of a full social life was a reason for this dissatisfaction. For example, persons with disabilities were about half as likely to have heard live music, gone to a movie, or attended a sporting event or concert over a one-year period [NOD 00], [Loprest 01]. Inadequate transportation limits access to these activities for individuals with disabilities. People with disabilities, both in urban and rural areas, frequently cite a lack of local transportation as hindering their ability to find employment. Lack of transportation (29%) was only second to a lack of appropriate jobs being available (53%), as the most frequently cited reason for being discouraged from looking for work [Loprest 01].

There is also a pressing need to address the current, and worsening, constrained supply of clinical driver rehabilitation specialists (CDRS). Current estimates place the number of practicing CDRS therapists in the vicinity of 300-400 for the entire United States. This is clearly not sustainable given the aging of the population and increasing policy attention on driver capability and licensing. Since there are very few new CDRS practioners entering the field, society needs ways to increase current CDRS efficiency and triage safe clients before they unnecessarily consume clinical time.

In response to these issues, QoLT *Safe Driving* is focused on technologies to support independent mobility through personal vehicles. A unifying approach is to provide appropriate short-range autonomy to serve targeted needs, identify driver capabilities, and modify driver behavior in order to shift decision-making tendencies toward safer ones. The latter is akin to efforts to combat driving-under-the-influence and drowsy driving through the use of technology. In contrast, the U.S. Department of Transportation is focused on stopping crashes through technologies designed to intervene during various dangerous situations, such as lane departure and collision warnings.

Safe Driving addresses two key issues related to transportation independence: 1) providing personalized advice and autonomy specific to the driver's safety, capabilities, and preferences; and 2) enabling driving by removal of barriers and improving delivery of clinical care. This has led us to the following core projects, which have evolved since last year:

- *DriveCap:* A low-cost aftermarket in-vehicle system that assists CDRS clinicians in measuring driver capability. This system is used to 1) gather driving data and 2) help driver therapy professionals assess clients using efficient, objective methods.

- *DriveCap Advisor:* A consumer-oriented system to provide driver-specific advice regarding capability. We use machine learning techniques to build driver capability assessment models with the intent of providing periodic feedback. Due to the increasing “app-ification” of the driver-vehicle interface, this effort includes an attempt to understand how novel interfaces interact with driver capability.
- *Vehicle Enhancement:* Short-range semi and fully autonomous vehicle actions designed to mitigate driving tasks deemed challenging by consumers. This year is focused on helping with left-hand turns at unprotected intersections.

These projects also translate well to drivers outside of the core QoLT target populations. The team uses a universal design approach to development. Safe Driving technologies have the potential to help distracted drivers and are being developed with an eye towards the sensors and systems already present in vehicles and regular smartphones. This broadens the potential user base and removes reliance on custom and niche-market hardware.

In terms of the strategic 3-plane chart, Safe Driving systems are in the top plane. Safe Driving research is also creating fundamental knowledge in *Human Function* and *Behavior and everyday living;* it is developing enabling technologies of *Task reasoning engines, User- and context-aware interfaces,* and *Activity recognition & prediction, Intent recognition & prediction;* it generates new knowledge through *Needs Assessment* and *Observation & evaluation studies.* Our Safe Driving systems directly address fundamental barriers of *User acceptance*, *Individual differences & unpredictability, Complex interactions, Interoperability, Safety assurance, Contextual variability, and Multi-disciplinary collaboration challenges*.

The barriers of *Individual Differences and Unpredictability*, *Model Noise and Uncertainty*, and *Contextual Variability* are the primary challenges for projects that involve driving on public roads due to the complex and highly variable environments and scenarios encountered during driving in suburban and urban settings. As systems mature and approach commercialization, *Market Factors* and *Robustness and Generalizability* are also concerns due to the need to costs low for mass production and price points within the competitive automotive market and the need to work reliabily in varying driving scenarios.

2.3.3.2 Relation to other Research Clusters

In recent years, *DriveCap* was refined to target clinical applications based on input from clinicians. *DriveCap Advisor* was formed by merging the machine learning aspects of *DriveCap* and the outputs of earlier projects (*DriveCap Navigator* and *Assessing Cognitive Load of Elder Drivers*) based on feedback from QoLT Advisory Boards. Activities last year for *Vehicle Enhancement: Virtual Valet* project were driven by feedback from the *Rich Stimuli Data Collection* project (*PST*).

DriveCap Advisor efforts continue to be strongly related to knowledge and technologies from *Virtual Coach* and *HSIT*. For example, coaching a user on how to manage a change in their capabilities is likely to be similar for both non-driving and driving activities.

This year, the *Vehicle Enhancement* team changed from the *Virtual Valet* case study to *Left Turn Assistance.* During initial development of the project plan using *Person and Society* feedback, this functionality was highlighted by participants as an important issue. Personel from the Perception and Awareness thrust participate in this effort by supporting the development of the perception technology.

2.3.3.3 Achievements

The following is a brief description of the Safe Driving technologies that have been developed since the beginning of the ERC:

- DriveCap Data Logger: This system consists of a prototype driver monitoring system that can be installed and calibrated in personal vehicles, without damage, in about an hour. System components include forward ranging radar (IPAB partner Bosch), forward looking lane tracking, GPS, inertial measurement, vehicle data collection, and hardened power and recording systems. The system has been used to collect naturalistic and clinical on-road data.

- DriveCap Navigator: This award winning work produced novel methods for learning driver navigation preferences and making meaningful predictions on destinations, turn selection, and appropriate routing. The techniques have been verified for both taxi drivers and older adults. The latter was accomplished with the assistance of a club of retired Westinghouse employees. The core algorithms have also been adapted for predicting pedestrian (QoLTbots) and on-screen cursor motion.
- Vehicle Transformation: This work developed basic knowledge on vehicle modifications and established concrete results for functional driver abilities for manipulation of vehicle interfaces by drivers with disabilities. No data on this topic existed prior to this project, so the vehicle modification industry made educated guesses when designing equipment.
- Virtual Valet: This autonomous system, developed based on requests from early QoLT focus groups, allows drivers to exit at the curb and observe their vehicle park autonomously. This approach utilizes Perception and Awareness techniques to traverse parking garages without GPS and to detect open parking spaces. Nissan (IPAB member) recently demonstrated similar capability in their Pivo 3 concept car at the 2011 Tokyo Motor Show. Audi also demonstrated similar functionality at the 2013 CES, which occurred after a visit to QoLT.
- Cognitive load: QoLT researchers, in partnership with GM (IPAB member), have developed methods for measuring cognitive load using physiological methods. These personalized models can accurately indicate whether participants are in high or low cognitive load states without the need for invasive survey questions. Unlike prior approaches, this technology identifies the correct collection of physiological sensors for each user, thereby increasing accuracy and optimizing the number of body worn sensors for each individual.

In 2008, the team brought in a major center focused on public transit. The Rehabilitation Engineering Research Center on Accessible Public Transportation (PI: Steinfeld, www.rercapt.org, NIDRR H133E080019, 10/01/08 – 09/30/13, NCE to 09/30/14, $4.7M over five years) provides a complement to Safe Driving's focus on personal vehicles. This allows the team to look at independent transportation within the community at the top level and share knowledge and findings between QoLT and the RERC-APT. The Tiramisu project within the RERC-APT has demonstrated significant success, having received awards for innovation (ITSA), accessibility (FCC), and two paper awards from peer reviewed conferences. The Tiramsu spinout company was also awarded a US DOT Phase I SBIR in 2012.

This year, the RERC-APT team was successful in renewing their funding with another 5-year RERC grant (PI: Steinfeld, www.rercapt.org, NIDRR H133E130004, 10/01/13 – 09/30/18, $4.6M over five years). This ensures continued complimentary work through the end of the QoLT ERC.

The highlights for the reporting year are (a) completion of the *DriveCap* on-road study and research project, (b) research in *DriveCap Advisor* on attention and cognitive workload and low cost sensing infrastructure, and (c) preparation for *Left Turn Assistance* implementation.

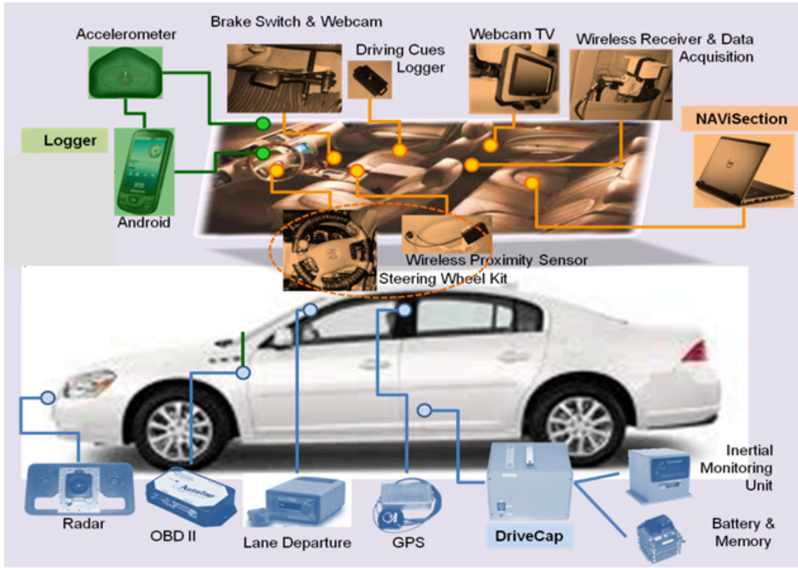

Figure SD-1: *DriveCap (blue and orange)* and *DriveCap Advisor (green)* equipment installed in clinical vehicle

DriveCap

This year the *DriveCap* team completed on-road documentation of ground truth therapist actions during regular clinical practice while the system logs vehicle data. Data from 16 clinical drivers was used to identify and evaluate methods for objective assessment of driver capability. The resulting method outperformed current clinical techniques (American Medical Association's Physicians' Guide to Address Driving Related Skills or ADReS, as well as self-report of key driving events). This project completed with the graduation of the project's PhD student. The work is now in the process of being transitioned to a QoLT spinout company led by the student, which was the recent recipient of an NSF I-Corps award.

DriveCap Advisor

In prior years the team members associated with *DriveCap Advisor* showed that shifts between high and low cognitive load can be captured using psycho-physiological measures (e.g., pupil size, etc). The team has explored whether changes in driver interfaces can be detected using these measures, thereby revealing the interaction between cognitive load and vehicle interface design. The team has continued the practice of using machine learning to evaluate drivers and examined prior data on aggressive driving.

Efforts this year have focused on reducing the set of psycho-physiologic sensors to commodity hardware. The team has developed an In-Vehicle SmartPhone Sensing Platform (IV-SP2). The core part of our system is the driver's own Android smartphone mounted on the front dashboard, which not only collects the location and movement of the vehicle but also accesses data wirelessly from vehicle and a reduced set of body worn sensors (compared to prior versions).

The team also completed a study on automated assessment of aggressive driving behaviors. Using the IV-SP2 system, the team defined a number of driving features that are used in building a machine learning (ML)-based model of driving style. Data was collected during naturalistic data collection from 22 licensed drivers for 3 weeks. Aside from identifying interesting behaviors, the automated system as able to reach a model accuracy of 90.5% (2 false negatives) when predicting a "violator" driving style classification and 81% (2 false negatives & 2 false positives) when predicting the whether a participant would be classified as aggressive by a questionnaire.

Vehicle Enhancement: Left Turn Assistance

Work this project year was split into two phases. The first was focued on preliminary activities necessary for proof-of-concept implementation. This consisted of a literature review, preliminary real-world data collection at intersections, and development of analysis software infrastructure. The collected data was analyzed to extract individual targets and plot trajectories. This data will be used to threshold clearance distances and determine the structure of possible safe turns. The second phase, which will occur after January 2014, is focused on actual implementation on NavLab 11 (fully autonomous Jeep).

2.3.3.4 Future Work

As the ERC progresses, we expect continued technology development within the *DriveCap Advisor* and *Vehicle Enhancement* projects. After Left Turn Assistance, the project team will explore One-Handed Steering. These case studies were informed by early ERC focus groups conducted by *PST*. Like Virtual Valet, the intent of these subprojects will be to demonstrate potential for such functionality to industry and spur implementation by others. As has been the case, we plan to conduct periodic evaluations of *Safe Driving* applications in cooperation with *PST*, iteratively incorporate *PST* identified issues into the technology development, and involve *PST* in project activities. Specific plans for next year include:

- Development of concept end user interfaces and interactions for a *DriveCap Advisor* system, including collection of *PST* relevant measures (e.g., acceptance, etc).
- Development of more sophisticated *DriveCap Advisor* methods for identifying differences in driving performance using the IV-SP2 platform.
- Implementation of a working proof-of-concept Left Turn Assistance system.
- Documentation of a Left Turn Assistance system for use in PST research.

As is apparent from the renewal of the RERC-APT, the core QoLT effort and overall mission provide an excellent opportunity for sustainable funding. The QoLT network also provides opportunities beyond the core partners. For example, the RERC-APT is a partnership with a member of the QoLT Scientific Advisory Board and the RERC-APT has pursued funding in partnership with the University of Southern Florida (LSAMP partner).

Over the long term, the team expects to produce *DriveCap Advisor* systems that have the potential for field-testing and other US Department of Transportation sponsored research. Carnegie Mellon recently renewed a University Transportation Center (Steinfeld and Kim are project leaders) and the university is becoming increasingly active in pursuit of other US DOT funding channels. Extensions of *DriveCap Advisor* are being funded by the UTC and are included in other proposal efforts.

DriveCap Advisor and the *Vehicle Transformation* projects are directly relevant to industry and there is potential funding from such sources. For example, the *DriveCap Advisor* team has collaborations with Samsung and AT&T. With the completion of the *DriveCap* project, we expect the clinical technology spun out this year will be attractive to sources like the Veterans Administration and other communities with a need to assess driver performance for therapeutic interventions and more efficient clinical practice.

2.3.3.5 Team

The Safe Driving team continues to be a very diverse group; technical professions include experts in driver-vehicle interaction, machine learning, robotics, human-computer interaction, and design. This mixture permits integration of *PST* into all technology development efforts and end user data collection. Future strong interaction with *HSIT* and *Virtual Coach* is expected as *DriveCap Advisor* evolves to offer advice to end users. *Safe Driving* has close ties to the *PAT* through the machine learning activities and *Virtual Valet*. Likewise, the team has close ties to *Virtual Coach* through a shared researcher.

2.3.3.6 Peer-Reviewed Publications

Beyene NM, Lane AK, Cooper RM, Cooper RA, On-Road Evaluation of Driver Capability: A Medical Record Review of the Adaptive Driving Program, Driving Assessment 2013, Bolton Landing, NY, June 17-20, 2013.

Beyene, NM. "The Synthesis of NAViSection: Modernizing Driver Rehabilitation Programs to Encompass Intelligent Vehicle Technologies." PhD Thesis, University of Pittsburgh, 2013.

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[NOD 00] National Organization on Disability. "2000 NOD-Harris Survey of Community Participation." http://www.nod.org/research_publications/surveys_research/harris/, 2000.

[Loprest 01] P. Loprest, and E. Maag, "Barriers to and supports for work among adults with disabilities: Results from the NHIS-D." Washington, DC: The Urban Institute, 2001.

2.3.4 Virtual Coaches (VC)

Asim Smailagic (leader)	CMU	Electrical & Computer Engineering
David Brienza	Pitt	Rehabilitation Science & Technology
Rory Cooper	Pitt	Rehabilitation Science & Technology
Rosemarie Cooper	Pitt	Rehabilitation Science & Technology
Theresa Crytzer	Pitt	Rehabilitation Science & Technology
Anind Dey	CMU	Human-Computer Interaction
Dan Ding	Pitt	Rehabilitation Science & Technology
Brad Dicianno	Pitt	Rehabilitation Science & Technology
Thomas Kamarck	Pitt	Psychology
Patricia Karg	Pitt	Nursing; Urban & Social Research
Annmarie Kelleher	Pitt	Rehabilitation Science & Technology
Judith Matthews	Pitt	Nursing; Urban & Social Research
Michael McCue	Pitt	Rehabilitation Science & Technology
Jonathan Pearlman	Pitt	Rehabilitation Science & Technology
Daniel Siewiorek	CMU	Human Computer Interaction
Reid Simmons	CMU	Robotics
Tzen, Yi-Ting	Pitt	Rehabilitation Science & Technology

2.3.4.1 Motivation and Rationale

Today's cognitive aids are simplistic: they can only provide scheduled reminders and rote instructions. The confluence of several new technologies has enabled a new generation of attentive personalized systems called *Virtual Coaches*. A *Virtual Coach* continuously monitors its client's activities and surroundings, detects situations where intervention would be desirable, offers prompt assistance, and provides appropriate feedback and encouragement. When teaching a new exercise or re-teaching a skill for example, the coach may reduce the number of verbal cues it provides if the client's performance improves, conversely, it will provide increased support to reverse a drop in the client's performance. *Virtual Coaches* are intended to augment, supplement and, in some circumstances, be a substitute for a clinician by offering guidance beyond and between episodic office visits. As such, they typically have a clinician interface in addition to user interactions.

Virtual Coaches is a highly interdisciplinary area of research and development that combines the expertise and science from the social sciences, informatics, computing sciences, human computer interaction, health sciences and engineering. The goal is to employ theory from social science, cognitive science, behavioral science and economics. Social science models of collaborative behavior can be used as a basis for determining the nature of the social setting. For example, theories and observations of what drives people to interrupt a social situation or draw attention to themselves can form the basis for software decisions in virtual coaches. By mapping observable parameters into cognitive states, the computing system can personalize the form of interaction that minimizes user distraction and the risk of cognitive overload.

Two main themes have emerged: 1) Moving more virtual coaches to cell phone/tablet form factor, such as Seating Coach and Stroke Therapy Coach; 2) Focusing on user engagement – games, adapting feedback to emotional state, and automatic goal adjustment.

In terms of the strategic 3-plane chart, *Virtual Coaches* are testbed systems in the top plane. *Virtual Coach* research is creating fundamental knowledge in *Human Function;* it is also developing enabling technologies of the *QoLT system architecture* and *QoLT design and redaction methodologies. Virtual Coaches* address several of QoLT Barriers*:*

- *Privacy Concerns: Virtual Coaches* collect, abstract, and share information with various constituencies based on permission and need to know.

- *User Acceptance:* Configuration and customization capabilities as well as compelling interaction help sustain user acceptance.

- *Demonstrating Value*: *Virtual Coaches* can complement clinical personnel and caregivers achieving cost reductions.
- *Robustness and Generality*: *Virtual Coaches* support a broad range of human performance and adaptation mechanisms thereby supporting a variety of users under various conditions.
- *Interoperability*: *Virtual Coaches* build upon commercially available platforms enhancing their capability.
- *Multi-Disciplinary Collaboration Challenges*: *Virtual Coaches* are designed by multi-disciplinary teams of computer scientists, social scientists, and clinicians.
- *Individual Differences and Unpredictability*: *Virtual Coaches* adapt based on contextual information gathered about the user, their environment and their situation.
- *Complex Interactions*: *Virtual Coaches* interact with clinicians, caregivers, and end users through context aware interfaces augmented with real time feedback capability.

Virtual Coaches can address a wide variety of quality of life needs, including physical therapy, exercise, medication management, diet management and general physical activity. A particularly important application domain for *Virtual Coaches* is to assist individuals whose own cognitive capabilities have been impaired due to natural aging, illness or traumatic injuries. Recent estimates indicate that over 20 million Americans experience some form of cognitive impairment. This includes older Americans living alone (~4M), people with Alzheimer's disease (~4.5M), people with mild cognitive impairments (~6M older adults), survivors of stroke (~2.5M) and people with traumatic brain injury (~5.3M). Of the many challenges faced by older individuals, they fear declines in memory and cognition most, and these fears have a large negative impact on themselves and their family members.

Current cognitive aids operate open-loop without regard for the user's activities or environment. In contrast, *Virtual Coaches* monitor how the user performs activities, provides situational awareness and gives feedback and encouragement matched to the user's cognitive state and circumstances at the time. Consider the difference between a medication reminder that blindly sounds an alert everyday at noon, versus a *Virtual Coach* that both realizes a user took their pill at 11:58 and cancels the reminder or when they are having a conversation, and sets itself to vibrate mode.

Transformative features of a Virtual Coach include:

- It matches its level of support – the number of and level of detail in the cues it provides – to the user according to the user's performance level. For example, goal setting can be modified during exercises;
- A clinician can upload new capabilities to the *Virtual Coach*, as required, without even an office visit; and,
- It provides constant and consistent monitoring of adherence to a clinician's instructions, enabling a deeper and timelier understanding of conditions beyond the episodic patient examinations available today.

Virtual Coaches based on understanding of user situations and needs are also effective for applications aimed at larger populations. For example, cognitive support can assure safe use and compliance with instructions in rehabilitation or management of chronic illness. Many individuals are released from the hospital to their home with inadequate training for themselves or their family caregivers for the operation of newly prescribed home medical devices or following complex medical regimens. Failure to properly follow directions often results in expensive re-hospitalizations.

2.3.4.2 Relation to other Research Clusters

Virtual coaches employ basic research from the Perception and Awareness Thrust (PAT) for sensor technology and data processing for interpreting the environment as well as the user's actions. For example, coaches using the PAT technology are Head Coach, Physical Therapy Coach, and Seating Coach. The Human Systems Interaction Thrust (HSIT) provides basic knowledge of user interaction, particularly in how to tune interactions and appropriately tailor system responses. The Person and Society Thrust (PST) provides access to end user populations (subjects, care givers, and clinicians) that are involved in surveying, design, critiquing, and evaluation of system inputs and output responses. We have been collaborating with PST on almost all Virtual Coaches projects.

Virtual Coach knowledge and elements are directly usable in the other three testbed systems. For example, knowledge from Virtual Coach systems has been employed in the design of the Health Kiosk; future versions of the Cueing Kitchen and DriveCap Advisor will also have Virtual Coach characteristics. The next section discusses the architectural elements common to all *Virtual Coaches*.

2.3.4.3 Achievements

Virtual Coach Functional Architecture

As indicated above, currently available aids are simplistic, providing only scheduled reminders and rote instructions. *Virtual coaches* monitor user performance of activities and user context (Sensor Processing), determines appropriate feedback (Coaching Model), and provides feedback and encouragement (User Engagement). A care provider could change the monitoring and feedback parameters of the virtual coach, as required (Prescription). Over time a customized personal interaction evolves (User Interaction). Figure 2 depicts how these five functional elements interact to create a Virtual Coach.

We have devised a variety of user engagement forms, including passively viewed computer and smart phone screens, audible and graphical interruptions, virtual reality games, responses based on user emotional state, and automatic goal adjustment as performance varies. By translating the vocabulary of a clinician into easily understandable forms, she can prescribe complex monitoring and feedback behavior without having to learn computer programming.

We developed a series of *Virtual Coaches* sharing approaches, design elements, techniques, and software. A Personal Wellness Coach, our first coach, was developed in 2005 (prior to the ERC) and employed a BodyMedia armband in exercise specific locations on the body to count repetitions, detect when the user was struggling and provide encouragement. It provides pacing for exercising by varying the tempo of music. Several trends emerged:

- Perceived need: Concepts for virtual coaches emerged from perceived need derived from discussion with clinicians. Several coaching topics were initially suggested by nurses and clinicians.
- User centered design: Nurses, clinicians, and end users were part of the design team throughout the project, which increased usability and acceptance.
- More and increasingly sophisticated sensors: The number, variety, and sophistication of sensors increased for both stationary (e.g. Kinect) and mobile (e.g. gyroscopes) sensors.
- Pipeline: A pipeline has been established for moving virtual coaches from prototype to deployment with each stage involving more extensive user evaluation and design refinement.

Our approach is to generalize the collective knowledge that has been obtained from *Virtual Coaches* we have already created into a *toolkit* to assist in building coaching models, support the tasks of configuration/personalization of existing *Virtual Coach* designs and/or assembly of novel *Virtual Coach* designs from basic functional subsystems. The Physical Motion Widgets (PMW) present a novel implementation paradigm for motion analysis applications. The widgets serve as mediators between the low-level sensor information and application programs allowing developers to attach their call-back functions to receive and process higher-level information and movement events.

In conjunction with clinicians we have developed a general approach to the patient allowing concise visualization of multiple days of rehabilitation exercises including compliance and performance. Initially developed for the Head Coach, the visualization modalities were directly applied to the Stroke Rehabilitation Coach as shown in Figure VC-1.

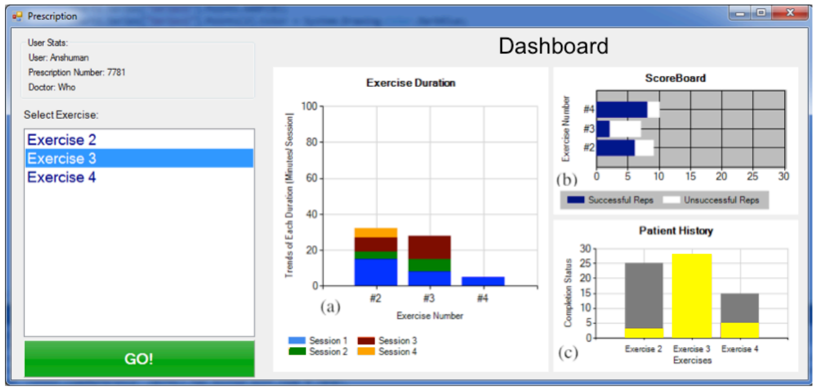


Figure VC-1. Example of visualization technique for virtual coaches (a) The exercise duration is extracted from how long the patient performed each exercise in all sessions. Different colors indicate different sessions. (b) Total number of repetitions performed by patient for each exercise, as well as number of successful and unsuccessful repetitions. (c) Patient performance history with the amount of time spent on each exercise (completed part of the exercise is indicated in yellow).

Evolution of Virtual Coaching systems

Figure VC-2 depicts the pipeline of Virtual Coaches that emerge from interdisciplinary design teams that include end users into a prototype (stage 1). We further develop the promising prototypes to improve hardware, software, and user interaction robustness (stage 2). The worthwhile prototypes go through user testing with end users and clinicians in the laboratory with further development based on what has been learned (stage 3). Subsequently the virtual coaches are deployed in the field, going home with end users for daily use (stage 4). We use the data collected in the field to evaluate the effectiveness of the coach. The position of the coaches is shown in Figure VC-2

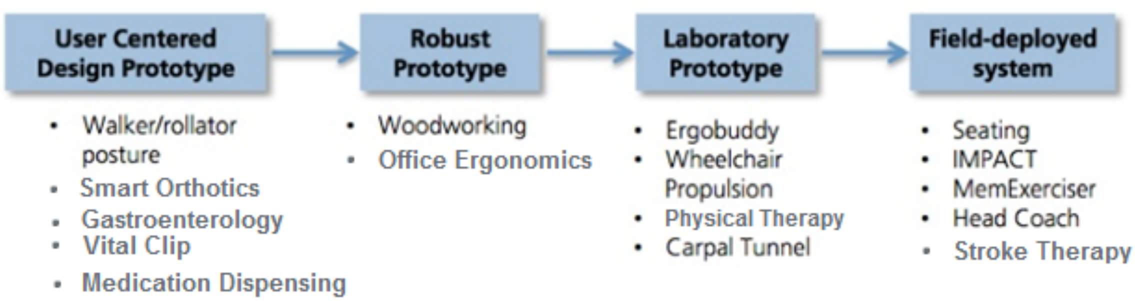


Figure VC-2. Pipeline stages of Virtual Coaches from design through field deployment

Summary of Implemented Virtual Coaches

Recent developments related to Virtual Coaches include:

- Medication Dispensing coach - provides nurses interface, medication dispensing condition error checking instructions for dispensing medications in hospitals and nursing homes
- Integrated emotion recognition with stroke therapy coach - adjusting their behavior depending on user's emotion
- Started working on Hospital Discharge coach - provides personalized user interface, discharge interactions at the patient discharge sessions, as well as a communication path…
- Automated goal adjustment applied to the Stroke Rehabilitation Coach
- Virtual reality games for rehabilitation – developed to encourage exercise compliance

The following is a brief description of the coaches that have been developed by the Center.

Seating Coach: smart reminder for power seat function usage: rule based model whose inut is prescription of positions and durations; sensors monitor positions and durations; Avatar provides reminders to do past due activities

ErgoBuddy: activity classification: machine learning to diagnosis potentially harmful lifting practices in package delivery occupation; employs multiple sensors, and sensor fusion; provides audio warning

Wheelchair Propulsion: machine learning to diagnosis stressful manual wheelchair propulsion motions; warning suppressed if context appropriate for external context

IMPACT (Improving and Motivating Physical Activity Using Context): motivate users to exercise through use of contextual information, such as events, places, and people, to support reflection on the factors that affect physical activity

MemExerciser: Alzheimer Disease Memory Reminder Coach: provides cues to those with episodic memory impairment (EMI) to remember experienced events; events sensed by still pictures, GPS, accelerometers, audio, and light

HeadCoach: vesicular balance exercise: monitors rehabilitation exercise, provide corrective cues, visualization for clinicians

Physical Therapy Coach: correct exercise form: monitors rehabilitation exercise, provide corrective feedback

Carpal Tunnel Exercise Coach: remind and monitor correct completion of arm, wrist exercise to mitigate carpal tunnel syndromes

Office Ergonomics: monitored back and arm posture offering suggestions to modify their posture and to taking breaks from their activity.

Stroke Rehabilitation: encourage rehabilitation exercise: exercises embedded in virtual reality game, frequency and order of exercises controlled by changing goals in game

Woodworking Angle Gauge: smart phone application that enables blind to set table saw cutting angle

Walker/rollator Posture: proper distance of the user's torso from the front rail of a walker or rollator is displayed via a color-coded bar graph

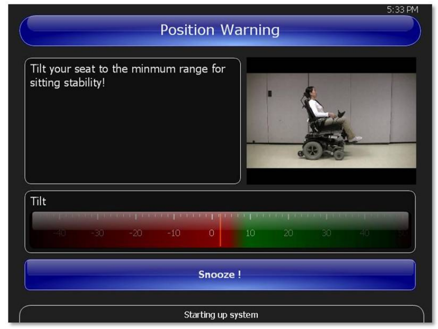
Smart Orthopedics: an indoor/outdoor geo-fence for mentally challenged patients minimizing the necessity of an escort. Utilizes built-in circuitry in shoes.

Gastroenterology : This is a wearable device that is capable of recording sound from the gastrointestinal tract during normal daily activities. The data can be reviewed for clinical analysis.

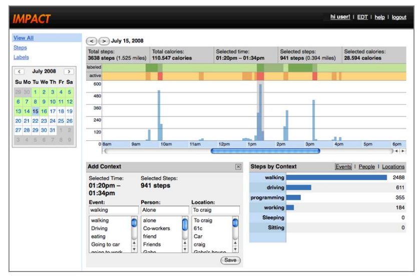
Vital Clip - a small device that takes the pulse of a person at their finger tip using a piezoelectric sensor to detect physical vibrations of the pulse wave form.

Medication Dispensing coach: Provides nurses interface, medication dispensing condition error checking instructions for dispensing medications in hospitals and nursing homes.

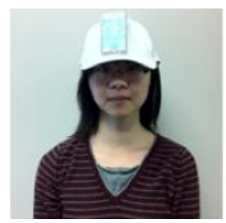
The strategic plan lays out a progression of functionality from activity recognition to intent recognition to autonomic coaches. The ultimate goal is an autonomic coach that recognizes



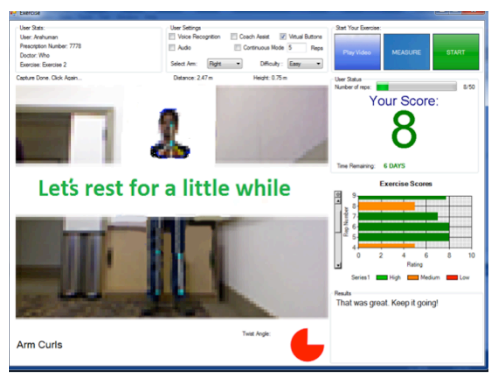
VC-3



VC-4



VC-5



VC-6

Figure VC 3-6 (right, top to bottom): Various Virtual Coach systems developed: (3) Seating Coach interface; (4) IMPACT activity monitoring dashboard; (5) HeadCoach worn by user; (6) Stroke therapy coach used by a patient, and integrated with emotion recognition.

changes in user ability, downloads new functionality, and automatically manages its own updates. Automatic goal setting is the first step in that direction. As the capability of our virtual coaches has become known, clinicians and researchers have approached QoLT with new challenges that have greatly expanded our coaching repertoire; enhanced creation and management of coaches (changing what to observe, response to observations) by non-technical clinicians, leading to a greater understanding and more complete taxonomy of coaching: logging, classification, compliance, advice. Note that we receive many more requests for coaches then we can service. We only take on new projects that will expand our repertoire in sensing, interaction, and domain modeling.

During the past year we:

- Integrated verbal emotion recognition with a stroke therapy virtual coach and visual emotion recognition with the health kiosk, adjusting their behavior depending on user's emotion
- Moved existing coaches to new stages of the pipeline (e.g. Stroke Rehabilitation to field deployment) and added real time user feedback (e.g. Stroke Rehabilitation coach)
- Automated goal adjustment applied to the Stroke Rehabilitation Coach
- Conducted a Seating Coach (SC) 8-week randomized group single-subject design study: Eighteen subjects were recruited in a randomized group study to compare the effectiveness between VSC and traditional education materials. 79 subject visits with accumulative driving distance of 6233 miles has been made since Nov 2011. Installed SCs on eight high-end power wheelchairs.
- Revised the Seating Coach into a user-friendly smartphone app with sensors that can be attached with simple hand tools.
- Used previous virtual coaches to develop elements of a software architecture as a precursor to virtual coach synthesis.
- Develop virtual coach software demonstration that supported multiple simultaneous virtual coaches.

2.3.4.4 Future Work

We plan the following milestones.

Year 9

Stroke Rehabilitation Coach and Head Coach: Run experiment to test patient recovery rate in the following conditions: a) no intervention; b) Coach with no feedback; c) Coach with real-time coaching feedback. Finish implementing architecture and run large study with PTs and patients to test the usability. Analyze data to see if efficacy can be determined. In addition, a suite of games for stroke rehabilitation to encourage individual usage and compliance will be finalized.

QoLT CAD: Automatically generated classification models from user provided datasets will be developed.

Seating Coach: Modify the context-awareness program of the Seating Coach according to the results from the 8-week trial to guide the change of display effects

Additional Coaches: Begin exploration of coaches to support caregivers (with PST), for performing IADLs and for wayfinding (with PAT), for Hospital Discharge.

Year 10

Stroke Rehabilitation Coach and Head Coach: Demonstrate therapy coaching architecture to allow PTs to specify exercises to be coached and visualized. Present usability results of a large study with PTs and patients. Infer detailed coach functionality from high level specification rules, namely: which components are needed, how they are configured.

QoLT CAD: Automatic assembly of the components into a complete Virtual Coach software system and automatic parameterization using cross-validation and provide a set of tuned models that could be run against a testing set for performance estimation. We will perform rule based generation of the Virtual Coach software system. Learning will be done by "demonstration" where clinician observes exercises and labels the performance. Run a user study to evaluate the capabilities

Multi-Virtual Coach: A goal is to have a convergence of Virtual Coach technology to a multi-use go anywhere, use anytime. In order to accomplish this goal advances on the basic science plane are needed to measure blood pressure at the fingertip and digital stethoscope to classify gastrointestinal sounds (enabling monitoring of food, liquid intake; detecting irregularity; and potentially providing advice in inconstancy).

2.3.4.5 Team

The Virtual Coach team is multi-disciplinary with participants from both CMU and the University of Pittsburgh involving rehabilitation science, robotics, human-computer interaction, computer science, psychology, and several practicing clinicians. Virtual Coaches introduce graduate students to multiple constraints in their research and technology development thereby directly addressing the educational barrier.

2.3.4.6 Peer-Reviewed Publications

Kelly, J., Siewiorek, D.P., Smailagic, A., Wang, W.(2013), Automated Filtering of Common-Mode Artifacts in Multichannel Physiological Recordings. IEEE Trans. Biomed. Engineering 60(10): 2760-2770.

Liu H, Cooper RM, Kelleher AR, Cooper RA, An Interview Study for Developing a User Guide for Power Seating Function Usage, Disability and Rehabilitation: Assistive Technology, Epub ahead of print, 2013.

Smailagic, A., Siewiorek, D.P., Chakravarthula, S.N., et. al. (2013). Emotion Recognition Modulating the Behavior of Intelligent Systems, Proceedings of the IEEE International Symposium on Multimedia, IEEE Computer Society Press, 2013, pp. 378-383.

Wu Y, Liu H, Kelleher AR, Wang H, Cooper RA, A Smartphone Application for Improving Powered Seat Functions Usage: A Preliminary Test, Proceedings of the Rehabilitation Engineering and Assistive Technology Society of North America Conference, Seattle, WA, June 20-24, 2013.

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3. Education, Outreach, and Diversity

3.1 *Overview*

The QoLT EOD program continues to grow by receiving additional grants; we are now supported by 10 external grants from federal agencies (e.g. NSF), foundations (e.g. Highmark), and other agencies (e.g. National Collegiate Innovators and Inventors Alliance). Our team consists of 4 staff, 2 faculty, 3 ambassadors, 2 graduate student chairs, and 7 advisory board members. We facilitate about 11 programs with approximately 90 participants per year. We also attend approximately 35 events per year, most of which are staffed by our ambassadors, resulting in approximately 3,500 interactions per year that promote the QoLT EOD vision to create a growing community of engineers, scientists, practitioners, and consumers who are intellectually prepared and motivated to create and apply technology to benefit people with disabilities and older adults.

We anticipate reaching sustainability through ELeVATE, graduate fellowships that may require joint-university mentorship and training activities, the RET and REU programs, and our Tech-Link program that existed prior to the ERC but has increased in scope and capacity through our ERC EOD efforts.

The following highlights demonstrate the gains we have made across the pipeline:

1. **K-12 expanded partnership with Google:** Google co-hosted several of our events in this reporting cycle, including job shadow day, black girls' code, and financially supported our Young Scholars Program through a Google community grant. We anticipate this partnership will continue to grow, allowing us to expand our reach and visibility among the community and high-tech sector in Pittsburgh.

2. **Our QoLT REU program was renewed for its 3rd cycle:** The QoLT REU program was successfully renewed for another cycle with more than one reviewer suggesting that we have developed a model framework for others to follow to incorporate more students with disabilities and other underrepresented groups. This award cycle will take us past the tenure of the ERC, demonstrating potential for sustainability because of its format that requires and receives willing participation from multiple departments across both campuses.

3. **Our veterans' initiatives have expanded to include vocational training:** Our efforts to help veterans re-enter the pipeline have expanded through providing vocational training. We developed the Advanced Inclusive Manufacturing (AIM) program and received funding through Highmark. This program will be expanded to include all PWDs and is currently in review at NSF for an Advanced Technology Education grant to meet this goal.

4. **We developed and implemented a new orientation process for graduate students:** We created and documented a new process for orienting graduate students to the center which has resulted better understanding of the center's structures (how systems and testbeds integrate and where students' projects fit into the picture).

5. **Our ambassadors have extended their effort from developing initiatives within the center to assisting other organizations realize their QoLT program potential:** In addition to continued representation of QoLT at public events, the QAs play a central role in the new Elderbots program. This collaborative effort of QoLT, long-term care provider Members, and schools near them, is an exploration of novel ways to use the Romibo personal robot for educational and intergenerational purposes. The ambassadors have played the key liaison role in this project's implementation.

3.2 *Response to Site Visit Team's SWOT Analysis*

Students are concerned about finding jobs strongly related to QoLT and disability:
We worked with Randy Eager (ILO) to develop a menu of industry opportunities for students. These opportunities range from shadowing to internships to full-time job placements. Students select the options they are interested in and industry partners select the type of experiences they can offer. The students' resumes are then shared with partners according to their mutual selections (mentorship, shadowing, internships, full-time jobs, or all of the above). The system is still in development but the first iteration, which we conducted over email, generated moderate interest.

Leverage the students' awareness and interests for the ILO to target and develop relationships with new industry partners:
Randy Eager has been very successful this year with bringing on several new industry partners. All of these companies see value in student involvement and would like their products or processes to be the focus of class, team, or internship projects. This will certainly help raise students' awareness of the role of industry partners. The new orientation process included an overview of these opportunities. As new SLC members are recruited, they are also made aware of the industry recruitment process. The intent of this briefing is to inform students that not only can they be a part of existing activities, but also assist in the recruitment of new partners through their own personal industry interactions.

3.3 *Pre-College*

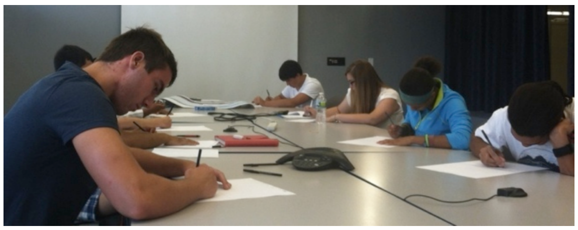
ERC Team Members

Lead:	Mary Goldberg
Faculty:	Rory Cooper, Rich Simpson, Jonathan Pearlman, Brad Dicianno, Christoph Mertz, Shawn Kelly
Staff:	Shelly Brown, Kimberly Robinson, Maria Milleville, Margaret Lindquist, Doug Hoecker, Joe McLaughlin, Garrett Grindle, Kristen Sabol, Sara Peterson, Michael Lain, Annmarie Kelleher, Aubrey Schick
PhD Students:	Elaine Houston, Robbie Paolini, Claire Hoelmer, Yu-Ting Cheng, Brandon Daveler, David Smeresky, Claire Alexandra Hoelmer, Daniel Osakue, Jorge Candiotti
MS Students:	Meng-Hsuan Chou
High School Students:	Amon Brown, Ananya Cleetus, Guilia Watkins, Andrew Vislosky, Omar Morsey, Matthew Neky, Kevelis Matthews-Alvarado, Beckett Cromer, Eric Kinderman, Walter Schaffer, Michael Mullen, Shaniqua Holyfield, Martina Thompson, Justen Turner-Thorne, Dustin McDuffey, Lindsay Grinage, Naoka Gunawardena, Winnie Matunga, Jada Clancy, Tishaya Walker, Claire Houston, Salvador Tarun, Anna Krakora, Jarrod Cingel, Jason Lin
Post-Docs:	Nahom Beyene, Harshal Mahajan, Deepan Kamaraj
Partners:	Pittsburgh Public Schools, City Charter High School, Propel Charter Schools, Community College of Allegheny County, First LEGO League, Robomatter, Baldwin School District, Plum School District, Boy Scouts of America – Trailblazers District, National Society of Black Engineers, Investing Now, Pitt School of Engineering – Department of Diversity

3.3.1 Young Scholars Summer Research Experience

One of our goals from 2012 was to establish a comprehensive internship experience for high school students; that goal was realized in the summer of 2013. We hosted 14 students for a 6-week experience, modeled after the Research Experience for Undergraduates program. Each high school participant was under the mentorship of a QoLT faculty member, graduate student, or staff person. Elements of the program included weekly workshops, daily assignments connected to real research projects, presenting an elevator pitch, and creating a scientific poster. Each student was asked, "*What was the most important thing you learned from the YS Experience?"* Two of the responses are noted here:

"Communication. Emailing back and forth between companies, product vendors, and my mentor allowed for me to improve my communication skills."
~ Student assigned to the Cueing Kitchen project



"I learned about the power of machine learning. I will certainly use this from now on in my future work, as it is such a powerful way to track more variables than humans are capable of."
~Student assigned to the Computer Vision project

Three of the participants in the YS program were hired as junior counselors for the 2013 Tech-Link LEGO Robotics summer camp.

3.3.2 Other Events

3.3.2.1 Job Shadow Day

We hosted 22 students from 3 school districts in the Greater Pittsburgh area. The students had an opportunity to tour QoLT laboratories, meet with research scientists, and observe demonstrations of innovative devices and systems.

3.3.2.2 Senior Internships and Externships, Tours

We continue our strong partnerships with regional school districts in the region to mentor high school students for required senior research projects, offer lab tours, and participate in science and technology school events. We have also collaborated with Allegheny County Community College and Penn State Greater Allegheny to provide their incoming freshman STEM outreach programs with tours of our research laboratories.

3.3.3 Partnerships

3.3.3.1 Black Girls Code

In partnership with Google, we spearheaded an effort to bring Black Girls Code to Pittsburgh, a program that exposes girls to computer science through 1-day workshops. The event was a huge success – 40 middle and high school African-American girls participated in the workshop with volunteer and technical support from QoLT faculty and students.

3.3.3.2 Carnegie Science Center

We continued our long-standing partnership with Carnegie Science Center (CSC) by providing a QoLT speaker for the bi-annual SciTech event, while also hosting an outreach booth to demonstrate QoLT developments such as Romibo.

3.3.4 RET

The Research Experience for Teachers program was revised to strengthen engineering design at the high school level by recruiting and pairing math and science teachers to create complementary units.

The change was quite successful and culminated in new curricula being infused into math and science courses, enhancing student understanding of engineering with a QoLT focus. We had 7 participants representing 5 different schools (2 public, 3 private). The teachers' students participated in a 4-week product development unit that was developed at our partner facility, the Learning Research and Development Center (LRDC). The products developed in the unit were entered in avirtual online design competition. Approximately 100 students competed in the completion, split up over 25 teams.

3.3.5 Future Plans

We will continue to build upon the success of our keystone programs and partnerships to increase the number of students who enter the STEM pipeline with an understanding of quality of life technology and the breadth of career options available in human-centered engineering.

3.4 *Undergraduate*

ERC Team Members

Faculty: Dan Ding, Jonathan Pearlman, Dan Siewiorek, Asim Smailagic
Staff: Shelly Brown, Randy Eager, Mary Goldberg, Maria Millevile, Jim Osborn

The goal of our undergraduate education initiatives is to engage students in multidisciplinary research by working on QoLT research projects under the guidance of faculty, graduate students, and research staff.

A new undergraduate course entitled "Human Robot Interaction" was offered for the first time in 2013. Taught through CMU's Robotics Institute by Reid Simmons and Illah Nourbakhsh, the course focuses on the approaches and technologies needed for getting intelligent machines to interact naturally with people. The course was inspired by the issues seen frequently in QoLT, and teaches many of the techniques that have been found to be effective in QoLT applications. The course, which is expected to be offered yearly, had 12 students in 2013, and has 20 registered for 2014.

We also facilitated the first iteration of the "College Achievement and Transition Seminar" (CATS), supported by our NSF-funded Quality of Life Technology Enrichment (QuOTE) project. The purpose of CATS is to assist students with disabilities on their transition to STEM disciplines. There were only 3 students enrolled in the course, but we archived all modules, and opened up the sessions to any interested students. Some guest speakers, including Sheryl Burgstahler from the DO-IT Alliance and Paul O'Hanlon, a local disability rights lawyer and activist, generated interest from seven additional students.

A group of undergraduate students in Pitt's College of Business Administration's *Leadership in the Social Environment* course worked with Dr. Dan Ding and explored commercialization options for bringing QoLT's cueing kitchen technologies to widespread use by multiple populations (Wounded Warrior/TBI, Physically Disabled, Aging, and the Mass Market).

We continued to infuse QoLT themes and principles into the design courses offered in both campuses (see the table below). For example, this year's Client-Centered Design series enrolled undergraduate students from the Department of Bioengineering. The students designed an adapted ice hockey sled for a client with mobility impairments. They used QoLT principles including participatory action design to develop and evaluate the sled.

Course Title	QoLT personnel	Semester Offered	Student participation	Recent Projects	Members Involved
Engineering Product Design (CMU)	Osborn, Eager	Spring & Fall	two teams of 6-8 design & engineering	Romibo Mechanical Upgrade	Jewish Association on Aging
Rapid Protoyping of Computer Systems (CMU)	Sieworiek, Smailagic	Spring	30 upper-classmen in engineering	Smart Orthotic	Vincentian

Mobile & Pervasive Computing (CMU)	Sieworiek, Smailagic	Spring	3-5 CS and ECE students	Medication Administration Wizard	Vincentian
Electrical & Comuter Engineering (CMU) independent study	Smailagic	Spring, Fall	1-2 MS students	Stroke Therapy Coach	Myomo
Health Care Policy & Management (CMU) independent study	Siewiorek, Eager	Spring	4-5 MS students	Patient Discharge 2025	Henry Ford Health System
Client-Centered Design I (Pitt)	Pearlman, Goldberg	Fall	10 undergrads in engineering	Adapted sled hockey	-
Client-Centered Design II (Pitt)	Pearlman, Goldberg	Spring	10 undergrads in engineering	Adapted ice hockey	-

3.4.1 QoLT REU Program

Project Goals and Impact

The main goals of the QoLT REU program are to enroll a diverse group of undergraduates and excite them about technology and engineering as tools that can be used to help people and improve society; to engage them in cross-disciplinary research in QoLT to gain an understanding of how to relate human functions to the design of intelligent devices and systems that aid and interact with people; to increase the number of students who are well-prepared for graduate studies and professional careers in QoLT-related fields; and to achieve exemplary participation of underrepresented groups, specifically, students with disabilities and students from underrepresented minority groups.

Role in Support of QoLT Strategic Plan

Our students worked on projects across QoLT testbed systems (QoLTbots, Virtual Coaches, Home & Community Health and Wellness) and participated in research activities, workshops, panels and symposia, which encouraged collaboration among participants of the QoLT REU, ASPIRE REU, TIPeD, and ELeVATE programs.

Fundamental Research Barriers and How They Are Being Addressed

Recruitment of Hispanic and Native American students remains a challenge. We will continue to attend the SACNAS, SHPE, and/ or AISES National Conferences and work with our colleagues from institutions with large Hispanic/ Native American student populations to bring our program to the attention of their students and advisors.

Achievements

Since the establishment of the REU program in 2007, over 95% stated that the internship met or exceeded their expectations and that they would recommend the program to others. Since 2007, 20 students submitted papers to research conferences and were accepted to present. QoLT REU students have presented at conferences ranging from national student minority conferences, such as SACNAS, to conferences hosted by professional societies, such as Rehabilitation Engineering Society of North America and American Psychological Association. Several papers have received awards.

For example, QoLT REU student Christopher Okonkwo (2012) co-authored a paper with an ELeVATE student and their graduate student mentor. Their paper was selected among the five finalists in the Best Student Scientific Paper competition at the RESNA 2013 conference. Rosedanny Ortiz (2011) won 1st place at the SACNAS National Conference 2012. Whitney Wilson (2012), Alex Kortum (2013), and Oluwapelumi Adenikinju (2013) worked alongside Business students and QoLT graduate students on TIPeD projects; all three TIPeD teams became finalists in the 2012 and 2013 MG Wells Entrepreneurship Competition.

Two students from the 2009 cohort, Jorge Candiotti (Hispanic) and Elaine Houston (female engineer with a physical disability) are now pursuing their doctoral degrees in Rehabilitation Science and Technology at Pitt. 2010 QoLT REU student Eleanor Avrunin is enrolled in the PhD program in Robotics at CMU; another 2010 student is enrolled in the MS Bioengineering program at CMU. Sossena Wood (African American, QoLT REU 2011), is enrolled in the Bioengineering PhD program at Pitt. Jessica Burkman (female engineer with a physical disability, QoLT REU 2012) has recently been admitted to the Pitt RST program and will begin her studies in Fall 2014.

Relevant Work Being Conducted Elsewhere; How this Project Differs

Unlike most current work in robotics, with its goal to replace human labor, the central theme of QoLT research is to develop intelligent systems that work *with* people and are safe, person-aware, and environment-aware. All QoLT research projects have the benefit of systems-wide context, with stakeholders representing multiple academic disciplines, organizations (e.g., caregiving groups), and end users. The REU projects emphasize and teach Participatory Action Design (PAD), a process of identifying, translating, and integrating contextual constraints into the conception and development of QoLT systems with the involvement of diverse stakeholders.

Recruiting students from backgrounds traditionally underrepresented in STEM has been QoLT EOD's top priority. Unlike most engineering departments, the QoLT REU program composition continues to mirror US demographics for people with disabilities, African Americans, and female students. Since the establishment of the QoLT REU in 2007, 80 students have participated in the program. Of those, 59% are African American, Hispanic, Native American, or students with a disability.

Future Plans, Milestones and Deliverables

The success of the QoLT REU program has resulted in the renewal of the site for 2014 – 2016. We will continue to refine our program by piloting new workshops and program activities.

3.4.2 Technology Innovation for People with Disabilities (TIPeD)

Funded by the National Collegiate Innovators and Inventors Alliance (NCIIA), TIPeD is a project-driven, team-based experiential learning program that supports undergraduate students' learning of entrepreneurship and innovation of technology for people with disabilities. TIPeD teams consist of students from the engineering, business and clinical disciplines and a faculty and/or graduate student mentor. Teams spend ten weeks working on a technology innovation project in the area of the mentor's interest. They are required to make substantial progress on the technology design and to generate a business and commercialization plan in the format of an SBIR proposal for developing a start-up that would commercialize the products. Through involvement in these projects and attendance at themed lectures and workshops, students learn the fundamentals of entrepreneurship including design processes, intellectual property considerations, and business planning.

In 2013, QoLT REU student Oluwapelumi Adenikinju worked with Colleen McDermott, a Pitt Business student, and Eric Wu, a PhD student on the Virtual Seating Coach project. Erik Dornbush (QoLT REU) worked with Andrew Wolf (Pitt Business student), Harshal Mahajan, PhD, and Daniel Osakue on the Cueing Kitchen project. Both teams became finalists in the 2013 MG Wells Entrepreneurship competition.

Publications: Current Reporting Cycle

Adenikinju, O., McDermott, C., Wu, Y. *Smartphone-based Virtual Seating Coach*. 2013 MG Wells Entrepreneurship Competition. University of Pittsburgh.

Dornbush, E., Wolf, A., Mahajan, H. *The Cueing Kitchen*. 2013 MG Wells Entrepreneurship Competition. University of Pittsburgh.

Mason, E., Nagabandi, A., Steinfeld, A., Bruggeman, C. (3/25/13). *Trust and Autonomous Systems*. 2013 Association for the Advancement of Artificial Intelligence Spring Symposium. Palo Alto, CA.

Hiremath, S., Okonkwo, C., Hannan, M. (6/20/13). *Validation of a Gyroscope Based Wheel Rotation Monitor for Manual Wheelchair Users*. 2013 Rehabilitation Engineering and Assistive Technology Society of North America Conference. Seattle, WA.

Chiles, S., Bender, C., McCue, M. (7/31/13). *The Effect of Breast Cancer Treatment on Employment*. American Psychological Association. Honolulu, HI.

Table EO-1: Matrix of organizations involved in education and outreach activities

	Course Materials for New and Ongoing Courses	Re-Entry	REU	RET	Young Scholar	Pre-College	Practitioner Education
Carnegie Mellon Univ.	✓		✓	✓	✓	✓	
Univ. of Pittsburgh	✓	✓	✓	✓	✓	✓	✓
Univ. of South Florida	✓		✓		✓	✓	
UMBC	☑		✓		✓	✓	

✓ = In Place ☑ =New This Year, ✔ = Future Year

3.5 *Re-entry*

ERC Team Members

Lead: Mary Goldberg
Faculty: Rory Cooper
Staff: Shelly Brown, Garrett Grindle, Maria Milleville, Kimberly Robinson

3.5.1 ELeVATE

Project Goals and Impact

The goal of the ELeVATE program is to integrate veterans interested in engineering and technology careers into civilian life by assisting them in the process of transitioning to college. ELeVATE is a 10-week program, in which veterans work on a research project, participate in workshops, and engage in college preparatory activities. ELeVATE students are assigned a one-on-one rehabilitation counseling mentor and a faculty mentor to assist in community re-integration, academic, and vocational preparation.

Participants meet in weekly group sessions led by a rehabilitation counselor to discuss family, relationships, and overall well being, while developing essential reintegration skills. Regular one-on-one meetings with the rehabilitation counselor help the veterans establish academic, professional, and life goals and develop a strategy for achieving those goals. Another goal of ELeVATE is to educate the academic community on veterans' issues so that faculty recognize the unique needs of student veterans and provide adequate instruction and advisement to this growing population. To do this, we provide training to faculty and graduate students that work with ELeVATE students.

Fundamental Barriers and How They Are Being Addressed

So far, only one female veteran has participated in the program. We will work with organizations that serve women veterans to bring the program to their attention.

Achievements

Since 2011, 17 veterans have participated in the program. The satisfaction rate among participants and mentors was 100% for all cohorts. Seven participants continued to work with their mentors on research projects after completion of the internship. ELeVATE student Matthew Hannan (2012) co-authored a paper with QoLT REU student Christopher Okonkwo and their graduate student mentor Shiv Hiremath, which became a finalist in the 2013 RESNA Student Scientific Paper Competition. Shawn O'Donnell (ELeVATE 2013) presented his work at the SACNAS National Conference 2013. ELeVATE students Nathan Bastien (2011) and Stephen Oakes (2011) completed their undergraduate studies and are now pursuing degrees in Medicine and Pharmacy at Uniformed Services University of the Health Sciences and University of Pittsburgh.

In response to the feedback we received from 2012 participants, our 2013 program activities were structured to accommodate academic and professional interests and rehabilitation needs of each veteran.

ELeVATE staff has presented ELeVATE at multiple venues, including a conference for academic professionals, a symposium for military medical and rehabilitation specialists, a conference on veterans education for student veterans and those working with veterans, and a conference for rehabilitation counseling professionals.

Relevant Work Being Conducted Elsewhere; How this Project Differs

To our knowledge, other schools do not offer transition programs for veterans that are similar to ELeVATE in scope. ELeVATE incorporates academic preparation with professional development as well as rehabilitation counseling in a holistic way. This year, the NSF selected ELeVATE to participate in the I-Corps for Learning program, whose goal is to scale and replicate innovations in STEM education. The I-Corps-L program will help us work with interested institutions to make ELeVATE available at other schools in the future.

Future Plans, Milestones and Deliverables

The survey of the 2013 cohort shows that the student veteran and mentor match was not always compatible. To better match the student veterans to a research project that is congruent with the education, status, and current capabilities of the veteran, we propose an improved system of identifying projects for ELeVATE interns. We will begin by soliciting interest from the graduate students and staff who have a desire to work specifically with veterans; we will consider the veteran applicants' interests and match veterans to mentors based on similarities in noted application interests with the outlined needs of the research projects. Another way in which successful matching will be realized is with the addition of a "speed-dating" session. During this time graduate students who are interested in mentoring and working with an ELeVATE participant will pitch their research project summary to the audience of the ELeVATE interns. This will be followed by a time when ELeVATE interns can individually talk with each graduate student researcher to see if the match is appropriate and desirable. In this way, both the ELeVATE intern and the graduate student are involved in the matching process.

3.5.2 REV-T

The Research Experience for Veterans and Teachers (REV-T) program supports veterans' potential to pursue careers in engineering and technology fields as they work with middle and high school teachers on developing innovative products that transform lives of people with reduced functional capabilities due to aging or disability. Together with math and science teachers, REV-T veterans participate in a course in product innovation, attend intensive math and writing seminars and workshops, and work with a rehabilitation counselor to prepare for college and employment.

In Spring 2013, four veterans participated in the program. Three applied and were admitted to ELeVATE; one applied and was accepted to ASPIRE REU program in Pitt RST.

3.5.3 AIM

Advancing Inclusive Manufacturing (AIM) is a transition program for Veterans and Service Members with Disabilities. The primary objective of AIM is to aid in the transition of rehabilitating active-duty wounded warriors and rehabilitating veterans to potential careers in machining. Over a 12-week period, AIM students learn the basic machining principles and practices as they cycle through the fundamental areas of fabrication, including 3D printing, welding, printed circuit boards, electronics, etc. As participants progress through the program, they obtain a general understanding of how the systems are designed and integrated. Upon completion of the program, AIM students can independently design, develop, and evaluate their own product (prototype) using established design principles.

Throughout the program, AIM students meet with the rehabilitation counselor to address their rehabilitation needs, refine their communication skills, work on decision making and problem solving, and have a better understanding of how to maximize their potential to identify an employment opportunity that is right for them. If a student needs assistance with math, we connect him/her with a math instructor who works with the student to address those specific areas that are important to this student's success in his/her career of choice.

After successful completion of the program, AIM students receive a Basics of Assistive Technology Fabrication Certificate from the Human Engineering Research Laboratories and are primed to take the NIMS Machining Level 1 exam or the America Makes Additive Manufacturing Certificate, and are ready for on-the-job training experiences at local companies, where a potential long-term, full-time placement could be secured.

Currently, two Veterans with Disabilities are participating in the program. We are looking to expand the program to offer it to not just veterans, but any person with a physical disability interested in a manufacturing career.

3.6 *Post-Baccalaureate*

ERC Team Members

Lead: Reid Simmons
Faculty: all QoLT Faculty
Staff: Mary Goldberg

Project Goals and Impact

Our goal is to provide significant education and training in technologies relevant to QoLT, as well as providing students with the insights and approaches (e.g., clinical, social) needed to carry out the types of interdisciplinary research that are a hallmark of QoLT. The aim is to produce world-class researchers, engineers and practitioners who are prepared to work at the interface of disparate disciplines, thereby being able to integrate basic understanding of human functions (psychological, physiological, physical, and cognitive) and behaviors in everyday living and socioeconomics in the design of intelligence devices and systems that aid, interact, and work in symbiosis with people in need.

To address these goals, we have developed an approach based on "competencies" that each student is expected to achieve during their tenure at QoLT. The list includes technical competence (research methodology, knowledge of field, innovation), competence in the understanding of issues associated people with different needs (person-centered approach), and inter-personal competence (leadership and communication skills). Students can achieve the various competencies through a combination of formal coursework, internships, mentorship, and informal learning. Competencies are evaluated through a bi-yearly web-based process, with both students and advisors providing rating information and comments (see below).

Role in Support of QoLT Strategic Plan

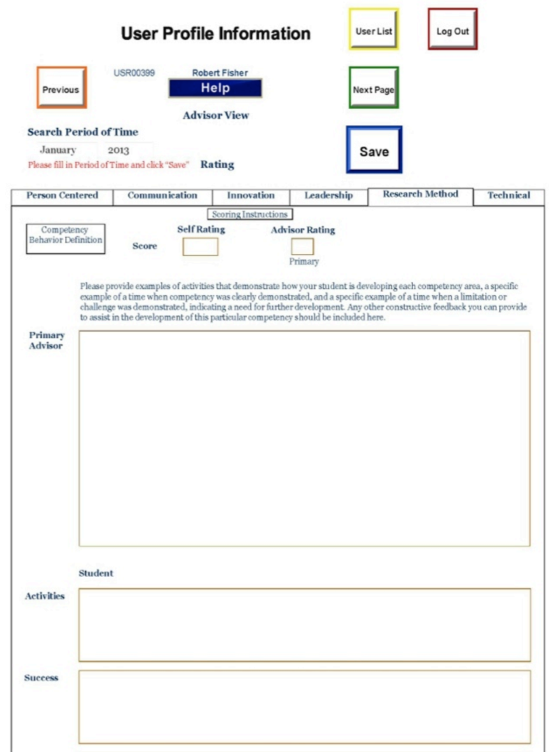
The graduate students are the lifeblood of the ERC, providing the creativity and technical prowess to advance the state-of-the-art in quality of life technologies. They are the people who will go off to found new companies and start new academic programs based on QoLT principles. We take our role in mentoring students in this new, interdisciplinary field very seriously, from orientation of new students, through encouraging students to publish and present their research, participate in SLC, help to recruit students and mentor undergraduates, and enter engineering and entrepreneurship competitions. We also encourage students to broaden their horizons by getting to know both the technical and clinical sides of QoLT research.

We have developed, or modified, a number of courses that provide graduate students with QoLT-related education and experiences. Since past reports have described most of these courses in detail, here we provide just a listing of the relevant courses offered on a regular basis: Ethnography (CMU/RI and Pitt/RST 2711), Adaptive Service Design (CMU/HCII), Rapid Prototyping of Computer Systems (CMU/HCII), Adaptive Control (CMU/RI), Biomechanics and Motor Control (CMU/RI), Dynamic Optimization (CMU/RI), Geometry-Based Methods in Vision (CMU/RI), Kinematics, Dynamics and Control (CMU/RI), Learning-Based Methods in Vision (CMU/RI), Principles of Human-Robot Interaction (CMU/RI), Robot Autonomy (CMU/RI), Robot Ethics (CMU/RI), Statistical Techniques in Robotics (CMU/RI), Assistive Technology Funding and Policy (Pitt/RST), Client Centered Design (Pitt/RST). Ethical Issues in Healthcare (Pitt/RST), Individual and Social Experience of Disability (Pitt/RST), Medical Aspects of Disability (Pitt/RST), Rehabilitation Engineering Design (Pitt/RST),

Fundamental Research Barriers and How They Are Being Addressed

The main barrier is trying to get the students to take time from their own research to learn other areas that we believe are important to QoLT. To address this, we have instituted the competency areas, mentioned above, along with a method for evaluating and rating a student's progress along these areas. The idea of a competency-based education for QoLT principles was reported two years ago. The initial (long) list was condensed down to six areas – technical (including knowledge of participatory design), research methodology (including ability to carry out human-subject studies), person-centered (including understanding the abilities and needs of the populace, the impact of technology on them, economic and political issues), innovation, leadership, and communication. In particular, the emphasis on the people who will be using the technology (including the people in need, caregivers, and clinicians) makes this set of competencies unique to QoLT.

Last year, we reported on the development of a web-based form for rating and evaluating a student's progress towards achieving competency. The idea is to record how students progress toward competency in each of the areas over time. While we understand that no one student is likely to achieve 100% competency in each of the areas, we do expect all students to have achieved a minimal competency in the areas by the time they graduate. Competencies can be achieved by a host of different means. For instance, each of the QoLT-related courses has a list of the areas that it covers. Students can increase their competence by taking short courses, such as the web-based modules on people and disability that we developed several years ago, as well as attending various seminars, shadowing clinicians, volunteering for the SLC, giving talks at conferences and other venues, and working with industry members. The list of activities that may help a student achieve competence in a particular area is maintained and updated periodically.



The first round of evaluations had over 70% of the all PhD students funded by core QoLT projects filling out the form. Based on feedback from students and advisors, we streamlined the form (at right) to make it easier to enter information and find past information about the students. We are rolling out this improved form and expect to have another round of evaluations done in time for the site visit.

Achievements

The rollout of the competency evaluation web site, including initial evaluation and subsequent modification to the forms, was a primary achievement of 2013. That achievement has been detailed above.

We instituted a novel approach to orientation of new graduate students being funded by core QoLT projects. Mary Goldberg, Education and Outreach Project Director for QoLT, took small groups of students (3-4) out to coffee to introduce QoLT and discuss issues related rights and responsibilities of QoLT-funded students. Veteran students were also invited, in order to provide their viewpoints and experiences with QoLT. This approach is in contrast to previous orientations, which were held on campus with all new students attending at once. It was found that this new approach, which provided for a more relaxed and intimate setting, resulted in a better understanding of the ERC's structure and functioning, and a better understanding amongst the new students of what differentiates QoLT students from other students in their programs. We have documented this process, and expect to continue it in the future.

We worked with Randy Eager, Industrial Liaison Officer, to help strengthen relationships between the QoLT students and our industrial members. We started with a survey of our students to see what they would like, in terms of industry participation; 17 students responded. The category with the highest number of responses was to obtain internships – 70% were looking for internships (mostly paid, although 40% of those claimed to be willing to intern for credit, and fully a third said they would be willing to volunteer, just to get the experience). 70% of the respondents also wanted the opportunity to shadow a tech/start-up partner, while about a third wanted the opportunity to shadow a clinical partner. Nearly 60%

were interested in being matched with a professional in the QoLT field, to act as a mentor, and 40% said that they would be interested in having a focus group together with QoLT professionals to help provide career suggestions and feedback. Based on the results of the survey, we instituted a system to collect student resumes and share them with our industrial partners. We also have been more proactive in getting students involved with recruiting of IPAB members (attending meetings, providing tours, etc.). We anticipate that these efforts will yield benefits with the expanded industrial membership base that was achieved in 2013.

On the entrepreneurial front, Nahom Beyene received iCorp funding for his spin-off company Navity, which aims to commercialize the NAViSection system as an embedded vehicle technology to measure driving capabilities of older drivers and teams. Beyene's company was also named a finalist in the Everyday Health Awards for Innovation. In addition, Yu-Kuang (Eric) Wu presented the smartphone virtual seating coach application at the MG Wells and Coulter entrepreneurship competitions (he was a semi-finalist in the MG Wells competition).

Finally, our very own Mary Goldberg received her PhD in Administrative and Policy Studies of Education at the University of Pittsburgh in October 2013. Congratulations, Mary!

Future Plans, Milestones and Deliverables

We will roll out the improved competency evaluation form in early 2014, and have data on the students who filled out the forms by the site visit. From then on, we will have students and advisors fill out the forms every six months. After the August 2014 evaluation, we will have enough data (three time periods) to do some data analysis and report on trends. We hope this will lead to publication. We will also be completing our new orientation program in the winter of 2014, and will run the same program for the new students starting fall 2014.

Table EO-2: Some exemplary QoLT Center PhD alumni

Name	Course of Study	Year	Current Employment	Contributions
Sonya Allin	CMU HCII	2007	University of Toronto	Applied computer vision and haptic technologies to occupational therapy after stroke
Nahom Beyene	Pitt RST	2013	Post-Doc, Pitt RST; starting his own company	Developed a NAViSection driving assessment tool (secured an NSF I-Corps for this work)
Alvaro Collet	CMU RI	2012	Researcher, Microsoft	Developed *Lifelong Robotic Object Discovery*
Shiv Hiremath	Pitt RST	2013	Post-Doc, Pitt PM&R	Developed a physical activity monitoring device for manual wheelchairs
Amy Hurst	CMU HCII	2010	Assistant Professor, UMBC	Building tools that empower others to "DIY" and build their own ATs
Portia Taylor	CMU Bioengineering	2012	Research Staff, Phillips	Developed *InForm Exercise Coach coach*

3.7 *Post-Docs*

ERC Team Members

Lead: Dan Ding
Faculty: QoLT Faculty
Post-docs: Shiv Hiremath (Pitt RST), Hyun Ka (Pitt RST), Kris Kitani (CMU RI), Harshal Mahajan (Pitt RST), Hongwu Wang (Pitt RST)
Staff: Mary Goldberg

Project Goals and Impact

Our goal is to provide interdisciplinary training and teaming, effective mentoring, and career guidance to increase the competitiveness of our postdoc fellows and lead to their further development as independent researchers. For postdocs with disabilities, we identify resources to help them manage their daily research, as well as identify unique fellowship opportunities for them.

The most important and productive strategy for research training is "immersion" in substantial research projects under the direction of accomplished scientists.

- Our postdocs are matched with senior mentors with active extramurally funded research programs and track records of postdoc mentoring experience. The mentor and postdoc generally delineate expectations for the postdoc experience, such as skills to be developed, expectation regarding collaboration on research projects, time commitment, and expectations on career development.
- The mentor recommends appropriate coursework as needed to complement the postdoc's needs in terms of relevance to a specific line of research and integration into his/her overall training experience, and also provides resources for additional research training opportunities, such as sending the postdoc to at least one professional conference per year, and including him/her in local lectures and symposia as presenter.
- The mentor meets with the postdoc frequently to discuss research projects and the postdoc's career goals, and to educate him/her about research conduct, grant writing, and how to mentor students.
- The mentor includes the postdoc in the preparation of proposals and manuscripts, and gradually gives him/her progressive responsibility for managing research projects. The postdocs are expected to produce primary-author peer-reviewed publications, and encouraged to pursue career development awards from relevant federal agencies and research proposals as principal investigator. We have been sending our postdocs to relevant grant workshops at CMU, Pitt, and other venues.

Our postdocs are provided with mentoring opportunities where they can test their propensity and practice for mentoring before beginning their careers as future scientists, professors, or researchers. They usually serve as mentors for undergraduate interns in our REU programs and assist their mentors to supervise graduate students. Sometimes, they are assigned teaching tasks as well. The mentoring opportunities help the postdocs develop professional and personal skills such as communication, teamwork, teaching, mentoring, and leadership.

Our postdocs take advantage of the numerous informal training opportunities available at CMU and Pitt, including QoLT and other related seminars. In particular, Pitt has a comprehensive postdoctoral support system through the University of Pittsburgh Office of Academic Career Development (www.oacd.health.pitt.edu/programs_postdoc.html) to help maximize their chances for a rewarding career. This office provides academic career development resources and a didactic training series for postdocs to enhance competency in areas such as effective networking and communication skills, efficient time management habits, and learning how to get the guidance and mentoring needed for success. The postdocs are also encouraged to attend the Postdoctoral Professionalism Workshop Series such as Scientific Management and Leadership, Maximizing Your Postdoctoral Success, A Negotiations Workshop for Early-Career Investigators, Acquiring Research Support, Publishing with Integrity in Academic Journals, Developing the Networking Skills to Advance Your Career, and Attaining a Faculty Position.

Role in Support of QoLT Strategic Plan

We emphasize interdisciplinary training at the postdoc level. We provide mentored clinical experience to postdocs to help them understand user needs, clinical decision-making process, contextual constraints of technology, and human subject testing process. They are also encouraged to visit and interact with various clinical groups, to attend ward and ground rounds, and to work with disability groups and community organizations in the area. In addition, we also provide postdocs cross-training opportunities by matching them with a clinical mentor.

Fundamental Research Barriers and How They Are Being Addressed

The book "Enhancing the Postdoctoral Experience for Scientists and Engineers" published by National Academy Press identifies several barriers to achieving successful postdoctoral experiences. The book reports that many postdocs express frustration at the lack of opportunity for growth toward independence, inadequate guidance from the mentors, and difficulties in finding appropriate employment to advance their careers towards rewarding professional positions. In addition, postdocs with disabilities face many of the same problems as undergraduates and graduates with disabilities – faculty mentors inexperienced in interacting with them (and often reluctant to hire persons with disabilities), inaccessible laboratory facilities, and lack of roles models. In addition, there are challenges in traveling to conferences and symposia, both physical and financial, grant information is typically not in accessible formats, and the need to obtain appropriate and affordable health insurance that covers pre-existing conditions. We are addressing these barriers with the strategies mentioned in the previous sections.

Achievements

We are able to to leverage the funding from the Advanced Rehabiltiation Research Training (ARRT) project by the National Institute of Disability and Rehabiltiation Research (NIDRR) to support some of the QoLT postdoc fellows. Our postdocs have been successful in publishing papers, presenting in conferences, and receiving external grant awards. Dr. Hongwu Wang received a prestigious fellowship award from the Craig H. Nielsen Foundation for his proposed work on developing an assistive robotic manipulation evaluation tool. This proposed work was derived from his previous work on PerMMA. Dr. Harshal Mahajan was invited to the NIDRR ARRT Young Investigator Panel in the 2013 American Congress of Rehabilitation Medicine where he presented his work on cueing kitchen. Drs. Jon Atkins, Yen-Sheng Lin, and Hyun Ka also have grant proposals in review with federal agencies or private foundations.

Future Plans, Milestones and Deliverables

We plan to renew our postdoc training program through the National Institute of Disability and Rehabilitation Research, which will allow us to recruit more postdoc fellows and provide structured training to these individuals.

3.8 *Community*

ERC Team Members

Lead:	Joseph F. McLaughlin
Staff:	Margaret Lindquist, Doug Hoecker

Project Goals and Impact

The QA (QoLT Ambassador) program supplements the EOD Coordinators' role in outreach to K-12 and the community at large. QAs are the "public face" of QoLT. QAs interact very enthusiastically with their target population. In 2013 they conducted 19 events over 29 days. These events were attended by at least 13,000 people. The QAs interacted directly with over 2000, of whom at least 1500 were children.

At the Carnegie Science Center SciTech Festival last November, QAs demonstrated a Lego model of a power wheelchair with a tilt function. Student visitors completed a brief survey concerning careers in QoLT. The responses were overwhelmingly positive, indicating the QAs did a good job explaining this unfamiliar concept.

QAs attend periodic QoLT training sessions as well as EOD events and meetings. Their primary role is to plan and staff public events both in conjunction with and independent of the EOD Coordinators. QAs are few in number and employed for only 5 hours/week. However, as the statistics above show, they play a major role in carrying the message of the QoLT Center to school age children and the public.

Role in Support of QoLT Strategic Plan

The development of QoLT's intelligent systems depends on a reliable pipeline of students entering the research field. QAs are actively engaged in educating and recruiting young people to consider careers in QoLT. QAs also spread the word to the public about the emerging field of QoLT. For instance, the Lego power wheelchair model's tilt function highlights the Virtual Seating Coach. This model is very effective in attracting attention in order to explain QoLT's research. In addition, the QAs demonstrate the Romibo mobile personal robot at public events. The team consists of three professional retirees with backgrounds in education, research, and the military.

Fundamental Research Barriers and How They Are Being Addressed
The QoLT EOD program is dedicated to reaching disengaged students and those who have limited access to technological education. The QA program is an important part of that effort.

Achievements
Since its inception in 2010, the QA program has been consistently praised by the NSF site visitors as "a major strength" and "very effective". An article about QAs titled "Joy Ride: QoLT Ambassadors Take Research into the Community" was featured in the Spring/Summer 2011 edition of the University of Pittsburgh's Facets magazine.

Relevant Work Being Conducted Elsewhere; How this Project Differs
To our knowledge, there is no similar program among other ERCs.

Future Plans, Milestones and Deliverables
In addition to continued representation of QoLT at public events, the QAs play a central role in the new Elderbots program. This collaborative effort of QoLT, long-term care provider Members, and schools near them, is an exploration of novel ways to use Romibo for educational and intergenerational purposes.

3.9 *Assessment*

Each program and event is assessed individually. We contract an external evaluation company, Open Minds, for our ELeVATE program. Additionally, we track the outcomes of all graduate students and outreach participants in a tracking database, as mentioned above. These measures help us determine the effectiveness of our programs and whether to modify, take out, or add initiatives to help gain participation across the pipeline. Individual program components are subject to the same scrutiny.

We compare the ratings with the other activity offerings to guide the development of the next year's program schedule to ensure we are reaching all of the desired learning outcomes across participants. For example, the REU assessment revealed that students wanted more interaction with industry. Based on this feedback, we are planning to increase QoLT REU students' interactions with industry practitioners by providing them with opportunities to meet current IPAB Members in environments conducive to networking. The REU assessment also suggested that we need to increase the number of scientific publications by QoLT REU participants. To do that, we are conducting training sessions for graduate student mentors in which we address the importance of undergraduate participants' publishing their work. During those sessions, more experienced graduate student mentors and faculty mentors share advice with new mentors; graduate students, faculty, and program staff discuss best practices for mentoring undergraduate students in the program. To ensure that each student's individualized project timeline meets her/ his needs, mentors communicate with their REU students a few weeks prior to the program. Thus, the mentor has time to adjust the timeline according to the student's interests and prior experience; both the mentor and student can discuss which conference they would like to submit the student's work to upon completion of the program.

Through the ELeVATE program assessment, previous participants suggested changes to the vocational counseling portion of the program. Specifically, they preferred weekly or bi-weekly one-on-one meetings, to the weekly group vocational session. The rehabilitation counselor also noted that it would be beneficial for the one-on-one sessions to be put into the formal schedule instead of trying to schedule time with them after internships begin. Additionally, the assessment suggested that trying to find more community Veteran mentors would benefit everyone involved. These mentors could provide networking opportunities, internships, or even jobs after college. This is something we will implement in the coming year.

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4. Industry/Practitioner Collaboration & Innovation

4.1 *Vision*

4.1.1 Goals and Strategy

Our goal to be the hub of an emerging QoLT industry has not changed since inception of the Center. In our nearly eight years of operation, needs for Quality of Life Technology (outlined in Section 1) have not changed and arguably have increased due to mounting pressure for healthcare reform. With these needs, the public is paying greater attention to healthcare models that are both patient centric and more efficient. Information technology is being touted – correctly – as a key means to making healthcare delivery more efficient, more effective and more personalized. Quality of Life Technology is not merely riding that wave; it is part of it. We are encouraged by our own progress in technology development, (described in the sections above), which has already yielded several QoLT systems that are making their way into practice, as well as through reflection on the knowledge we have accumulated about consumer and clinician attitudes that shape QoLT markets. We are further encouraged by our own discovery of business models for QoLT products to penetrate markets broader than our specified target populations, older adults and people with disabilities, and by the collective breadth of markets served by the members of our Industry/Practitioner Advisory Board (IPAB), the consortium of companies and service providers that are members of the QoLT Center.

Our optimism is tempered somewhat by lingering uncertainties about exactly how and when QoLTs will figure in healthcare. Third-party reimbursement models, a major factor governing QoLT product uptake, are antiquated yet persistent. Those models are also in flux. Our IPAB members and prospects are necessarily cautious, yet bullish, as are we, on the emergence of QoLT as an industry. Most members joined because association with the QoLT Center affords them the opportunity to learn as we learn so they can better understand the dynamics of emerging QoLT markets.

In the early years of the Center, we began to recognize that there is potential for QoLT products beyond long-term care and rehabilitation, at it may in fact exceed the potential in those markets. We also realized that a prevailing trend in the medical devices industry – for established firms to make strategic acquisitions of small companies that have proven the viability of new technologies in the marketplace rather than licensing earlier stage technologies from universities – is also operative in other sectors relevant to QoLT such as robots, electronics, IT and consumer products.

Another objective of our industry/practitioner collaboration and innovation program is to prove the relevance of QoLT. For that to be achieved, we need advice from members to identify and prioritize our system and enabling technology targets. We also need to validate our system prototypes through testing and evaluation in real world scenarios. We have always contended that the best private sector partnerships are working relationships. That premise and the objective of demonstrating relevance shape our approach to engaging companies and providers as members and prospective members, and for conducting translational research and development.

4.1.2 Actions taken in response to 2013 Site Visit report SWOT analysis

Threats

1. Extend payer engagement to include payer foundations as additional revenue source; Define top 10 self-insured corporations that are a good fit with the center. Example: what companies have the best track record with the disabled; what companies are considered pioneers in the health and wellness space for their employees?

- Working with a future member Highmark (33.5M insured, over 20,000 employees, and $15.2B in revenue) to better understand this issue. A significant portion of their business comes from managing the self-insured corporations healthcare programs.
- Highmark currently sponsors the $11 million Disruptive Health Technology Institute at CMU that is aimed at transforming health care.

2. The new ILO's job description may be pulling him into too many different directions [recommendation] Engage alumni association to determine CMU and Pitt alum who are working for companies that fit criteria for industry partnership. Specifically look for alum who have worked in some capacity at QoLT

- Make better use of existing university resources (technology transfer offices, CMU Center for Innovation and Entrepreneurship, CMU Corporate Relations, CMU and Pitt Foundation Relations, CMU and Pitt Alumni Relations.
- CMU assigned a licensing officer to QoLT.
- Working with Pitts corporate and foundation staff on licensing and membership.
- Pitt Tech Transfer led the way on three license negotiations, seating coach (license to Permobil), Strong Arm (ongoing), and MEBot (ongoing).
- QoLT faculty and staff have been making introductions to corporate partners.
- Regular meetings with CMU's Office of Corporate and Institutional Partnerships.

3. Lack of appreciation of the importance of targeting some end uses identified with the help of industrial partners

- We have learned that it is our members, especially the Affiliated Providers, which have the best understanding of what problems are to be solved.
- Several of the identified problems were more "D" than "R" have been turned into capstone engineering class projects and one of them is in the process of being licensed.
- We have learned from our new Technology Tracking program that the members prioritize research projects that are the highest Maturity Level (see the Opportunity figure in section 1.2.2) like Romibo, KitchenBot, and Strong Arm.

Weaknesses

1. There are gaps in the IPAB value chain; for example, not enough cutting edge robotics firms;

- We have made significant progress toward this goal with the addition of iRobot, one of the most respected cutting edge robotics companies, Henry Ford Health System that is an acute care hospital, an insurance company, and have a very large home health care business.
- One other significant gap that was filled is the quantified self market segment. Our new Master member Epson who has products in this category and have placed a visiting researcher at Carnegie Mellon for 12 months working on a new quantified self sensor.

2. Industrial partners not interested in licensing technology

- We now have several license negotiations under way, Seating Coach was license to Permobil at the end of February,
- Strong Arm; RE2 was recently awarded a SBIR Phase I and intends to license the technology and begin commercializing,

- MEBot; HStar was recently awarded a SBIR Phase I and intends to license the technology and begin commercializing. All of these companies have expressed interest in joining the IPAB.
- QoLT has established a working group (Faith Based Network/QoLT Innovation Team) comprised of nine long-term care industry organizations with the explicit mission of commercializing QoLT technology. They are specifically focused on labor saving technologies that they can purchase for their facilities.

Recommendation
1. Rework the “sales” presentation to more concisely communicate to industry. Keep it simple by stating who you are, problem you are solving FOR THAT INDUSTRY PARTNER, industry drivers, competitive differentiators (establish credibility upfront), etc. There is an opportunity here to include feedback from other internal industry site visit members – researchers, students, marketing, etc.

- The QoLT sales process has evolved over the years and is now organized by industry.
- Through our involvement with industry associations and the Thought Leaders that are part of the redesigned IPAB, we better understand the dynamics in most of the industry segments.
- Establishing the QoLT Ecosystem strategy has allowed us to more narrowly define market segments and hone the presentation content.

2. Implement a more formal sales/engagement process with continual analysis of key metrics at each stage of the funnel

- QoLT has implemented Zoho CRM cloud based customer relationship management system. This has allowed us to track all sales activity through a defined sales process.
- Zoho has allowed us to track and quantify the QoLT sales process. We have found from the companies that have transitioned through the sales cycle to members that, on average, we are able to close a small company in the same quarter that we make the initial contact and that the large company takes into the third quarter to close. From an analysis of the duration in each of the sales steps, on average, the Commitment stage is the longest (for both large and small companies). The Commitment stage begins when the company management has agreed to membership but doesn’t end until their legal representative signs off on the agreement.

3. To the extent IPAB members are not involved with testbeds, the likelihood of translation to commercialization is greatly reduced

- The new QoLT Project Tracking program is a step to ensuring input on projects. Every member company, even the Thought Leaders, is allowed to choose three current projects to track. This enables members to interact, on at least a quarterly basis, with the researchers on three projects that are relevant to their interests.
- We have several current projects that are in the hands of our members testing their effectiveness, Health Kiosk, Romibo, Drive Cap, and First person Vision.

4. Consider increasing [Membership] pricing for closer alignment with the reputation of the center (branding) and benefits of partnering; Continue to offer a combination of both in-kind and cash [dues] for small business partners who may offer a resource that is beneficial to the center, but has little financial resources to contribute (for example, the mechanical arm in the Cueing Kitchen);

- QoLT management thought long and hard about the decision to make changes to the member benefits and therefor the Participation Agreement. Time was spent to get other ILO’s, QoLT members and Thought Leaders, QoLT center directors, and ILO consultants Erik Sander and Ann Schmierer’s opinions regarding the proposed changes to the member benefits. Ultimately we changed the Master member level fee from $100,000 to $50,000, left the Full member dues at $20,000 and the Associate level at $5,000, and added a new level of Affiliated Providers at $2,000. Affiliated Providers are the long-term care organizations that have small budgets.
- We did maintain the discounts for not-for-profits and the reduction in dues for specific in-kind activities.

4.2 *Membership*

4.2.1 Membership Goals and Strategy

We seek to maintain a portfolio of industry and practitioner members that is balanced and heterogeneous in terms of company size and the sectors in which they operate. Small companies are of interest because they tend to be more entrepreneurial than large ones. They also typically have a better appetite for translational research, though because they are so focused, their technology roadmaps are tighter and do not always resonate with ours. Larger firms typically have a broader understanding of markets and have greater depth of knowledge in complex spaces like healthcare, both of which are invaluable to us. On one hand, as noted above, large companies tend to shy away from direct licensing, opting instead to acquire small companies after they have proven the viability of their technologies and business models.

The new QoLT member strategy was put in place in December of 2012, shown in Figure IPCA-1 below, is an ecosystem model driven by members identifying problems to solve, research being performed within the Center, rough prototypes are created, tested by provider members, licensed by product manufacturer members and after the completion of a commercial product, sold to provider members. We have entered the second phase of targeted membership recruitment. The first phase encompassed testing of the new strategy by presenting it to representative companies in the market segments for which the new strategy focuses. While receiving very positive feedback from everyone, we began to add new members. During phase one the new members that joined were those that could make quick decisions internally, this was primarily returning members and small companies – we were focused on the April 2013 Site Visit. Phase two timing has allowed us to add several very large organizations that took extended time to work through the sales funnel – companies like iRobot (cutting edge robotic firm), Henry Ford Health System (acute care hospital, insurance company, and a home care provider), and Epson a consumer electronics company. As you can see from the list, we have been building out membership in each of our targeted market segments. With 24 members, we believe that the IPAB now has critical mass and by itself is attracting additional members.

Formally, the member strategy has providers of the following services as the *Core Members* of the IPAB; independent living, home care, assisted living, rehabilitation centers, skilled nursing, acute care organizations, and payers (insurance providers). These core members are anxious to join the QoLT IPAB because they believe that technology will provide the solutions to their challenges to remain profitable in both the short and the long term and to provide a higher quality of life for their customers and their employees. They want to have input in solution development and they universally want to participate in field deployments of testbed systems.

The middle ring of the consortium, *Suppliers*, includes product manufacturers and service providers from a large variety of industries. They are motivated to join to track technology trends, access QoLT technology and intellectual property – and have access to potential customers that are *Core Members*.

The outer ring contains a vital component of the ecosystem, *Key Thought Leaders*. This new aspect of the consortium was added after interviewing current and potential members and reviewing the SWOT analysis, and looking at the commercialization goals of the Center. Both *Core Members* and *Suppliers* requested that QoLT find a way to add more market expertise to the IPAB. The *Key Thought Leaders* bring well-informed perspectives on public policy issues and trends at the national level, as well as market data and extensive access to additional prospective Members. Several impressive organizations have already committed to participating *Key Thought Leaders*, including AARP, National Council on Aging, MS World, LeadingAge, LeadingAge PA, and Area Agency on Aging; we are in dialog with the American Association of People with Disabilities (AAPD), Oncology Nurse Association (ONS), and the Center for Medicare & Medicaid Services (CMS). We already have an FDA representative on our Scientific Advisory Board.

The new member strategy was designed to meet several requirements:

- Attract a wider range of industries.
- Enhance the Member/Member inter-relationship component of our existing value proposition.
- Augment our knowledge base of the markets that QoLT products are being introduced into.
- Increase our access to end-users.
- Attract more companies that are inclined to commercialize QoLT Center outputs.
- Broaden our perspectives on end-user needs and system-level problems.
- Increase industry and practitioner involvement in prioritizing basic research problems.
- Identify opportunities to use our enabling technologies in other applications.
- Increase Member participation in testbed projects.
- Contribute to the sustainability of the Center.

The new QoLT ecosystem strategy was tested in 2013 with great results. It has already generated or retained a total of 24 members and a pipeline of 12 companies that are in the last two stages of the sales process.

Figure IPCI-1: QoLT Center Consortium Strategy.

Relationships with practitioner organizations, such as long term care providers, are also give-and-take. They can afford us access to end-user venues for testing and evaluating systems and hone our understanding of real world needs and constraints. Reciprocally, we afford them with expertise and perspectives on how to implement technologies.

On a regular basis, we analyze our research portfolio in terms of perceived fit to and interest of various industry sectors. Factoring in how difficult it will be to penetrate specific companies determines how we should prioritize our recruiting efforts. Our IPAB reviews this analysis annually.

Table IPCI-1: Target Industry Segments for the QoLT Center

Industry Segments	Priority of Engaging	Potential interest in QoLT Systems & Thrusts	Why Interested
Advanced Sensors	Medium	HCHW	Home Automation, Wellness Monitoring
		VC, HSIT	Personal Sensing
		PAT	Grand Challenge
		SD	Driver Monitoring, Environment Monitoring
Assistive Technology	Low	MoMaT	Human Robot Interaction, Therapeutic Robots
		PAT	Sensory Prosthetics
Athletics/Exercise Equipment	High	VC, HSIT	Personal Training, Personal Monitoring
		PAT	Personal Monitoring
Automobiles	High	SD	New Designs, Enhanced Safety, Differentiation
Cell Phones	High	VC	New Functionalities
Comm/Internet	Medium	HCHW	New Content, New Networking
Computers & IT	Medium	VC, HSIT	Personal Assistants
Consumer Electronics	High	HCHW	Home Automation
		VC, HSIT	New Modes Of Human-Device Interaction
		PAT	Wearable Products
Consumer Robots	Low	QB	Personal Robots, Home Automation
		MoMaT	Navigation In Residential Environments, Robot Safety
Auto Suppliers	Medium	SD	New Designs
Healthcare IT	Low	HCHW	Personalized Medicine, Wellness Monitoring
		PAT	Wellness Monitoring
Home Healthcare	High	HCHW	Personalized Medicine, Wellness Monitoring
		PAT	Wellness Monitoring
		VC, HSIT	Rehab, Personalized Medicine
Institutional & Long Term Care	Low	HCHW	Personalized Medicine, Wellness Monitoring
		PAT	Wellness Monitoring
		VC, HSIT	Rehab, Personalized Medicine
Insurance	High	VC	Personalized Medicine, Personal Safety
		SD	Driving Safety
Manipulators	Low	QB	New Market
		MoMaT	Safety Algorithms, Soft Interaction
Monitoring	High	HCHW	Wellness Sensing
		PAT	Activity Recognition
Navigation	High	SD	New Forms Of Navigation Assistance, Safety
Other Manufacturers	Low	PAT	Prediction (Safety), Quality Control
Personal Transportation	Low	MoMaT	Navigation In Residential Environments, Robot Safety
Security	Medium	HCHW	Wellness Sensing
		PAT	Activity Recognition
Wheelchairs	Low	QB	New Market, Wheelchair Navigation
		MoMaT	Enhanced Control Modes

4.2.2 Engaging Current Members

Over the past seven-plus years the Industry Practitioner Advisory Board (IPAB) has grown to include industrial members from a variety of industries, including automotive, home healthcare, electronics, robotics, and public and private aging services, in sectors such as research, development and manufacturing. There are now 15 Affiliated Providers (practitioners) including a variety of senior care providers and centers, an elderly technology advisory group, an assistive technology center and a world renowned medical center. The participation of the IPAB in the Center's research, planning, and commercialization activities has expanded significantly this past year, yielding increased understanding and collaboration among all constituencies.

Our IPAB is a heterogeneous mix of companies and service providers in the automotive, consumer electronics, medical device, insurance and long term care sectors. While we of course appreciate their financial support, it has always been our position that collaborative activities with IPAB members are even more valuable. Many of them are directly involved in core projects including Health Kiosk (Presbyterian SeniorCare and Vincentian), and Romibo (Jewish Association on Aging). Several of our new members are assisted living service providers and part of an organization called the Faith Based Network. This is an organization that has 15 members representing more than 50 facilities, a full continuum of housing and home and community-based services, serving over 8,000 seniors every day. Together with QoLT we have formed the FBN/QoLT Innovation Team and have agreed on a mission statement; the FBN and QoLT Innovation Team has changed their focus from the previous year to that of commercialization of current and future QoLT technologies, they have been very engaged. As proof that the current ecosystem strategy is gaining momentum, two of our members, iRobot and Vincentian are working together to develop a new product for the long term care industry. Also one of our spin-off companies, Rubitection, is working with five of our affiliated provider members to test their pressure ulcer detection device prior to FDA phase one trials.

The following table summarizes our collaborative relationships with industry and practitioners.

Table IPCI-2: Industry Collaborations at the QoLT Center

Firm	Collaboration(s)	Status
Vincentian (member)	Student project, working to design and implement a process by which low skilled person can safely deliver medication in a skilled nursing facility	Ongoing
Grane Healthcare, Jewish Association on Aging, The Abramson Center for Jewish Life, MS World, and Vincentian (members)	This taskforce is working to write a position paper to facilitate the updating of long term care policy at the state level, to facilitate the use of QoLT technologies.	Ongoing
Henry Ford Medical Center (member)	Participating in a capstone engineering class where they are looking at improving the discharge process from an acute care hospital	Ongoing
Epson (member)	Moved from an associate to a Master level member and now has placed a visiting researcher at QoLT	Ongoing
GM (member)	Collaboration on DriveCap Advisor	Ongoing
Myomo (member)	Myomo was awarded a Small-Business/ ERC Collaborative Opportunity: (SECO) grant to continue the commercialization efforts around the stroke therapy coach.	Ongoing
Nissan (member)	Workshop about electric car; workshop on issues of older adults driving, sponsored project in autonomous driving	Ongoing
Presbyterian SeniorCare (member)	Access to facilities, staff and clients for QoLT researchers and QoLT industrial affiliates; collaboration on Health Kiosk project	Ongoing

Firm	Collaboration(s)	Status
PHRQL (prospective member)	Entrepreneurial capstone course and joint lab facilities established to investigate remote monitoring of data indicative of health and to create a personal health record for QoL.	Finished 2013
Pinney & Associates (member)	Collaboration on medication sorting evaluation	Finished 2012
Robert Bosch Corporation (member)	Collaboration on InForm Exercise Coach, Modeling Human Balance, and Grand Challenge projects	Finished 2013
TFH USA Ltd. (member)	Course project to develop a sensory room that can automatically adapt to the next patient. This is a joint project with TFH and Bosch, TFH is supplying the sensory equipment and Bosch is supplying the room sensors.	Finished 2013

In the past year we ramped up our efforts to engage our IPAB through increased contact with Center leadership via on-site meetings, increased flow of information nuggets and telephone conferences. This has resulted in greater involvement in influencing the Center's strategic plan and specific projects, which has led them having a more complete understanding of the scope of the Center's goals, and in turn enabled richer dialogs during our annual research portfolio review and planning process (described in the Strategic Research Plan section). The IPAB Chairman, Steve Kelley of Myomo, and the Deputy Chairman Ray Washburn of Vincentian, have taken an active role in devising the updated IPAB membership strategy and additional membership benefits.

Communications with Members

Following the concerns expressed by the Site Visit Team about member engagement, we undertook a Communication Needs Analysis of our current IPAB members. A representative sample of prospective members that we felt were close to conversion were also invited to respond to assure that our findings were geared properly towards growth. The Needs Analysis had three facets: 1.) one-on-one conversations with the outbound and inbound IPAB chairs to explore member interests and opportunities as well as IPAB member-to-member interactions; 2.) an online survey addressing member objectives, content interests, awareness levels and channel uses; and 3.) a live, group discussion at the QoLT Summit to review the survey findings for final affirmation and buy-in of the revitalized communications effort.

The Survey revealed that member-to-member networking and technology updates are the two most important facets of the QoLT Member Consortium's value proposition. Industry members noted that they are looking for an understanding of how other industries are solving problems that touch upon the QoLT domain and "scanning for innovations that can be adapted [in]to [their own] systems' domain." Practitioner members are simply interested in learning more about technologies that they may wish to implement in their care communities.

A key challenge for Member Communications in previous years has been establishing and stabilizing a regular cyclical calendar of content interactions that members can rely on predictably. Our survey findings revealed that such formalized member communications are not necessarily a prime concern at this time. Rather, our Members seek individualized attention from QoLT leadership and faculty as well as greater interaction opportunities focused around specific research opportunities.

A first step towards improving member interactions at the leadership and faculty levels is to strengthen the member onboarding process. To that end, we have created a new workflow that documents a repeatable order of touch points new members should gain access to as they join the QOLT Center. Optional collaborations will be introduced to new members with the goal to extend the member's ability to interface effectively with the Center on a variety of different needs.

Based on the preferences expressed in the Needs Analysis, our Members have requested a simplified communications infrastructure consisting of the following four components: two live meetings per year (plus occasional webinars on specific topics as requested by the group); two conference calls per year;

privileged access to select content made available by QoLT participants - and organized by cluster or project - via a closed intranet system; quarterly updates in a newsletter format; and an online group via LinkedIn for sharing broader industry news and facilitating member-to-member networking.

Beyond the obvious tracking of increases and decreases in membership support, we will continue to track the sales process using Zoho CRM tool and content access habits in the Basecamp intranet to hone in on specific interests expressed by individual members. The Zoho Campaign tool will also allow us to view open-rates and click-through data from email outreach so that we may better identify the types of content and subject matter individual members respond to best.

4.2.2.1 History of Memberships

The table below lists current and past affiliates.

Table IPCI-3: QoLT Center Membership.

Name of Firm	Business Sector	Membership Level	Status
Allstate	Insurance	Full	Joined 2009 no longer a member, expect to rejoin in 2014
Baptist Home Society	Continuing Care Provider	Affiliated Provider	Joined 2013
Beacon Communities	Senior Oriented Real-estate Developer	Affiliated Provider	Joined 2014
Blueroof Technologies	Housing	Full (in-kind)	Joined 2006; no longer a member as of 2013
Epson	Electronic sensors, Quantified Self	Master	Joined as Associate member in 2013 and moved to Master member in 2014
ETRI	Research Institute	Full	Joined in 2010; no longer a member as of 2012
Etovia Systems	Sensors	Associate	Joined 2007; no longer a member
First Person Vision	QoLT Spin-off and Vision Systems	Associate	Joined 2013
General Motors	Automobiles	Associate	Joined 2008; took leave of absence in 2011 and rejoined in 2013
Grane Healthcare	Continuing Care Provider	Affiliated Provider	Joined 2014
Henry Ford Health System	Payer, Acute Care Hospital, and Home Health co.	Master	Joined 2013
Honeywell	Consumer Electronics	Full	Joined 2007; no longer a member, expect to rejoin in 2014
Intel	Information Technology	Associate / Collaborator on HERB QoLTbot	Joined 2007; no longer a member as of 2010
iRobot	Personal, Commercial, and Military Robots	Affiliated	Joined 2014
Jewish Association on Aging	Continuing Care Provider	Affiliated Provider	Joined 2013

Name of Firm	Business Sector	Membership Level	Status
Laurel View Village	Continuing Care Provider	Affiliated Provider	Joined 2014
Lutheran SeniorLife	Continuing Care Provider	Affiliated Provider	Joined 2013
Myomo	Medical Device	Associate	Joined 2012
Nissan	Automobiles	Full to Associate	Joined 2008
Panasonic	Consumer Electronics	Full	Joined 2009; no longer a member as of 2010
Pinney and Associates	Pharmaceuticals	Associate	Joined 2012
Presbyterian SeniorCare	Senior Living	Affiliated Provider	Joined 2008 as an in-kind Associate, now Affiliated Provider
Presbyterian Senior Living	Continuing Care Provider	Affiliated Provider	Joined 2014
Robert Bosch Corporation	Consumer Electronics	Associate	Joined 2006; no longer a member as of 2012
Samsung	Consumer Electronics	Full	Joined 2008; no longer a member, expect to rejoin in 2014
Seagate	Information technology	Full	Joined 2007; no longer a member in 2009
Redstone Highlands	Continuing Care Provider	Affiliated Provider	Joined 2013
Reformed Presbyterian Home	Continuing Care Provider	Affiliated Provider	Joined 2013
Sony	Consumer Electronics & IT	Associate	Joined 2007; no longer a member in 2010
St. Anne Home	Continuing Care Provider	Affiliated Provider	Joined 2013
The Abramson Center for Jewish Life	Continuing Care Provider	Affiliated Provider	Joined 2013
The Affective Computing Company	Virtual Coach Software	Associate	Joined as a Full member but, switched to an Associate Joined 2013
Touchtown, Inc.	Long Term Care Products	Associate	Joined 2014
Villa St. Joseph	Continuing Care Provider	Affiliated Provider	Joined 2013
Vincentian Collaborative Systems	Continuing Care Provider	Affiliated Provider	Joined 2013

4.2.3 Recruiting New Members

We use several networks to find contacts within companies targeted for recruitment. The networks that have been most fruitful to date are those of our own faculty, the universities' Corporate Relations and technology transfer offices, and those of our innovation partners. They have also brought prospects to us. We obtain additional leads through established national organization networks and their annual meetings: Center for Aging Services Technologies, of which we are a member, RESNA conferences and the American Association of Housing and Services for the Aging (AAHSA). Other organizations and their conferences where leads are generated include; LeadingAge Annual Meeting, LeadingAge PEAK conference, LeadingAge PA conference, Healthcare Information, Management Systems Society (HIMSS), Silvers Summit at the Consumer Electronic Show, and the Louisville Innovation Summit. Also, we are members of the LeadingAge CAST Commission which is the governing body of the research that CAST is performing – this group is comprised of continuing care providers and long term care product manufacturers of all types.

The new strategy of adding a Key Thought Leader aspect to the IPAB is already paying dividends with several of them already making introductions to key members of their own advisory boards or membership. This year we intend to better leverage our alumni tracking data similarly for additional lead generation purposes.

Our QoLT social media channels (especially Twitter and LinkedIn) are also beginning to generate soft leads. Although contact with online followers is generally much more limited qualitatively, social media should not be overlooked as a source of potential support and community building. Accordingly, we are evolving a pipeline strategy that we hope will better enable prospect engagement and relationship building from these initial community level contacts all the way through to full membership engagement. Core communications components of this strategy include brand journalism, influencer mobilization and email marketing enabled by the new Zoho Campaign tool adopted in late 2012.

The table below, Table IPCI-5, is a summary of our top potential prospects: the “Sales Prospect Level” is the ranking each organizations holds based on where they are in the sales process. We keep track of this process with Zoho CRM an inexpensive yet powerful web based customer relationship management system. The list is sorted by stage in the sales process and by product manufacture and provider. The table below, Table IPCI-4, describes the Sales Prospect Levels.

Table IPCI-4: QoLT Sales Prospect Levels.

Sales Prospect Level	Name	Description
1	Qualification	The Prospect is thought to have an interest in QoLT, they make products or supply services that are a fit with QoLT.
2	Engaged	We have had at least one discussion with the prospect and they have said that they are interested in continuing the decision.
3	Decision Makers	The engaged representative of the prospect is the person who controls the budget that will pay for the membership.
4	Participation Agreement	Prospect has asked for and received the QoLT Participation Agreement.
5	Commitment	Prospect has made a verbal commitment to join.
6	Members	Signed agreement and payment has arrived at QoLT.

Table IPCI-5: Current QoLT Center Membership Prospects.

Prospect Level	Company Name	Industry Segment	Likely Level
4	Highmark	Insurance	Full
5	Golden Living	Continuing Care Provider	Full
5	Link-Age Ventures	Venture Capital	Associate
5	Samsung	Consumer Electronics	Full
5	Comcast	Entertainment, Telecomm	Associate
5	Net.Orange	Healthcare IT	Master
3	IBM	Healthcare IT	Full
3	Microsoft	Healthcare IT	Full
3	AT&T	Healthcare IT	Full
3	Toyota	Auto Manufacturer	Full
3	Humana	Insurance	Master
2	Walgreens	Retailer	Full
4	Bossa Nova Robotics	Robotics	Associate
4	Allstate	Insurance	Full
2	GE Care Innovations	Consumer Electronics	Associate
3	Philips Healthcare	Medical Devices	Full
3	United Healthcare	Insurance	Full
3	Qualcom Life	Monitoring	Full
3	Texas Instruments	Robotics	Associate
3	HStar	Robotics	Associate
3	Ideal Life, Inc.	Home Healthcare	Associate
3	re2	Robotics	Associate
3	Sony	Consumer Electronics	Associate
3	HealthSense	Monitoring	Associate
3	Hstar Technologies	Robotics	Associate
3	Engineered Care	Healthcare IT	Associate
3	Permobil	Wheelchairs	Associate
2	GrandCare Systems	Monitoring	Associate
3	NewCare Solutions	Monitoring	Associate
Affiliated Providers			
4	The Cedars of Monroeville	Continuing Care Provider	Affiliated Provider
4	Shenango Presbyterian SeniorCare	Continuing Care Provider	Affiliated Provider
4	Mt. Macrina Manor	Continuing Care Provider	Affiliated Provider
4	Concordia Lutheran Ministries	Continuing Care Provider	Affiliated Provider
4	Canterbury Place	Continuing Care Provider	Affiliated Provider
3	Front Porch	Continuing Care Provider	Affiliated Provider
3	Covenant Retirement Communities	Continuing Care Provider	Affiliated Provider
3	Brookdale Living	Continuing Care Provider	Affiliated Provider
3	Lutheran Homes of Michigan	Continuing Care Provider	Affiliated Provider
3	Evangelical Homes of Michigan	Continuing Care Provider	Affiliated Provider
3	Sunrise Senior Living	Continuing Care Provider	Affiliated Provider
3	Capable Living	Home Care	Affiliated Provider
3	Gallagher Home Health	Home Care	Affiliated Provider
3	Lutheran Home Association	Continuing Care Provider	Affiliated Provider
3	Westminster at Lake Ridge	Continuing Care Provider	Affiliated Provider
3	Asbury Heights	Continuing Care Provider	Affiliated Provider

4.2.4 Membership Structure

To support the new IPAB strategy, the membership structure was reviewed and updated. All member companies enjoy facilitated access to ERC faculty, students, and research results, and the specific benefits of membership as shown in the following table. To be more attractive to recruiting targets such as long term care and other healthcare providers, we offer a 50% discount to non-profits at the Associate and Full levels. The member benefits have been improved to better meet the long-term view of sustainability. The members now have the opportunity and are encouraged to be more involved with the individual research projects of interest to their companies. This level of involvement will also provide necessary feedback to the specific research team to help achieve market driven research outcomes. With the approval of our new Participation agreement, we added an additional benefit category to facilitate the construction of the ecosystem, Affiliated Providers. Affiliated Providers are Core Member providers that include independent living, home care, assisted living, rehabilitation centers, and skilled nursing service providers.

Table IPCI-6: Benefits of Membership in the QOLT Consortium.

Category	Affiliated Providers	Associate	Full	Master
Open invitation to visit to interact with Faculty and Staff	X	X	X	X
Advance copies of all publications	X	X	X	X
Facilitated access to students including recruiting	X	X	X	X
Opportunity to interact with Faculty and Staff – list available	X	X	X	X
Logo and listing on the QoLT Center website	X	X	X	X
Quarterly Newsletter	X	X	X	X
Quarterly membership meetings – two in person and two by video conference	X	X	X	X
Member of the Quality of Life Technology Industry/Practitioner Advisory Board (also known as the QoLT Consortium)	X	X	X	X
Participation in periodic research project informational conference calls (up to 3 projects per member company)	X	X	X	X
Notice of invention disclosures		X	X	X
Opportunity for on site QoLT prototype testing	X			
Members vote on research project funding (based on a percentage of member dues pool)			X	2 voting seats
Student Involvement (one project per year based on availability of students)			Team project	Class project
Member exclusive white papers, topics chosen by voting members from a list of appropriate topics (one per year)			X	X
Opportunity for researcher in residence			Optional w/fee	Included
Annual meeting at member's site				X
License to new quality of life technologies			Non-exclusive royalty-free non-commercial	Member-only option (up to 3 years) to negotiate exclusive licenses
Not for profit discount	50%	50%	50%	0%
Annual Dues	$2K	$5K	$20K	$50K

Membership in the consortium is formalized through the QoLT Center's Participation Agreement, to which all participating companies, organizations and universities are signatories. It defines intellectual property, membership levels, membership benefits, participant roles, etc.; spells out licensing rights and procedures; has provisions to manage confidential information; describes the government's rights and requirements, including export controls and the NSF grant terms and conditions; and includes no-warranty, indemnification and other legal clauses. All told, the document is a modest 16 pages.

The ERC provides special opportunities and licensing arrangements for companies that join at the Full and Master levels. Beyond membership in the QoLT Center Industry Consortium, there are many additional mechanisms for companies to license QoLT Center technologies. All existing CMU and Pitt licensing opportunities are still operative; a company need not be a member of the ERC consortium to license any ERC technology. Licensing terms typically include one-time/lump-sum payments and various royalty arrangements with payments tied to net sales of products and services that incorporate licensed technologies. It is worth noting that many of the licensing deals done each year by both CMU and Pitt are with start-ups and other small businesses.

Intellectual Property (IP) created by the QoLT Center with core funds is referred to as “ERC Technology” and is shared by CMU, Pitt, and partner universities. It is made available to all industry members to the extent allowable under the Bayh-Dole Act. Master Members have an option to negotiate exclusive licenses; Full and Master Members are entitled to non-exclusive, non-commercial, royalty-free licenses for a limited time, after which they can obtain royalty-bearing license. Industry-funded projects are governed by sponsored research agreements with CMU or Pitt. Each defines the technologies to be created as ERC Technology (which will also be shared by CMU, Pitt and all member companies), or technology that may be exclusively licensed to the sponsoring company. Both universities retain non-exclusive rights to use resulting IP for non-commercial research and educational purposes.

When researchers submit an invention disclosure to either institution, indicating that the invention may be jointly owned, both offices of technology management confer and then prepare and execute an appendix to the master agreement. The appendix designates the responsible institution for patenting, marketing licensing and managing the IP. It also delineates split of royalties and other revenues. This existing agreement is important since it will expedite otherwise time- and energy-consuming process of inter-institution handling of IP.

We send our invention disclosures to all members in a sealed envelope with an affixed non-disclosing abstract so the Member can elect whether to read the full document or not. Some opt not to, so as to avoid potential future intellectual property disputes. Master Members have 90 days to decide whether or not to request a license. If they do not, the other Members have 90 days. After that, the university(ies) can enter into licensing negotiations with non-Members, i.e., the rest of the world.

CMU requires graduate students to sign a form indicating that they understand the university’s IP policy. We require all CMU researchers to sign a form indicating that they understand the QoLT Center’s additional IP constraints (Pitt researchers have more limited rights to IP and has determined that such acknowledgements are unnecessary).

Having a dedicated ILO and a new IPAB strategy, and the early success, and a strong pipeline gives us the confidence that the revenue generated by annual membership dues will be at the 2011 levels by the end of Q4 2013 (year 8) and in the $250K range by the end of Q2 2014.

4.3 *Technology Transfer and New Business Development*

4.3.1 Patents and Licenses

Due to technology maturation, our rate of invention disclosures has steadily increased, nine invention disclosures were filed in the past year. The table that follows lists all 63 since inception of the ERC.

Table IPCI-7: History of Invention Disclosures at the QOLT Center.

Invention Name	ERC Portfolio	Disclosure Docket #	Patent Status	Licensed To
Intuitive Interaction with an Assistive Robot	Core	Pitt 01764		
MemExerciser	Core	CMU 08-106	Provision filed 10/2008; full patent application being filed	
A Continuum Type Soft Robot Arm	Core	CMU 12-048		
Inflatable Soft Manipulator	Core	CMU 12-047		
The Variable Buckling Hinge Mechanism	Core	CMU 12-049		
Head Coach: A Home Balance rehabilitation Exercise Monitoring Device	Core	CMU 11-059	Provisional filed 11/17/11	
Manipulation planning algorithm for personal assistive robot	Associated	CMU 12-078		
A novel low cost computer based system for at home monitoring and rehabilitation of motor deficits	Associated	CMU 12-004		
NAViSection: enhanced assessment of driving capability during on-road evaluations and training	Core	Pitt 02557		
Mobile Base of Personal Mobility and Manipulation Appliance Generation II	Core	Pitt 02606		
Craniux: A LabVIEW-based Modular Software Framework for Brain-Machine Interface Research	Associated	Pitt 02392		
Robotic Strong Arm	Core	Pitt 02618	Provisional patent filed	
Occlusion Reasoning for Object Detection under Arbitrary Viewpoint	Core	CMU 12-076		
Object Instance Discovery from Images	Core	CMU 12-045		
Integration of Personal Informatics Visualizations	Core	CMU 12-046		
Semi-Autonomous Virtual Valet Parking	Core	CMU 12-055		
Lifelogging Support for People with Episodic Memory Impairments	Core	CMU 08-106		
Ergonomic Lift Chair	Associated	CMU 11-116		
Modular Wall System	Core	Pitt 02081		
First-person /inside-out vision	Core	CMU 08-096		First Person Vision
Compact 3D laser scanner for Personal Robotics	Associated	CMU 10-065		

Invention Name	ERC Portfolio	Disclosure Docket #	Patent Status	Licensed To
3D video conferencing	Associated	CMU 10-056		DUPR
Fuel distribution	Associated	CMU 08-046		
inhabited web	Associated	CMU 10-060		inVynt
Lean and Zoom	Associated	CMU 08-043		Lean and Zoom
Material detection	Associated	CMU 10-057		inVynt
Minput	Associated	CMU 11-074		inVynt
Noise generation	Associated	CMU 08-049		
Optical tracking for mob devices	Associated	CMU 11-075		inVynt
Rumble strips	Associated	CMU 08-044		
Scratch input	Associated	CMU 10-059		inVynt
Skinput	Associated	CMU 10-058		inVynt
Speed sensing	Associated	CMU 08-047		
Spherical display	Associated	CMU 08-048		
Exploiting Metadata for Unsupervised Object Discovery	Core	CMU 12-054		
Auto collection, conversion and storage of 3D images for 3D recognition Systems	Associated	CMU 10-108		
Low-Cost Neck and Snap-Fit Design for MEmote Robot	Core	CMU 12-090		Future license to Origami Robotics
Romibo Robot Project	Core	CMU 12-091		Future license to Origami Robotics
MeMote Robot	Affiliated	CMU 12-089		Future license to Origami Robotics
Intelligent Sensor-Based Home Coaching and Monitoring System for Therapeutic Rehabilitation	Core	CMU 12-117		
Unwrapping the Eye for Iris Detection and Gaze Estimation	Core	CMU 12-155		First Person Vision
InContext Smartphone interpretability prediction platform	Core	CMU 12-163		
Wireless Illuminated Grab Handle	Core	Pitt 02771	Provisional patent filed	
Software for Extreme Locomotion Planning for Legged Robots	Associated	CMU 13-050		
Orcdchomp, An Implementation of the CHOMP Trajectory Optimizer for OpenRAVE Using Libcd	Core	CMU 13-049		
Contributions to Libcd, A General-Purpose Robotics Software Library	Core	CMU 13-048		
Adaptive Sinusoid Canceler	Associated	CMU 13-085	Provisional patent filed	
Adaptive Common Average Reference	Associated	CMU 13-084	Provisional patent filed	
Talkerapplet	Core	CMU 13-131		
"Libherb" Python Libraries	Core	CMU 13-130		
Pan/tilt Head for the Robot HERB	Core	CMU 13-137		
Connecting Missing Links: Object Discovery from Sparse Observations Using 5 Million Product Images	Core	CMU 13-133		
Data-driven Objectness	Core	CMU 13-132		

Invention Name	ERC Portfolio	Disclosure Docket #	Patent Status	Licensed To
Community Health Kiosk	Core	CMU 13-142		
Vibrotactile steering wheel for route guidance support in car	Core	CMU 13-150		
Methods for Sensory Adaptable and Customizable Therapy Robots	Core	CMU 13-209	Provisional filed	
Friction-free Elastic Suspension and Actuation for Flexible Joints	Core	CMU 13-225	Provisional filed	
Model-based Controller for Leg Placement in Swing in Robotic Legs	Core	CMU 13-227	Two provisionals filed	
Push-Grasping Planner Plugin for OpenRAVE	Core	CMU 14-013		
Virtual Coach for Stroke Therapy	Core	CMU 14-091		
Virtual Coach for Rehabilitation Therapy	Core	CMU 14-092		
Virtual Coach for Physical Activity	Core	CMU 14-118		
Smartphone Based Virtual Seating Coach	Core	Pitt 3065	Provisional filed	Permobil

Table IPCI-8: Technology Transfer.

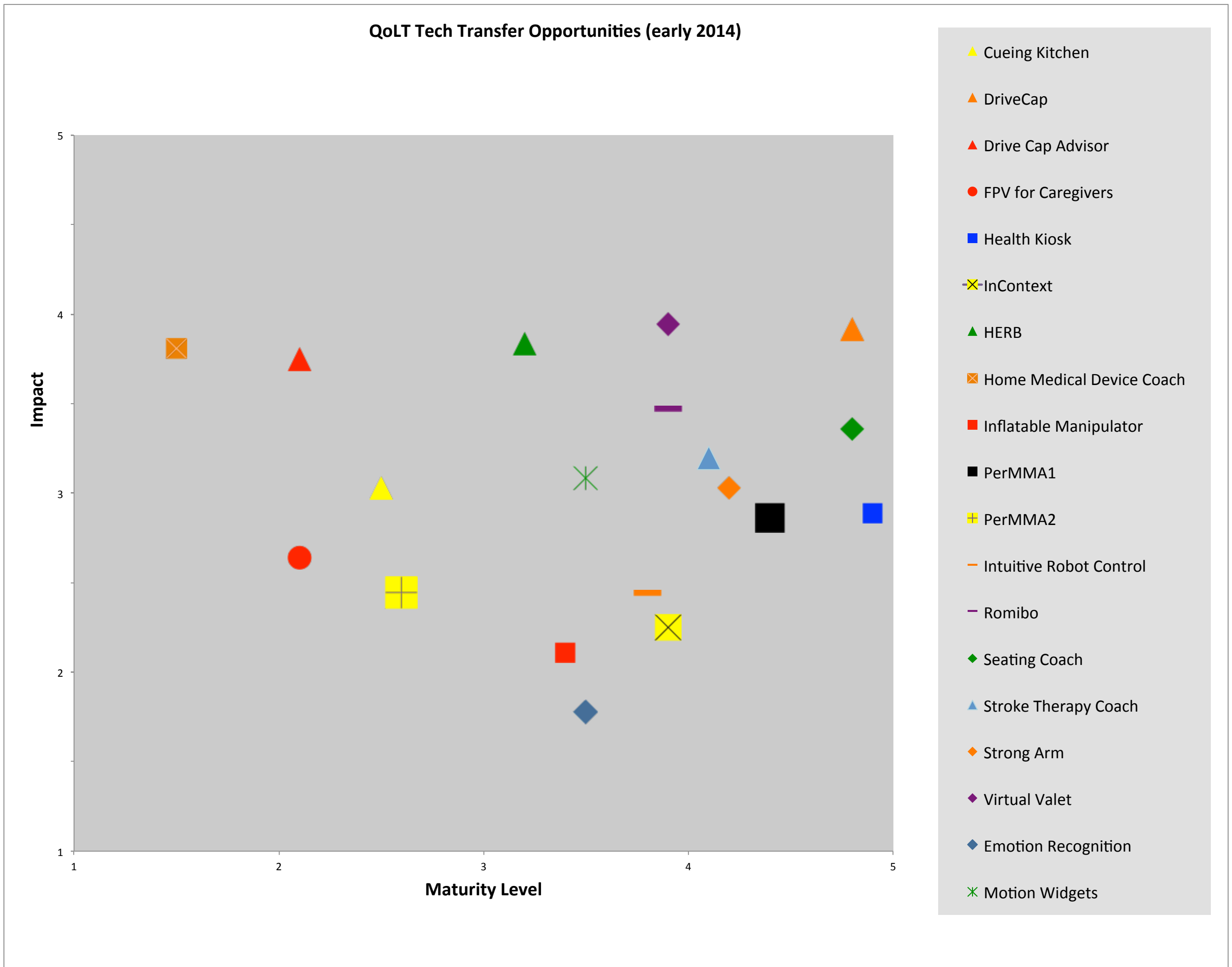
Adopting Company	Technology	When Transferred	Use in Company	Market Impact
NavPrescience, Inc.	Learning and Predictive GPS Navigation	June 2009	Primary Product	TBD
VibeAttire, Inc	Vibrotactile clothing for entertainment and assistive technology	September 2009 (no university claim)	Primary Product	TBD
Invynt, LLC	Interaction technologies for electronics, auto and home	June 2011	Development & integration	TBD
Lean&Zoom, LLC	Lean & Zoom software to reduce strain on eyes and back	October 2010 (no university claim)	Primary Product	Yes
Joel Olson, Sole Prop.	Ergonomic Joystick	January 2010 (no university claim)	Primary Product	TBD
Dupr, LLC	3D video conference system	June 2010	Primary Product	TBD
First Person Vision, LLC	Inside/Out Vision for training, security and memory assistance	June 2010	Primary Product	TBD
Tiramisu, LLC	Real-time bus tracking via iPhone crowdsourcing application	December 2010	Primary Product	Yes
Rubitection	Subcutaneous pressure ulcer detection	October 2010	Primary Product	Yes
Permobil	Seating Coach	February 2014	Additional Feature	Yes

4.3.2 Technology Transfer Opportunities

In the figure below and the table that follows, we present technologies that have sufficiently matured to contemplate commercialization within two years. The figure plots conceptual products according to its potential for technology transfer (y-axis) against the QoLT Center's potential to be a leader in the relevant technological areas (x-axis).

In our preliminary analysis, the criteria used to qualify the opportunities within the Center are principally technology and market. The filters in the technology category are the current stage of research and the anticipated time needed to develop this into a commercial product. Market factors incorporate the qualification of need, market dynamics and uniqueness. If the product meets a well-defined need, a higher rank is assigned than if the need is just perceived and not qualified through our partners and testbeds. A higher ranking for market dynamics includes favorable size for successful commercialization, competition, price-point acceptance and a clear payment model, as well as a regulatory path. Additional evaluation of the proprietary nature and intellectual property protection of the technology is considered, including the barriers to additional competition to enter the market with a competing technology.

Figure IPCI-2: Maturity Level and Impact of QoLT Tech Transfer Opportunities.



We quantify 'Impact' as the weighted sum of four individual categories:

- How ***lucrative*** the project is projected to be in the next 5 years (weighting factor 0.35). That includes profit margins and accounts for commercialization delays such as gearing up for production, as well as maturity of the market(s) in which the product would be introduced.
- ***Quality of Life impact***, i.e., how much of change it is expected to make in the life of an individual (weighting factor 0.20). *HERB* and *PerMMA* could have profound effects on people's ability to live

independently, hence score very high, while *Emotion Recognition* will make far less impact. This component reflects our core mission.

- How many consumers the product could ***reach*** (weighting factor 0.35). This takes into consideration both the size of the markets and how easy it will be to penetrate them. It accounts for regulatory hurdles and ease/difficulty of establishing distribution channels. Our flagship robots *PerMMA* and *HE*RB are targeted at wheelchair users and older adults, respectively, and the latter market is much larger. The *Cueing Kitchen* will almost certainly need FDA approval, while *Romibo*, will not.
- How ***disruptive*** the technology is. A *Home Medical Device Coach* could revolutionize how consumers use their home healthcare products, while *Health Kiosk* faces a number of similar albeit less usable competing products (weighting factor 0.10).

Each technology is rated in four categories on a scale of 1 (low) to 9 (high) and the sum of the weighted total is normalized to a scale of 5. Maturity is directly proportional to Technology Readiness Level (TRL) scaled that values between 1 (low readiness for market) and 5 (high readiness for market). This analysis is instructive and we have incorporated into our research planning. Table IPCI-9 presents the technology products in the figure above in terms of future R&D and business model development steps needed to advance them toward commercialization.

Table IPCI-9: Identified Tech Transfer Opportunities Emerging from QoLT Research.

Technology	Description	Future steps
Seating Coach	System to encourage proper, healthy use of power wheelchairs	• A smartphone-based revision is has been licensed to Permobil.
DriveCap Advisor	Coaching to drivers about how to improve/maintain their driving skills.	• This has large potential impact, but is an immature technology. Substantial R&D is still needed (and is ongoing).
Health Kiosk	Patient triage and check in system, tracking of vitals	• Though there are several competing products, our design has advantages of being easily customized and usability by people with few computer skills.
Virtual Valet	Semi-autonomous vehicle parking using a phone application	• Demonstration projects are needed to determine viable use cases. We are exploring those with a number of IPAB Members and prospects.
Inflatable Manipulator	Inflatable arm intended to assist with close human-robot contact	• Partner with a robotics company to develop commercial version
MEBot	Novel power wheelchair with terrain adaption and active weight balancing	• Complete development, then explore licensing to power wheelchair manufacturers.
HERB	Autonomous personal assistive robot	• This has large potential impact, but is an immature technology. Substantial R&D is still needed (and is ongoing).
Home Medical Device Coach	System to observe a person's use and maintenance of home medical equipment	• This has large potential impact, but is an immature technology. Substantial R&D is still needed. This was an associated project that Center is considering adding to its portfolio.
PerMMA1	Semi-autonomous personal assistive robot based on a power wheelchair	• Substantial R&D is still needed (and is ongoing).
Stroke Therapy Coach	Companion tracking and motivational Virtual Coach to the Myomo mPower device	• Myomo to commercialize
InContext	Automated smartphone ringer setting based on perceived context of its user	• Field studies (ongoing) are needed to demonstrate accuracy and user acceptance.

Technology	Description	Future steps
Cueing Kitchen	Automated assessment of a person's likelihood of completing a kitchen task and delivery of prompts	• This has significant potential impact, but is an immature technology. Substantial R&D is still needed (and is ongoing).
DriveCap	Technology to assess driver's on-road performance	• Field studies (ongoing) are needed to demonstrate accuracy.
First Person Vision (FPV) for Care Givers	Automated summarization of events recorded by a wearable camera	• This project is in the very earliest stage. Substantial R&D is still needed (and is ongoing).
Intuitive Robot Control	Touch-sensitive wrap to facilitate Direct Interaction of a person with a manipulator	• This technology has been incorporated into Strong Arm and an associated project.
Romibo	Inexpensive mobile social robot to facilitate behavioral therapy	• Field deployments are needed to validate clinical efficacy and usability. A spin-off company has been formed to commercialize it.
Emotion Recognition	Technology that enables virtual coaches to react to the emotion that the user is experiencing	• This technology has been incorporated into several projects including the Health Kiosk. More work is needed to build a more robust system.
Motion Widgets	Technology that improves the ability to create virtual coaches	• This technology has been incorporated into several virtual coach projects. More work is needed to build a more robust system.
Strong Arm	A wheelchair-mounted manipulator to assist with transfers between seating surfaces	• We have submitted SBIR proposals with a robotics company and are engaged in license negotiations with them.

4.3.3 Future Plans

We will continue our commercialization efforts with the goal of spinning-off at least two additional companies and licensing at least two QoLT technologies in 2014 with the help of our ILO who has four years of licensing experience at Carnegie Mellon's Tech Transfer office. We will also continue to build out the updated consortium strategy, emphasizing product manufacturers to fill the gaps in our Value Chain and to consider licensing QoLT technology. We will continue to leverage the complete IPAB ecosystem, including internal resources, to factor in business models and market opportunity while doing research planning.

4.4 *Innovation*

4.4.1 Strategy for Launching New Firms

What have made the Foundry successful are the commercialization process that was developed and the seasoned support that was provided by EIRs, and the legwork provided by the student interns. Because they are a proven success, Foundry elements have been adopted by the campus-wide Carnegie Mellon program that has a broader reach within the university. The Carnegie Mellon Center of Innovation and Entrepreneurship (CIE) is housed within the Don Jones Center for Entrepreneurship within the Tepper MBA program. Staffing includes EIRs and student teams. The Center offers a broad range of offerings and activities focused on innovation and entrepreneurship. Notably, the merger provides a "one-stop shop" for entrepreneurial resources and education for faculty, researchers, students, and alumni. The faculty co-directors, Lenore Blum, Distinguished Career Professor of Computer Science and David Mawhinney, Executive Director of the Don Jones Center, are closest to the entrepreneurship activities on campus and are responsible for directing the project and responding to campus needs.

Table IPCI-10: Carnegie Mellon Center of Innovation and Entrepreneurship Center Activities

Programs
Innovation Fellows
Innovation Scholars
Student PROBEs
Faculty PROBEs
Spark Grant Funds
Swartz Fellows Internship Program
i6 Agile Innovation Program
Faculty Commercialization Seminars
CTTEC Gap Funds

Entrepreneurs-in-Residence
Coach Faculty Projects/Teams
Coach Student Projects/Teams
Manage Olympus Incubator

Events
Launch|CMU
Olympus Show & Tells
Olympus CONNECTs
Swartz Speaker Series
McGinnis Venture Competition
Treks
Start-up Job Fairs

Alumni Involvement
Open Field Entrepreneurs Fund
Mentorship Network

Informal Learning/ Student-Initiated Programs
StartSmart
Global Entrepreneurship Week
Bootcamps
TartanHacks/ScottyLabs
Women@CS
Entrepreneurial Clubs

Outreach Opportunities
Economic Development Groups
Investment Community
PowerUpPgh
Silicon Valley
International

The strong relationship with the Tepper MBA program extends to the students and key classes. The QoLT ILO is focused on commercializing the core Center technologies and works closely with these students and classes including;

Commercialization and Innovation, 45-807/907 is a course where students focus on developing markets-first commercialization strategies for opportunities identified by them or by partners from other CMU units. The markets first approach focuses on customers/users and filling identified need as opposed to "pushing technology" into non-receptive markets or markets that are slow to accept innovations. Students learn how to understand market need, analyze industry competitive landscapes, determine market driven solutions and market entry points. They use several methodologies including disruptive innovation, open innovation, Blue Ocean Strategy, multisided markets, and needs driven innovation. We also deal with both functional and emotional need. Student teams composed of Tepper School MBA candidates, and a cohort of graduate students from engineering, Computer Sciences, etc. form teams to carry out projects. Two projects were carried out that related to QoLT were included in the Fall suite of projects.

The Designing and Leading a Business Capstone Project class (45-909) is a course that is designed for Tepper MBAs who have concentrated in Entrepreneurship in Organizations and Technology Leadership. Tepper and School of Design faculty members lead the course. The class strives for a collaborative interdisciplinary approach that utilizes entrepreneurship and design thinking to bring innovations to the market. Student teams from the two schools are augmented by grad students from other schools who have expertise in technology in various fields pertinent to the projects. The goal of each project is to validate market need, minimum viable products, business models and go to market strategies for two classes of projects: 1) student or faculty originated startups; and 2) externally sponsored projects from outside organizations. The same two projects from the previous course were included since the faculty, student teams and QoLT sponsors all agreed that further work was needed and had high potential.

This past year, the QoLT ILO also helped the teams that are forming around QoLT IP with the expectation of spin-out companies, because of his background (founder and CEO of two CMU spin-off companies and a EIR at Innovation Works) he plays the EIR role but, leans heavily on CIE and their programs to educate the team and assist them in commercialization efforts, the Tepper MBA class have played a valuable role. A former QoLT EIR pitched in as an I-CORPS mentor for our newest spin-off Navity.

4.4.2 Results

QoLT has generated thirteen spin-off companies in six years, with 6 of them still active and several of them thriving. The following table shows the details.

Table IPCI-11: QoLT Spin-off Companies.

Name	Incorporated	in state (file #)	Target Market/Social Benefit	Technology	ERC Project Type	Tech Transfer Mechanism	Date of Transfer	ERC Personnel Involved	Funding	Status
NavPrescience, Inc.	5/27/09	DE (4691868)	Personal Navigation system (consumer electronics)	Learning and Predictive GPS Navigation	Core	Non-exclusive license	July 2009	Anind Dey, Brian Ziebar, Drew Bagnell	Received a seed grant from Innovation Works	Dormant
Invynt, LLC	6/1/09	PA (3885011)	Consumer Electronics	Interaction technologies for electronics, auto and home	Affiliated	Exclusive licenses	October 2009	Chris Harrison	Seeking funding	Dormant
VibeAttire, Inc.	8/12/09	DE (4719517)	Consumer Electronics	Vibrotactile clothing for entertainment and assistive technology	Affiliated	None (no university claim on IP)	not applicable	Aubrey Shick	Seeking funding	Dormant
Joel Olson, Sole Prop	1/31/10		Consumer Electronics, Rehab, Healthcare	Ergonomic Joystick	Associated	None (no university claim on IP)	not applicable	Joe Olson	Seeking funding	Dormant
Rubitection	3/22/10	PA (3943013)	hospitals, nursing homes	subcutaneous pressure ulcer detection	Affiliated	license	October 2010	Sanna Gaspard	Received Angel funding	Active
First Person Vision, LLC	6/7/10	PA (3960031)	Sports Media, Vision Assistance	Inside.Out Vision for training security and memory assistance	Core	Exclusive license	August 2010	Brendan McManus, Takeo Kanade, Martial Hebert	Received angel funding	Active
Lean&Zoom, LLC	9/27/10	PA (3982180)	Consumer Electronics, Vision Assistance	Lean & Zoom software to reduce strain on eyes and back	Affiliated	Non-exclusive license	October 2010	Chris Harrison	Seeking funding	Dormant
Tiramisu, LLC	11/12/10	DE (4897145)	Public Transportation planning and tracking	Real-time bus tracking via iPhone crowdsourcing application	Associated	Exclusive license	December 2010	Aaron Steinfeld	SBIR under review	Active
Origami Robotics	11/14/11	PA (4067428)	Robots to teach social interaction, consumer electronics	Robots to Motivate	Core	In Process	November 2011	Aubrey Shick	Received Angel funding	Active
PHRQL	12/30/11	DE (5082380)	Diabetes monitoring, medical, healthcare	Diabetes monitoring through smartphone application	Associated	None (no university claim on IP)	not applicable	affiliated	Seed grants from Innovation Works and The Technology Collaborative, has large paying customers, received Angel funding	Active
Lyftu, LLC	2/29/12		Chair to assist with standing from a sitting position	Mobility assistive device for seating and standing assistance	Associated	None (no university claim on IP)	not applicable	7 Students in CMU course "Engineering Product Design" (Spring 2011)	Seeking funding	Dormant
Dupr, LLC	6/30/12		Video Conferencing	3D video conference system	Affiliated	Non-exclusive license	July 2010	Chris Harrison	Seeking funding	Dormant
Navity	1/7/14	DE (5459935)	Driver Training	Technology to assess driver's on-road performance; Drive Cap Clinical Tools	Core	In Process	Expected April 2014	Nahom Beyene	I-CORPS program and incubator funding	Active

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4.4.2.1 Translational Research

In our Year 2 Annual Report, we noted that small businesses consistently seek technical assistance with short-term needs such as engineering and product testing, which may conflict with the Center's transformative research. We pledged to encourage co-development of SBIR and STTR proposals for collaborative projects that could support progress toward, rather than distract us from our long-term technology goals and simultaneously accommodate the needs of small companies. Since then, we have actively engaged firms for collaborative translational research with our ERC and done so successfully. We have secured six projects in aggregate from three rounds of the NSF Small-business ERC Collaboration Opportunity Program (SECO). Our general SECO strategy is to leverage QoLT Center outputs, giving priority to technology artifacts over knowledge that we have created, and simultaneously advance one or more QoLT Center goals. For small business partner, the objective is to generate a new product offering and/or enhance one of its existing products.

The table below summarizes our translational research projects; they are described in greater detail in Section 2.1.4.3 of this volume and in Volume 2.

Table IPCI-12: Translational Research Projects with the QoLT Center.

Small Business	Status	Benefits to Company	Benefits to QoLT Center
TravellingWave, Inc.	Completed	Significant usability improvement of its voice predict system over conventional text-input systems.	Integration of voice predict interface into the Seating Coach.
Rehabtek LLC	Completed	Validation of electronic measurements as an alternative to the clinical gold standard of mechanical measurements of human joint range of motion; validation of visual feedback distortion as a clinically useful technique in physical therapy.	Pre-clinical evidence supporting the clinical value of Virtual Coaches for exercise and physical therapy.
Barrett Technology, Inc.	Completed	Enhanced software library for their 3-fingered robotic hand.	Improved performance of the HERB testbed system.
Anthrotronix, Inc.	Completed	New product for in-home hand and finger physical therapy.	Clinician interface technologies for exercise coaches.
Wicab, Inc.	Completed	Computer vision algorithms to enhance their Brainport vision prosthetic.	New branch of R&D in vision prosthetics.
Myomo, Inc	1st SECO Completed 2nd SECO approved for funding	New patient and clinician interfaces for their mpower neurobotic stroke rehabilitation device.	New/enhanced user engagement technologies for exercise coaches.

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5 Infrastructure

5.1 Configuration and Leadership Effort

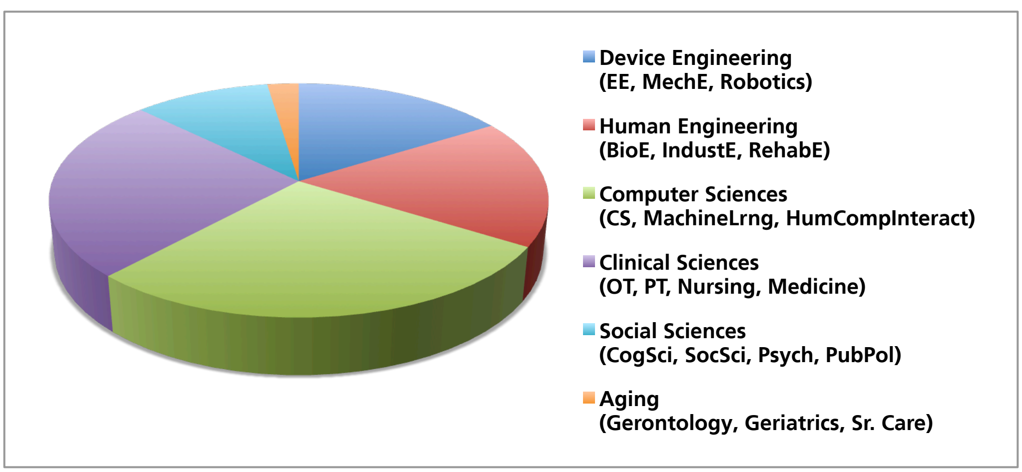
5.1.1 Personnel

We count among the QoLT Center's accomplishments the development of a very heterogeneous team that works very effectively together. QoLT R&D requires a eclectic yet balanced mix of technical, clinical and social science expertise. Assembling those ingredients was a challenge in itself (indeed, *Multi-disciplinary Collaboration* is one of our twelve fundamental challenges), but achieving synergy took several years. Sharing the QoLT vision proved to be a key in overcoming differences in knowledge, perspectives, culture, motivations and even vocabulary. Our team members now appreciate each other's complementary expertise, and actively and creatively seek ways to combine them. Indeed, by virtue of the connectivity it has instilled, this ERC has become a vehicle to accelerate and proliferate collaborative relationships.

The majority of the QoLT team is comprised of faculty members, staff and students from Carnegie Mellon University (CMU) and University of Pittsburgh (Pitt). Together, they bring deep experience and notable accomplishments in robotics, rehabilitation engineering, human-computer interaction, assistive technology, machine learning, gerontology, computer science, social science, electrical engineering and bioengineering. Our team represents some of the best in the US:

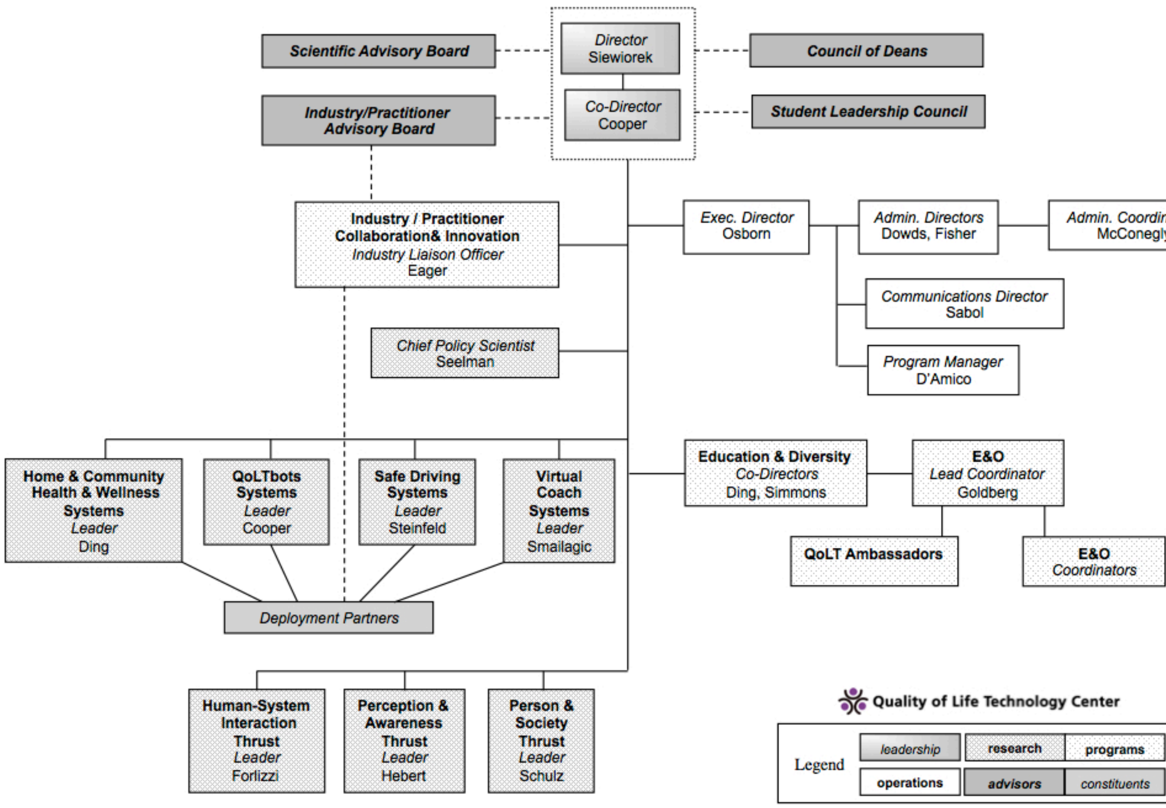
- CMU's Robotics Institute and Human-Computer Interaction Institute are widely regarded as the best academic departments in their fields.
- Pitt's Department of Rehabilitation Science and Technology (RST) is the only place in the United States, where one can obtain a degree in rehabilitation technology.
- CMU's engineering school is a top-10 program.
- Pitt's School of Health and Rehabilitation Sciences has one of the highest concentrations of people with disabilities of any academic program in the world.
- CMU's School of Computer Science is perennially ranked among the top four in the U.S.
- Pitt's Department of Physical Therapy is ranked #3 in the U.S.
- Pitt's School of Nursing is ranked #7 among graduate programs in the country.

The interdisciplinary nature of QoLT research is reflected in the composition of our faculty, as shown in the graph below.



That shared vision flows from the top. Our founding Director, Takeo Kanade, a world-renowned roboticist and computer vision expert, and his successor, Dan Siewiorek, an equally renowned computer engineer, acknowledge that understanding of physiological, physical, and cognitive human functions is needed to design intelligent devices and systems that aid and interact with people, and originates the idea of science of everyday living. Rory Cooper, one of the world's most prominent rehabilitation engineers and a passionate advocate for people with disabilities of all ages, acknowledges that the products and policies needed to improve their quality of life depend on the best that computer science and robotics can offer. Coming from them, that simple reciprocal acknowledgement has a profound effect on peer researchers.

5.1.2 Organization



The Cooperative Agreement contractually designates CMU the lead institution and Pitt the core partner. We regard this ERC as a genuine CMU/Pitt partnership in order to make the best use of our complementary technical and scientific expertise and strong support from the two institutions.

Dan Siewiorek is the *Center Director* having been unanimously selected by a Search Committee constituted to conduct a nationwide search for a permanent replacement for Founding Director, Takeo Kanade. He is ultimately responsible for translating the QoLT vision into actionable strategy and for staffing, fiscal and resources management. Rory Cooper is the *Center Co-Director* and the Principal Investigator of the sub-award to Pitt. In addition to having earned great respect in the research community and high regard within their institutions, both Siewiorek and Cooper are strong intellectual and administrative leaders of faculty (Siewiorek is a former Director of the Human-Computer Interaction Institute and Cooper is Chairman of the Rehabilitation Science and Technology Department, as well as Director of the Pitt/VA Human Engineering Research Laboratories). Both have clout within their university administrations (each holds a University Professorship), which was instrumental in obtaining their universities' buy-in to the QoLT vision and continues to be instrumental in solidifying institutional support of the Center's operations.

Their influence among peers was evident at an early, yet critical juncture of the Center. In response to the December 2006 site visit report they did major reorganization of the QoLT Center's research program and organizational structure into what it is now. The vision was unchanged, but the research strategy was unified by the QoLT Systems. That approach required re-orienting faculty already engaged and drafting new researchers. Kanade and Cooper used that opportunity to instill the system-driven QoLT vision in the entire team. That was done in part in recognition of the SWOT observations "it is not clear that all researchers fully understand the Center's vision and system goals" and "choices as to what work will be funded appears politically driven").

Jim Osborn is *Executive Director* and is responsible for day-to-day operations, cultivating and concreting external partnerships, public relations, events, and budgeting. Through a long career at CMU as a robotics program manager and connections to local economic development organizations, the clinical community, businesses, and foundations, as well as practical knowledge of technology transfer, he has earned the trust of faculty, staff, and students. His role as Coordinator for University Life Science Initiatives has afforded him access to the highest levels of the CMU administration.

Katherine Seelman is now *Chief Policy Scientist.* She is extraordinarily well connected in the disability community locally and nationally and serves on several national and international committees including a World Health Organization editorial committee. Her credentials include being former Director of the National Institute on Disability and Rehabilitation Research.

Randy Eager is the *Industry Liaison Officer*. He was previously a Licensing Officer in CMU tech transfer, an Executive in Residence at Innovation Works (a local tech-based economic development organization and one of our innovation partners), founder of three start-ups, and an employee in a large multi-national corporation.

Kristen Sabol is *Communications and Media Director.* She handles both public relations and internal communications, including our website. Meg Dowds is *Administrative Director.* She is responsible for financial administration, human resources and reporting. Col. Dan Fisher (US Army, Retired) and Michael McConegly are *Administrative Coordinators* and manage financial administration for the Pitt sub-award.

Martial Hebert, Richard Schulz and Jodi Forlizzi are *Thrust Leaders*. They are responsible for the definition and management of thrust research projects and recruitment of faculty and students. All are full professors and acknowledged leaders in their fields. Schulz is a department chair and Associate Director of the UPMC Aging Institute. Hebert is one of the most cited researchers in computer vision; Atkeson built the first smart house while at Georgia Tech. Like Kanade and Cooper, all have great influence with peer faculty and are among the most sought-after faculty by graduate students seeking advisors.

Rory Cooper, Dan Ding, Asim Smailagic and Aaron Steinfeld are Testbed System Leaders. DD and Aaron are acknowledged rising stars in their respective fields of rehabilitation engineering and intelligent transportation; Aaron is also Co-Director of the Rehabilitation Engineering Research Center on Accessible Public Transportation sponsored by NIDRR.

Dan "DD" Ding and Reid Simmons are *Education Co-Directors*.
They are responsible for creation of university curricula and certificate programs, infusion of QoLT into existing courses and recruitment of faculty and instructors. Beyond their QoLT Center roles, each is central to the educational program of their respective departments (Dr. Simmons is the Associate Director for Education of CMU's Robotics Institute). Mary Goldberg is *Lead Education and Outreach Coordinator;* Shelly Brown, Maria Milleville, and Kim Robinson are *Education and Outreach Coordinators.* Together they execute of QoLT's E&O agenda. In 2010, the Education and Outreach team also took on responsibility for diversity enhancement.

The Scientific Advisory Board (SAB) advises the QoLT Center on strategic directions and the selection and assessment of projects to be pursued and underway. The SAB has ten members representing various science, engineering, and social science disciplines located at universities and agencies throughout the United States (they are listed in the Participant Table at the beginning of this report).

Our Industry/Practitioner Advisory Board (IPAB) is chartered to ensure the QoLT Center incorporates perspectives of the private sector in all program aspects. At the strategic level, it was a strong voice in the restructuring our research program, particularly by calling for a larger part of the research portfolio to explore and understand dynamics of the QoLT market. We have dedicated a substantial portion of membership dues towards such activities (e.g., QoLT Summit, QoLT Knowledge Base, QoLT Foundry). Tactically, it has advised us that activities like the QoLT Summit would be better if more tightly focused.
Our Council of Deans consists of five Deans and three Vice Provosts:

James Garrett (chair)	CMU Carnegie Institute of Technology
Cliff Brubaker	Pitt School of Health and Rehabilitation Sciences
Randal Bryant	CMU School of Computer Science
Jacqueline Dunbar-Jacob	Pitt School of Nursing
Gerald Holder	Pitt School of Engineering
Dave Dzombak	CMU Vice Provost for Sponsored Programs
Mark Redfern	Pitt Vice Provost for Research
Thanassis Rikasis	CMU Vice Provost for Design, Arts and Technology

Our Student Leadership Council consists of the following.

Role	Duties	Incumbent(s)
Co-Chairs	represent the QoLiTy student group and its Student Leadership Council to the Center leadership; manage the SLC	Anca Dragan (CMU) Hervens Jeannis (Pitt)
Social Chair Coordinator	organize events	Liz Cha (CMU)
Industry Liaison	develop means for students to learn from and interact with industry	Esteban Ruiz (Pitt)
Research Co-Chairs	organize the QoLiTy undergraduate research fellowship program, assist with REU & RET programs, advise Center leadership on research initiatives of interest to students	Robert Fisher (CMU) Daniel Osakue (Pitt)
Treasurer	manage the finances of the SLC	Jorge Candiotti (Pitt)

5.1.3 Response to 2013 SLC SWOT Analysis

The most significant weakness cited was Communication ("it's unclear who the new students are; who the staff are," there aren't enough Center updates.") Communications was also cited as a threat ("not enough team meetings"; "lack of status reports"). We took this to heart, making news updates on the Center website a priority. We have encouraged greater student participation in Center events like the QoLT Summit in October and QoLT Town Hall in March. As the SLC noted at the Site Visit, "*the leadership has already taken steps to address the weakness in communication."*

A lesser weakness was the overhead of being a Center ("too many demos" and "too much administrative work"). Leadership has pointed out that this comes with the territory, and in particular that visibility of the Center is valuable. In fact, the SLC itself pointed out that coverage in popular media is a strength. They cited intellectual property policies as a weakness, pointing out that the policies are complicated and that they can't open-source software code. Leadership has held meetings with students to inform them that the Center's IP policy stems from NSF terms and conditions for ERCs and includes giving Members the opportunity to license our IP before offering it to the rest of the world. As another weakness, they pointed out that it is difficult to do randomized controlled trials, mainly due to the challenge of enrolling subjects. That is an ongoing concern for the whole Center and has proven to be a major difficulty despite our access to registries of participants.

As a threat, weakness and opportunity, they citied paucity of jobs in industry (especially for rehabilitation science and technology students) and the small number of robotics companies. Those are beyond our control, but we can and have taken steps to help connect our students with Member and prospective Member organizations. A process is now in place and some of the students are using it. As the SLC noted at the Site Visit. "*the new ecosystem structure of QoLT Consortium provides more opportunities for involvement with industry and practitioners."*

Somewhat contradictory is the cited threat about our applications ("some projects may not have benefits to general public"; "inadequate time to develop-test-commercialize QoLT's") and the cited the breadth of our research as a strength.

Our students view the Center's diversity as a strength and see an opportunity to capitalize on that. Many are involved in a students with disabilities advocacy group at Pitt and participated in its first conference in October.

The most significant threat cited was losing our NSF funding.

5.2 Diversity Effort and Impact

5.2.1 Summary of Diversity Strategic Plan

Our Diversity Plan focuses on four primary tactics: recruitment; educational programming to help propel diverse students forward at critical junctures; effective mentoring; and demonstration of strong leadership examples. A particular focus for QoLT's diversity efforts is to reach out to students with disabilities (SWDs) and help integrate them into the mainstream of STEM education. One example of this is highlighted in our Education and Outreach Team's efforts to document easily adoptable best practices and provide training for faculty to better accommodate SWDs. Another example is our efforts to integrate veterans, especially those with disabilities, back into an academic environment. Of particular concern is priming the education pipeline by outreach to K-12 diverse populations. As in years past, much of our diversity effort in 2013 was aimed at this segment, where it is often acknowledged that early intervention can be particularly beneficial.

A unique feature of our ERC is that its application focus (developing technology to aid older adults and people with disabilities) is a natural attractor for diverse populations of students and researchers. In this respect, the QoLT ERC is very well positioned to support diversity concerns as an active and immersive environment - a hub for stimulating student interest in STEM fields through the authenticity and immediacy of its engaged communities – which are themselves diverse – and with evidence-in-action of the far-reaching impact potential available in QoLT-based careers. Also, the Center endeavors to create productive dialogues and exploratory interaction experiences that engage faculty and students with older adults, PWDs and veterans. The participation of these groups in QoLT programs and research activities enlivens the diversity climate with real and practical perspectives that better support enculturation by generating learning experiences that are more personalized and memorable. Finally, QoLT attempts to education the target communities through communication and diversity outreach efforts in our local communities, promoting our success stories of positively influencing and mobilizing diverse student populations.

5.2.2 Progress Toward Diversity Goals

In 2013, the QoLT ERC continued to maintain its strong participation amongst persons with disabilities (PWDs) and women, while we worked to improve our efforts to attract under-represented racial minorities and Hispanics.

5.3 *Management Effort*

5.3.1 Financial Summary

We suffered financial setbacks in Year 8. As of this writing, the base grant has not yet been renewed, hence Year 8 NSF ERC funding was capped at 67% of $4M. The summary chart below is therefore a snapshot of $3.25M total center-controlled direct costs: $2.0M authorized by NSF, $100k of Member dues, $970k of cost sharing, $180k of REU/RET for the current Year 8, according to major program area.

The general distribution is somewhat different than recent prior years in that the costs of operating the Center (e.g., administration and management) represent a higher percentage. Within the research budget, systems make up 55% of the total as in prior years (recall that most of the agenda in the former *Mobility and Manipulation Thrust* has been taken on by *QoLTbots*). It is uncertain when we will be authorized to spend the remaining third of the Year 8 allocation, of which larger fractions will be allocated to research than in the distribution below.

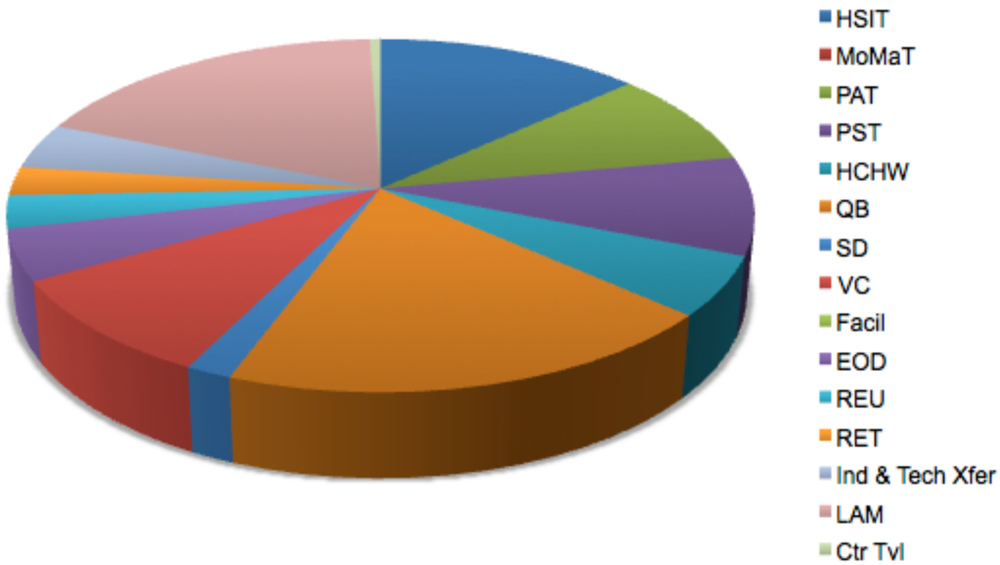


Figure FIN-1. Split of Budgeted Direct Costs for ERC Year 8

In addition to the $2.2M of direct support for research, the Center continues to leverage a substantial portfolio of Associated Projects – an additional $3.5M, which is an increase over the approximately $3.1M we have averaged in recent years. Nearly 90% of that figure is research, and the thrust/systems balance is titled toward the thrusts. This is attributable to the fact that our researchers are committed to the QoLT agenda and are seeking additional resources to pursue it. We anticipate even higher rates of increase for both sponsored and associated projects in the future in the form of new branches of QoLT research budding from results to date. (Our procedure for identifying Associated Projects is to ask our faculty investigators which of their non-ERC projects have goals that are aligned with the QoLT vision and technology roadmap. The PI's provide a "percentage overlap" to reflect that alignment and we compute the value of each associated project by pro-rating its expenses in each ERC financial year by that percentage. Hence the $3.5M in Associated Projects stems from a $22M body of work.)

We have reversed the trajectory of membership dues (doubled with respect to Year 7) and continue to move in the right direction.

5.3.2 Financial Details

Refer to the Tables/Figures 8-11 in the ERC Web table Appendix. A particular financial issue to note is university cost sharing, which is presented in Tables 9, 9a, and 9b.

5.3.3 Business Plan for Post-Graduation Self-Sufficiency

We have been exploring several avenues for the QoLT Center's self-sufficiency beyond NSF's investment. The plan has three funding components: the core, seeding new projects, and on-going research. Securing on-going research funds is essential to maintain buy-in – first and foremost of the faculty, and our parent departments, colleges and universities, the leaders of which are decision-makers regarding internal allocations and external philanthropic fund-raising. We have already received assurance that we will be able to maintain our current office and laboratory space upon graduation.

It is important that core funding be stable. Combinations of the following have been successful.

- *Ongoing direct support from the Provosts.* Most typically, this is in the form of overhead return on research grants.
- *State support.* Both CMU and Pitt receive an annual grant from state government to support health sciences research with strong economic development outcomes. We are generally very well positioned because of QoLT's theme and success in spinning off companies. State funding has been very important for one of CMU's graduated ERCs, the Engineering Design Research Center (which evolved to become the Institute for Complex Engineered Systems, or ICES) in that it allowed ICES to inject seed research funding into the university and maintaining faculty interest in the mission of the center.
- *Thematic centers*. CMU has a number of industry-funded centers with research themes. We realistically envision a center focused on *Safe Driving* funded by automotive companies (GM currently funds two centers at CMU) and perhaps insurers. We also envision one focused on *QoLTbots* anchored by large grants from DARPA, the National Robotics Initiative and the National Additive Manufacturing initiative, with robotics companies (growing steadily in number) as collaborators. CMU's Vice Provost for Art, Design and Technology is leading a university-wide effort called *IDEATE* (for Integrative Design, Arts and Technology) of which QoLT is a central element.
- *Industry.* A stable industrial affiliates program, which is now based on an ecosystem model and more focused on particular sectors: healthcare, long-term care, automotive and robotics. This has been very important for CMU's other graduated ERC, the Digital Storage Systems Center. Over the next few years, CMU will more than double the size of its 136,000 sq. ft. Collaborative Innovation Center that has housed Intel, Apple, Google and Disney corporate research labs.
- We have received and continue to pursue grants to support commercialization. Sources include private foundations, state government and NSF's Accelerating Innovation Research program. Highmark's new strategic research alliance with CMU includes support for the Center for Innovation and Entrepreneurship, the university-wide activity that has adopted the QoLT Foundry's best practices.

We have identified several viable targets for major research grants – and steps that we need to take in the next two years in order to position the QoLT Center for such funding:

- Key opportunities from the National Institutes of Health (NIH) are program project (P01) grants that are akin to centers in that they support a small number of thematically linked projects and "cores" (e.g., administration, data management with aggregate budgets on the order of $1.5M per year in direct costs).
- NIH's principal grant mechanism is the R01, which can be a single investigator project or a medium sized collaboration, e.g., a Biomedical Research Partnership. R01s typically provide $250-500k per year for 2-4 years. Well-matched targets to our present core research are the National Institute on Aging, the National Institute on Biomedical Imaging and Bioengineering, National Institute of Nursing Research and the Office of Behavioral and Social Science Research. Our research in technologies to remedy autism, blindness and stroke, will open additional

opportunities with National Institute of Child Health and Human Development, the National Eye Institute and National Institute of Neurological Disorders and Stroke, respectively.

- A new multi-year/multi-Institute theme that emerged from a workshop at which two QoLT members presented is “Technologies for Healthy Independent Living.” Even in its exploratory (R21) research grants, NIH tends to favor research that is driven by medical and/or clinical hypotheses over research that is technologically driven. Further, grant applications in which the authors present preliminary data in support of their hypotheses have a higher success rate than those that do not. One element of our strategy, therefore, is to generate such data in the next two years through pre-clinical testing of QoLT prototypes (near-term candidates include *Health Kiosk, Seating Coach* and *Stroke Therapy Coach*). Several QoLT faculty members, particularly at Pitt, are long-time recipients of NIH funding.
- The Department of Veterans Affairs (VA) principally funds intramural research through mechanisms ranging from small single-investigator grants to centers, e.g., the Center of Excellence on Wheelchairs and associated Rehabilitation Engineering (WaRE) that is headed by QoLT Center Co-Director, Rory Cooper. Many other QoLT faculty members also have VA appointments and are eligible for intramural grants from the VA. Our “in” with the VA coupled with its dedication to serving veterans with disabilities (with particular emphasis on survivors of the two ongoing wars) positions QoLT to receive VA funding. In addition, the VA now has extramural programs.
- NSF itself has a range of funding mechanisms for investigator-initiated research. Key target NSF thematic programs include “Smart Health & Well-being” (within the Division of Information and Intelligent Systems Directorate) and “General & Age Related Disabilities Engineering” (within the Engineering Directorate). An additional important NSF funding mechanism well-suited to QoLT research is “Expeditions in Computing” which is currently funding one of our associated projects in autism research and a CMU project in social robotics. Many QoLT faculty have long-standing track records with NSF.
- For several decades, DoD has supported QoLT-related enabling technology research in perception, human-system interaction and robotics. More recently it is funding efforts to provide better care to Wounded Warriors, particularly those who have survived traumatic brain injuries. DARPA tends to support more integrative research and has also shown interest in technology for Wounded Warriors through a $100M project to create the world’s most sophisticated upper extremity prosthetic, the DARPA Arm.

The interdisciplinary make-up of our personnel affords us deep aggregate knowledge of virtually every potential sponsor. To capitalize on that, our next annual retreat, early in Year 9, will focus on 1) assessing how well our research and technology portfolio is positioned relative to all of those sources and 2) creating plans to improve our position in the upcoming years.

5.4 Management Processes

5.4.1 Program Assessments and Funding Decisions

The strategic planning process that we now use started in late 2009 with a top down directive from Director Takeo Kanade that the research projects should be categorized along four dimensions of synergy:

- Technology Trajectory – were the capabilities of the technology increasing (upward) or level
- Reuse/integration – could the technology be used in other projects, was the technology being integrated with other technologies to produce a more capable system
- Collaboration – was there collaboration with other projects and between organizations
- External engagement – was there engagement with partners and the public beyond the ERC

Near the end of each year, research cluster (thrusts or testbed system leaders grade current projects with respect to Impact (Scientific, Commercial, Public, Educational), Relevance/Synergy (technical/scientific, interdisciplinary, and external), and Execution Quality. In addition, they craft brief proposals for the next year's research portfolio. All advisory boards (SAB, IPAB, EAB) are included in the project review and selection process. We have established a regular process by which all of the projects are regularly reviewed jointly by both IPAB and SAB members. This review is implemented primarily through an on-line meeting with criteria addressed uniformly for each current and future project. Each project is assigned specific members from each advisory board to examine it in depth. We obtain input from them on the primary NSF criteria of intellectual merit and broader impact for each, including scientific, commercial or educational impact and issues of outreach and execution quality.

The Director makes the final project selection and budget allocations.

5.4.2 Mentoring of Postdoctoral Researchers

All QoLT postdocs are mentored by senior faculty. Currently there is one postdoc at Pitt and one at our LSAMP partner Florida State University. Specifics include

- training in grant writing grants and papers;
- coaching in presentation preparation and delivery;
- counseling on research management; and
- counseling on how to work effectively with graduate and undergraduate students.

Postdocs in health sciences at Pitt also have a second clinical mentor who provides basic clinical understanding and coaching in the IRB process and human-subjects-research.

Postdoc mentoring is discussed further in section 3.7.

5.5 Resources and University Commitment

5.5.1 Facilities

In September 2009, the QoLT Center moved into new spaces. At Carnegie Mellon, we took occupancy of prime location within the School of Computer Science complex. Headquarters staff, several faculty and students are now in a contiguous 5000 sq. ft. space on the 4th floor of Newell-Simon Hall. The location is ideal logistically, as it is adjacent to both the Robotics Institute and Human-Computer Interaction Institute, the home departments of 70% of core and associated faculty and students at Carnegie Mellon. From this location, one can walk to all of the laboratories used by Carnegie Mellon researchers within three minutes and without going outside. The location is also highly visible, being at a heavily trafficked gateway to the campus. QoLT personnel at the University of Pittsburgh Rehabilitation Science and Technology Department moved into new spaces: "Bakery Square," a newly renovated development in Pittsburgh's East End, approximately two miles from the CMU & Pitt campuses). In 2011, Pitt/VA Human Engineering Research Laboratories will also move to Bakery Square.

The new spaces in Newell-Simon include several laboratories, the largest of which has a glass front onto one of the busiest corridors on campus. This "Everyday Living Laboratory" will thus double as a showcase. Other QoLT Center research is embedded in lab areas of the main parent academic departments. That keeps faculty and students connected to their home departments and peers. Both the last site visit report and SLC SWOT analyses pointed out that centralized laboratories might "distract [QoLT personnel] from their fundamental base[s]." We are beginning to take advantage of each others' facilities, for example, in having a Pitt rapid prototyping lab create multiple copies of the CMU eWatch device.

Laboratories used by the QoLT Center (and their faculty managers) include

- Activities of Daily Living (Cooper, Pitt)
- Assistive Technology Evaluation Cooper, Pitt)
- Design & Prototyping (Cooper, Pitt)
- Electronics (Cooper, Pitt)
- Humanoids (Atkeson, CMU)
- Informedia/CareMedia (Wactlar, CMU)
- Interactive Computer Systems (Smailagic, CMU)
- Motion Capture (Hodgins, CMU)
- "MISC" (Hebert, CMU)
- NavLab (Hebert, CMU)
- Physiology (Ding, Pitt)
- Robotics (Cooper, Pitt)
- User Studies (Siewiorek, CMU)
- Vision and Autonomous Systems (Kanade, CMU)

At CMU, the QoLT Center has access to other facilities of the Human-Computer Interaction Institute, Institute for Complex Engineered Systems and Robotics Institute. Those include two 5000 sq ft high bays and 5000 sq ft of dedicated shop spaces. RI currently has over 30 distinct laboratories with a total footprint of over 20000 sq ft, and over 24000 of office space housing over 250 people. Many configured for interdisciplinary research, while others are dedicated to investigation in a particular technology. In aggregate they possess a full complement of commercial prototyping and testing equipment for all aspects of intelligent systems research. Most of these facilities are in Newell-Simon Hall; the others are in two adjacent buildings. The parent School of Computer Science maintains one of academia's best computational infrastructures.

At Pitt, QoLT accesses the Department of Rehabilitation Science and Technology (RST), now in Bakery Square, and the UPMC Center for Assistive Technology (CAT) in Forbes Tower, which is three-quarters of a mile from Newell-Simon Hall. RST has approximately 20,000 sq ft of teaching, laboratory, clinical, and faculty/staff office space. RST is headquarters of two NIDRR Rehabilitation Engineering Research Centers (Wheelchair Transportation Safety and Telerehabilitation). RST has a complete machine shop for the fabrication of assistive devices, student projects, and research equipment. The CAT provides clinical training opportunities for RST and Bioengineering students as well as students from other rehabilitation disciplines. It has computer access equipment, augmentative communication equipment, a modified van for driver assessment, and a plethora of wheelchairs and seating systems, environmental control units, and other assistive devices.

QoLT also uses the Pitt/VA Human Engineering Research Laboratories (HERL) that is located about four miles away. HERL has nearly 20000 sq ft of research space featuring exercise and training equipment for people with lower extremity paralysis, a full complement of ANSI-RESNA/ISO testing equipment, and complete mechanical and electronics fabrication, assembly and testing equipment including the most sophisticated rapid-prototyping and fabrication facilities of any assistive device research center in the world. In 2011,the Pitt/VA HERL is moving into newly renovated space (28,000 sq ft) contiguous with RST in Bakery Square Complex.

5.5.2 University Commitment

As neighbors and the two largest universities in Pittsburgh, Carnegie Mellon and the University of Pittsburgh have a long-standing collaborative relationship. The QoLT Center is one of the most recent of major joint activity. Others include the Pittsburgh Supercomputing Center, the Pittsburgh Mind-Body Center, the Center for the Neural Basis of Cognition, MD/PhD program and PhD program in computational biology.

Our academic environment is highly conducive toward interdisciplinary research. QoLT students can take classes in either core university, by virtue of an inter-institutional mechanism for cross-registration between Carnegie Mellon and the University of Pittsburgh. Under Pittsburgh Council on Higher Education guidelines, students may cross register for one course per term. Recognizing that collaborative activity, especially interdisciplinary collaborative activity, results in greater impact, both CMU and Pitt encourage it at all faculty levels and take this into consideration in promotion decisions.