ROBOTIC ASSISTIVE TECHNOLOGY FOR COMMUNITY-RESIDING OLDER ADULTS AND PERSONS WITH DISABILITIES: AN INTER-INSTITUTIONAL INITIATIVE FOR STUDENTS IN THE HEALTH AND TECHNOLOGY FIELDS

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Abstract *¾ An educational initiative spawned from the Nursebot Project has brought together students in health care and technology from two universities to design, develop, and evaluate mobile robotic applications for older adults and persons with disabilities. Laboratory activities, field trips, and multidisciplinary group projects were used to complement didactic content regarding frailty, disability, and robotic assistive technology in our first offering of an inter-institutional course and seminar series. This paper describes the components of this educational initiative that included focus group and brainstorming sessions involving roboticists, older adults and persons with disabilities, as well as personnel who work with the frail or disabled. Also described are the projects undertaken by two groups of students in developing a robotic walker, engaging one another in simulation exercises, and extending field testing of Pearl, the prototype robot from the Nursebot Project.*

Index Terms ¾ Assistive technology, disability, frail elderly, robotics

OVERVIEW AND GOALS

Multidisciplinary teamwork is essential to the development of assistive technology that sustains the independence of frail older adults and persons with disabilities living in the community. Current educational venues separate the teaching of technology development from the end users of technological innovations. Typically, students in the robotics and information technology fields know very little about the operational needs and opportunities in the arenas of elderly health care and disability. Similarly, students in the health disciplines know very little about recent technological advances that could lead to new ways of providing or augmenting health services to community-residing individuals and their families. This disconnect has become a major obstacle to developing new solutions for the segments of the population that currently need them the most: frail and disabled adults.

We have developed an inter-institutional educational initiative that builds upon the existing synergies of the Nursebot Project, a research collaboration involving the University of Pittsburgh, Carnegie Mellon University, and the University of Michigan for the purpose of developing a personal robotic assistant for frail older adults with mild cognitive impairment. Collaborators envision a robot that will "embody several functions tailored to an individual's evolving needs. Such functions include issuing reminders to eat, drink fluids, and take medication; monitoring health status and adherence to the prescribed treatment regimen; enhancing communication with family, friends, and health care providers; providing physical assistance with ambulation and other activities of daily living; and promoting personal safety [1]."

The three overarching goals that drive this educational initiative are as follows:

- To increase the depth and breadth of student experience in designing, developing, and evaluating robotic applications that enhance independent living among community-residing, frail older adults and persons with disabilities.
- To enlarge the cadre of students involved in multidisciplinary problem solving that harnesses knowledge of aging and disability with technological advances in information and computer science to address real-world challenges facing vulnerable members of our aging community.
- To enable greater complexity in the projects that students undertake in a graduate-level course offered to University of Pittsburgh and Carnegie Mellon University students in the health science and technology fields.

COURSE AND STUDENT PROFILE

The initiative involved a course that was cross-listed as "NUR 2840: Robotic Applications in Clinical Practice" at the University of Pittsburgh School of Nursing and "16/899D: Robotic Applications to Nursing and Health Care" at Carnegie Mellon University School of Computer Science. The first two authors co-taught the course, drawing upon their expertise in nursing and robotics, respectively. Class met weekly, alternating among several locations at

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both universities, with students self-scheduling smaller group meetings once or twice each week to work on their group projects at convenient locations.

The eight students in the course represented many disciplines and varied considerably in their work experience:

- Two students were registered nurses enrolled in the University of Pittsburgh masters program in nursing informatics. One had worked for many years in the home health nursing arena and held two bachelor's degrees, one in nursing and one in speech pathology.
- The other nursing student had several years' experience in critical care and emergency nursing, and was currently employed as a flight nurse.
- Two students were physicians completing fellowships in geriatric medicine at the University of Pittsburgh Medical Center (UPMC). One was also completing a fellowship with the Center for Biomedical Informatics at UPMC.
- Three students were in their first year of the masters program in robotics at Carnegie Mellon University. Their undergraduate work had been in mechanical engineering, electrical engineering, and computer science, respectively, and they had worked in industry briefly, if at all, prior to enrolling in graduate study.
- One student was an undergraduate, completing his final semester of the senior year as a computer science major. He had no prior professional experience.

Class Activities

During class sessions, students were regularly encouraged to interact with both faculty and each other. Topics covered included description of the history, funding (National Science Foundation), and organization of the Nursebot Project. Students heard how the project originated among clinicians and researchers interested in developing a personal robotic assistive device that could help compensate for the cognitive, functional, and behavioral limitations associated with aging and disability. The robot would be an adjunct to, rather than a replacement for, assistance provided by family members and lay and professional health care providers. Students also learned that the corps of investigators involved in the Nursebot Project hailed from such diverse disciplines as nursing, occupational therapy, robotics and computer science, industrial design, and psychology.

Students were apprised of the five collaborating teams that work concurrently on several aspects of the project:

- Developing reminding software that will accommodate changing daily routines, including diet and medicine
- Refining sensor technology to enable the robot to detect changes in biometric parameters such as stride, vocalization, and posture
- Constructing prototype robots and integrating navigational and communication technology
- Examining design features with respect to human-robot interaction
- Conducting clinical studies with older adults to describe their cognitive, behavioral, and functional abilities and field test performance of the robot.

Faculty also discussed the components of proposal development and procedures in place at both institutions to ensure the protection of human subjects involved with research. This content was covered in greater depth when some of the activities proposed for a group project necessitated obtaining approval of modifications in the existing protocol by each of the participating universities' respective Institutional Review Boards.

Issues of frailty and disability were described, including cognitive, behavioral, and functional limitations associated with aging, disease, and disability. The evidence base in support of selected health promotion and disease prevention measures (e.g., blood pressure and cancer screening, counseling aimed at behavioral change, efficacy of adult immunizations, prophylactic use of medications such as aspirin and hormone replacement therapy) used to reduce morbidity and mortality among older adults and persons with disabilities living in the community was also explored. In addition, students learned about the network of health and social services available to help individuals and families cope with these issues at home.

Students were asked to reflect on the heterogeneity of living arrangements and environmental conditions of frail older adults and persons with disabilities. Likewise, faculty focused attention on the contribution that varying emotional, financial, and material resources may have on health and well-being. Further, emphasis was placed on the respect for privacy, property, and personal safety that should be accorded persons receiving in-home services by those who deliver them.

One class was devoted to a brainstorming session that included guests invited because of their personal or professional experience with frailty and disability. Participants in the brainstorming session included:

- Faculty and students
- A staff member dealing with a parent's progressive deterioration due to Alzheimer's disease
- Three older adults (80+ years) living independently in a nearby, inner-city community
- An ombudsman and care manager who coordinated and provided in-home services to rural, homebound elders
- A nurse who administered a special program for parents with disabilities
- Four members of the Nursebot Project focused on human-robot interaction and clinical studies

Following a brief presentation explaining the background and goals of the Nursebot Project, participants were asked to share their views about the utility and acceptability of developing a personal robotic assistant for frail older adults, particularly those residing in the community with mild cognitive impairment.

Health care and social service providers with experience visiting older adults in the community pointed out that significant numbers of these individuals live alone either by choice or due to lack of proximity to willing family and friends. They indicated enthusiastic support for a robotic assistant to help the elderly. Those who were elderly or disabled themselves voiced their support for the endeavor, but cautioned against developing a robot that would diminish family involvement or enable users to become unnecessarily passive as a result of the robot assuming responsibility for functions that would otherwise be performed independently. There was consensus that the Nursebot Project is an ambitious, timely, and worthwhile undertaking in keeping with other technological advances directed at improving life quality.

Seminar Series

Embedded in the course was a seminar series open to students and faculty at both universities. Dr. Yoky Matsuoka from the Robotics Institute at Carnegie Mellon University spoke about the state of the art of robotics in general and robotic applications in health care in particular. Dr. William Mann from the Rehabilitation Engineering Research Center on Aging at the University of Florida shared his work, which has documented older adults' use of "low tech" assistive technology (e.g., adaptive devices to aid in dressing, bathing, and meal preparation) and how they improve functionally and emotionally when equipped with all of the assistive devices warranted by their condition and environment. He also described design work currently underway on a handheld device with features for controlling selected telecommunications devices, household appliances, and home security functions.

Dr. Latanya Sweeney from Carnegie Mellon University alerted students to the potential threats to privacy that must be anticipated and guarded against when personal data, such as biometric data gathered by a robot, are aggregated, even with identifiers removed. She illustrated the inadequacy of data management conventions frequently used to protect anonymity in datasets publicly disseminated by governmental agencies. She then shared the programming approach she has developed to enhance data privacy, including her efforts to affect public policy in this arena.

Three panelists participated in our final seminar. Dr. Susan Leight of the University of Pittsburgh School of Nursing described working with engineering colleagues and a privately-held company to develop, license, and patent a breast model designed to measure and provide visual feedback regarding a user's proficiency (depth of palpation and percentage of surface area palpated) performing breast examination to screen for breast cancer and other breast anomalies. Mr. Reed McManigle, a Technology Licensing Specialist with the University of Pittsburgh Office of Technology Management, explained the processes involved in filing invention disclosures and patent applications. Mr. Randy Eager, Project Manager for the Innovation Transfer Center at Carnegie Mellon University, described how inventors develop a robust business plan and form successful spin-off companies.

Interface with the Nursebot Project

Throughout the semester, students engaged in a variety of activities with Pearl, depicted in Figure 1, one of two prototype robots created for the Nursebot Project. Pearl "is equipped with a differential drive system, two on-board Pentium PCs, wireless Ethernet, two SICK laser range finders, sonar sensors, microphones for speech recognition, speakers for speech synthesis, touch- sensitive graphical displays, actuated head units, and stereo camera systems…On the software side, Pearl features off- the-shelf autonomous mobile robotic navigation systems, speech recognition and speech synthesis software, fast image capture and compression software for online video streaming, and face detection and tracking software." Pearl also has software modules that assist with reminding tasks and navigation [2].

FIGURE 1.
PEARL, THE CURRENT NURSEBOT PROTOTYPE.

Laboratory Activities

On several occasions, the entire class visited the Robot Learning Laboratory at Carnegie Mellon University where Pearl resides. During the first visit, Pearl demonstrated her neck, head, and voice capabilities and described her hardware features, using a self-demonstration program delivered through her touchscreen interface. Preliminary discussion between faculty and students ensued about forming multidisciplinary teams to work on one of two projects: developing a haptic device with a hardware interface for a robotic walker or field testing Pearl. with older adults. Though students would designate one of the projects as their primary focus, they would need to remain familiar with the other and follow its progress. In addition, all students would need to learn how to operate Pearl. To facilitate communication, a student agreed to add a course web page to the existing Nursebot website on which class notes, papers, and announcements would be posted.

The students returned to the lab a few days later and received a more detailed explanation of Pearl's hardware and software design from the robotics doctoral students and the staff research technician who work there. The software that enables Pearl to map an area and then navigate autonomously within it was also demonstrated, and students had an opportunity to work briefly with Pearl's navigational and communication software.

A third lab visit by the students followed again within days, at which time they received printed instructions for operating Pearl and spent two hours being shown by one of the doctoral students how to have Pearl create a new map, navigate within it, and generate speech. Additional visits were made to the lab by students, individually or in small groups, as worked progressed on their group projects and they needed to more finely hone their operational skills, seek clarification of Pearl's capabilities, or obtain guidance in the construction of the robotic walker.

Field Trips

A number of field trips further exposed students to the concerns of older adults, the perceptions of providers of in-home services for the frail and disabled, and local resources for assistive technology. All students without recent home visit experience, which included all but one of the nurses and one of the physicians, were required to spend at least half a day making home visits with nurses in the UPMC Living at Home Program. This program offers periodic home visits by nurses, pharmacists, social workers, and home health aides to community-residing, frail older adults in selected Pittsburgh communities.

Once the students knew how to operate Pearl, they accompanied the faculty, Pearl, and an engineer from the Robot Learning Laboratory to Longwood at Oakmont, the retirement community where field testing for the Nursebot Project is conducted.

Longwood at Oakmont has over 250 residents who live in one of three settings:

- Independent living: homes and apartments with access to meals served in a common dining room
- Assisted living: private rooms with staff who provide assistance with personal care, meals, ambulation, medications, and treatments
- Health center: private rooms with staff who provide skilled nursing and restorative care.

Students conducted focus group sessions with three panels from Longwood, each with 5-8 participants: professional staff, nonprofessional staff, and residents from both independent and assisted living. The students opened each focus group session with Pearl's self-demonstration program, then directed open-ended questions to participants regarding whether a robot functioning as Pearl's developers had envisioned could be useful and acceptable to older adults.

All focus groups affirmed the belief that such a robot had the potential to be helpful, if eventually capable of performing as conceptualized. However, they expressed concern that persons with cognitive impairment could find interaction with the robot confusing, even distressing, to use. They also expressed concern over the poor sound quality of her voice and her limited vocabulary.

The nonprofessional group, consisting of a dietary worker, a housekeeping aide, a physical therapy aide, a nursing assistant, and a practical nurse, denied concern that Pearl would replace what they do. Instead they welcomed the prospect of working alongside a robotic device that could assume mundane, repetitive tasks such as giving frequent reminders, helping with walking, and providing social stimulation, thus enabling them to increase the quality and quantity of time spent in activities requiring their intense personal involvement with residents.

Students also had the opportunity to tour both the Center for Assistive Technology at the University of Pittsburgh and the Rehabilitation Engineering Research Center at the Heinz Unit of the Pittsburgh VA Healthcare System. At both centers research and development pertaining to wheelchair assistive technology were the predominant foci of activity. At the latter location, students in the walker group were able to see and operate a prototype walker with obstacle avoidance capabilities that would ultimately rely on sensors embedded in the environment to localize its position and enable navigation. Students in the robot walker group undertook one final trip to the Three Rivers Center for Independent Living to obtain used standard walkers in a variety of sizes and styles for their group project.

Robotic Walker Group

Hands-on learning figured prominently into the design and execution of this educational initiative. Students indicated their preference for one of the two projects on which they would work in multidisciplinary groups for the duration of the semester, and each group included a mix of health and technology students. Though students would primarily focus on their own group project, they would remain apprised of progress on the other group's project through periodic updates at class. Each group made of formal in-class presentation describing their plan and results at the fifth and final class meeting, respectively.

The group that opted to work on the robot walker consisted of the three robotics students and one of the physicians in geriatric medicine. At the outset, faculty informed them that elements of their design would likely be integrated into a future Nursebot prototype. The group set out to build a self-powered walker that would provide stable support for ambulation, respond to user control unless obstacles were encountered, and have an intuitive interface. They also sought to develop software that would enable detection of changes in an individual's pattern of activity with the walker that might signal improvement or deterioration in health.status [3].

Each of the aforementioned objectives was achieved, as will be described momentarily. However, members of the group scaled back their initial plan to include among the walker's capabilities the capacity to provide assistance in getting people from a sitting to a standing position, and vice versa. Based upon input from clinicians in class and at Longwood about safe transfer techniques and as a result of their observation of older adults walking and receiving assistance with transfers, the group became convinced that the challenge far exceeded their resources. They also abandoned early expectations of incorporating the navigational technology used by Pearl into the robotic walker, as such work required more time than was available within the time constraints imposed by the semester. Instead, the three robotics students resolved to integrate the navigational software into the robot walker as part of a future independent study.

The students started their project by observing the three basic forces exerted when people operate unpowered standard and roller walkers: downward (user load), transnational (pushing forward and pulling backward), and torque (turning corners) [3]. They then constructed the haptic controller illustrated in Figure 2 that consisted of a prismatic gripper on the end of a handlebar made of PVC pipe, with end caps that restricted motion and were embedded with force-sensing resistors (FSR) that could determine the user's motion.

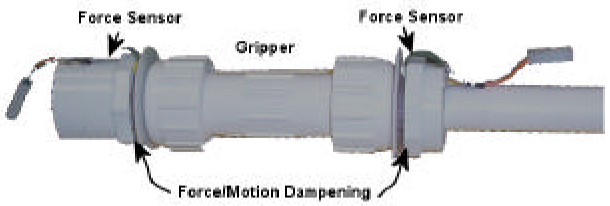

FIGURE 2.
HAPTIC DEVICE DESIGN.

Mounting the haptic controller on an unpowered roller walker, the students established the robustness of the FSR design in capturing data while moving the walker over a variety of surfaces. The students developed a software control system that enabled data from the FSRs to direct actuators in an existing mobile robotic platform, the XR4000, to move in the user's intended walking direction. The XR4000 was equipped with a laser range finder and ringed at the top and bottom with sonar sensors for obstacle detection and avoidance. It also had a holonomic drive system, which gave it a tight turning radius. Shaped like a large garbage can, the robot platform weighed approximately 150 kg, including its batteries, and provided a very stable base for forward and rotational movement, though no backward movement [4].

By semester's end, this group had developed the working robot walker illustrated in Figure 3 that integrated two haptic devices, a control system, and a laptop for graphical interface with the XR4000. They had also conducted preliminary user testing with five able-bodied, young adults between 20 and 30 years of age. These respondents indicated feeling safe operating the robot walker, despite its large size, yet required brief instruction to operate the haptic devices and faulted its maneuverability because of its inability to move in reverse.

FIGURE 3.
ROBOTIC WALKER AS CONFIGURED BY SEMESTER END.

Field Testing Group

The field testing group consisted of the second geriatric fellow, both nurses in informatics, and the undergraduate computer science student. They were first asked by faculty to review the protocol that had already received Institutional Review Board (IRB) approval at all three universities and make suggestions for modifications that would improve the methodology.

The protocol as approved specified that residents of Longwood at Oakmont who were cognitively intact, lived independently, and could walk with or without an assistive device such as a cane or walker would be asked to participate in two studies. The first study was designed to assess older adults' gait speed and social interaction while walking, and to use the data obtained to improve Pearl's ability to keep pace with older adults and engage in acceptable dialogue. Individuals who took part in this study would be asked to walk for one and six minutes, respectively, with the one-minute walk used to determine the distance covered in that interval and the six-minute walk yielding data regarding natural dialogue that occurs when older adults walk accompanied by another person. The second study involved videotaping older adults walking with Pearl for up to six minutes for the purpose of observing their response to her movements and speech. Age was to have been the only demographic variable ascertained.

The students suggested several modifications to the protocol, such as including residents from assisted living in the sample, since Pearl's utility would ultimately aid persons with increasing dependency. They also recommended that additional demographic information be collected (e.g., race, ethnicity, marital status) and that measures of cognitive function, functional status, and use of technology be added to both studies.

Further, the students suggested adding a second six-minute walk to the second study, so that Pearl's communication could be varied to permit evaluation of older adults' responses to one of four communication approaches while accompanying an older adult on a walk: silence, speech only, speech combined with touchscreen display of the spoken words, or speech combined with touchscreen display and invitation to respond via options displayed on the touchscreen.

Students helped prepare and submit the modifications to the respective IRBs. But since final approval was not forthcoming until the very end of the semester, the students assisted faculty in consenting participants and collecting data for the first study as originally conceived.

In the meantime, they decided to engage themselves and the members of the robot walker group in a simulation exercise to assess what it would be like to walk with Pearl while experiencing limited mobility or sensory impairment. Simulating joint restriction with a knee brace, low vision using goggles that mimicked visual changes resulting from cataracts, hemianopsia, and macular degeneration, and hearing impairment imposed by earplugs and muffs, the students gathered anecdotal data regarding the experience.

They particularly noted how these impairments affected their ability to detect Pearl's location when she moved ahead or behind them as they walked, to understand her speech, and to interact with her touchscreen. Students reported that impaired mobility made it more difficult to keep up when Pearl walked ahead, and sensory impairment posed hazards when they were less able to hear or see Pearl when she followed them. Since obstacle avoidance precluded Pearl from moving alongside a person, the students suggested that handle or tether be added that would enable people to approximate her position relative to their own.

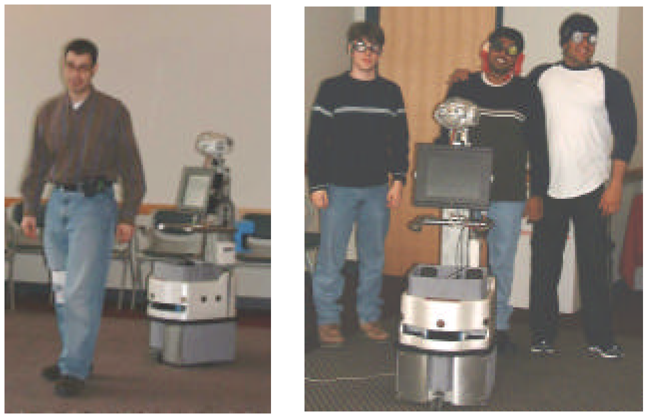

FIGURE 4.
STUDENTS SIMULATING DISABILITY IN "DRY RUN."

CONCLUSION

Our experience reveals that exposing students in the health disciplines to contemporary developments in robotics helps them acquire a deeper understanding of the challenges faced by technology, as well as the skills needed for innovative solutions to practical problems. Similarly, exposing robotics students to the health concerns and needs of the frail or disabled deepens their understanding of the problem domain, enabling them to focus their creative efforts toward innovations that really make a difference.

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