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Automation as Caregiver: A Survey Of Issues and Technologies

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Abstract

In the United States, the number of people over 65 will double between now and 2030 to 69.4 million. Providing care for this increasing population becomes increasingly difficult as the cognitive and physical health of elders deteriorates. This survey article describes some of the factors that contribute to the institutionalization of elders, and then presents some of the work done towards providing technological support for this vulnerable community.

Introduction

A person's control of his/her personal space is an important component of human dignity and the quality of life [53].

An unprecedented boom in the elderly population will hit all industrialized nations and many other countries over the next 30 years. The number of people in the U.S. over the age of 65 will double from 34.7 million now to 69.4 million by 2030 [4]. Historically, 43% of people over the age of 65 enter a nursing home for at least one year, yet a Health Care Financing Administration survey found that 30% of the elderly would "rather die" than do so [3].

As the cognitive and physical health of elders begins to deteriorate, they require increasing assistance from caregivers. The strain on families and individuals is enormous–numerous studies have shown that caregiver burden is a major factor in nursing home placement [14; 130; 74]. Informal caregivers use prescription drugs for depression, anxiety, and insomnia at a rate of two to three times that of the average population [59].

Stone [155] describes the current and future state of caregiving for the elderly, both from a formal and an informal caregivng prespective. Dawson *et al* [44], Macken [104] and Manton [111] provide demographic studies of elders broken out by limitations in Activities of Daily Life (ADL)[1] and Instrumental ADLs (IADLs)[2].

In many cases, governments, social service organizations and even individuals and families are turning to technological solutions to aid in care giving for this elderly population. While much of this technology continues to occupy traditional assistive roles such as aiding in walking, door opening, and communication, increasingly advanced technological solutions are being proposed to aid in monitoring, diagnosis, situation awareness, decision aiding and the direct automation of tasks for either the elderly themselves or for their caregivers. From the human-factors perspective, failure to consider the needs, desires, capabilities and limitations of users will lead to unsatisfactory technological solutions at best, and disasters at worst. Czaja [39] describes existing technology that aids older adults and areas where new technology would be helpful, while also suggesting many ideas about what an assistive system could provide.

This survey article describes some of the factors that contribute to the institutionalization of elders, and then presents some of the work done towards providing technological support for this vulnerable community.

Factors

Top factors contributing to the institutionalization of elders can be described within the high-level categories of burden on informal caregivers, impairment on ADLs or IADLs, and cognitive dysfunction. Some of the top factors within these categories include medical monitoring, medication management, mobility (including falls), toileting, eating, dementia, wandering, safety (including environment monitoring and home security), isolation, and transportation.

Czaja [37] is a very thorough analysis of issues in daily life with the home, work, and driving environments as well as problems with aging and communications, safety and leisure. Clark [31] also goes into many of these issues.

[1]ADLs focus on assessing ability to perform basic self-care activities, and include eating, dressing, bathing, toileting, transferring in and out of bed/chair and walking.

[2]IADLs assess the need for services, and include preparing meals, shopping for personal items, medication management, managing money, using the telephone, laundry doing housework, and transportation ability.

A good starting point for understanding these factors is to look at major reasons for admitting someone to a nursing home. The Family Caregiver Alliance [8] is a very informative study detailing some of the major decision issues between the care receiver and the informal care giver. Weiman [177] presents a short, hyperlinked list of events that usually precipitate admission, conditions common in nursing home populations, and pointers to more statistics. The Women & Aging Letter [128] presents statistics and tradeoffs to consider when moving to a nursing home.

Tibbits [161] presents statistics, intrinsic (client) and extrinsic (environment) risk factors, risk reduction and injury reduction techniques. Many studies have measured nursing home entrants and predictors of nursing home placement, e.g. [18; 32; 82; 132]. Shugarman [146] examined the similarities and differences between nursing home populations and in-home care populations.

Lawton [96] discusses capabilities of older adults on different tasks around the house. TriData Corporation [163] created a report for the U.S. Fire Administration outlining fire safety issues for the elderly. Mann [109] examines environmental problems in the homes of elderly persons with disabilities and identifies specific problems. Lipsitz [101] describes one patient's case but presents a comprehensive listing of all physiological and medical factors affecting falls. Lipsitz also lists tests to be performed to idenify specific phsio-medical causes. There is some discussion of prevention techniques as well.

Schoenfelder [142] dissusses many of the current risk and injury assessment tools used by nurses, along with a brief review of risk factors for the elderly. Some of these tools include the Minnesota screening tool used by nursing homes to assess residents and determine care needs [120], Functional Assessment Questionnaire [134], the Mini-mental State [56], and the Physical Self Maintenance Scale (PSMS) and the Instrumental Activities of Daily Living (IADL) [95]. The AARP has a short tool that describes what you need to do in order to carry out an assessment of your older parent and his/her ability to live independently [10].

Smart Home Technologies

By "Smart Home Technologies," we mean systems that have sensors and actuators that monitor the occupants, communicate with each other, and intelligently support the occupants in their daily activities. For elders, tasks can range in complexity from reminders to take medication to monitoring the general deterioration in functional capability.

Warren *et al* [175] describe their vision for elder home-care technology. They provide detailed descriptions of concepts for care delivery, sensors, smart devices and interactions among smart devices, information frameworks, information security, and patient-device interaction. Allen [7] discusses capabilities the technology should have to provide and and how that technology could be implemented. Cooper and Keating [34] present a general overview of home systems and their role in rehabilitation. Dewsbury and Edge [46; 52] discuss smart home technology and its potential care for the elderly and disabled; it also has a brief discussion on the social impact of smart homes. In this proceedings, Miller *et al* [117] discuss the obligations of intelligent systems to elders.

Targeted Assistance

Numerous projects have targeted specific problems within the more general umbrella of supporting elders in their home. This section will touch only on a very small subset of projects, in part because the area is so broad, and in part because the line distinguishing "targeted assistance" from "broad-based assistance" is not firm.

Furlong [58] addressed the issue of elder isolation, discussing the success of SeniorNet, an e-community network. SeniorNet offers a member directory, email, and bulletin board. This article shows how computers can be used to increase social interaction.

An electronic community was also the subject of Gallienne *et al* [60], but in this case addressing the subject of caregiver coordination. The study examines the use of a computer network for caregivers of Alzheimer's patients; caregivers were able to share stories, ideas and, most beneficially, emotions with one another. The paper highlights how computers can be used to alleviate some of the emotional burden from caregiving.

Medication reminder systems have been shown to improve medication compliance [57]; a wide variety of systems have been built to provide this service, e.g. [26; 51; 114; 115].

Doughty [49] provides an excellent review of fall sensing technology for older adults. The article looks at different sensors, inferencing logic needed for good sensors, risk analysis, and other fall issues.

Numerous companies have developed small wearable sensors that measure vital signs, detect falls, and provide location tracking, as well as a 'panic button' feature, e.g. [48; 156; 100]. Noury *et al* [131] describe a smart fall sensor that they designed used for more general activity monitoring tasks. Medical monitoring at home is becoming a noticable trend [141].

Several efforts have also been undertaken to design "centralized controllers" for smart homes [42; 108; 110]; these systems do not monitor the elder in any way. Elders prefer remote devices with larger buttons, fewer functions and higher contrast. Custodian [46; 54] is a software tool designed to make it easier for non-technical people to utilize smart home technologies. Chatterjee [30] built an agent-based system with three device agents (TV, phone, stereo), and tried to find correlations between the interactions of those agents.

Broad-based Assistance

The systems in this section seem to address numerous issues for supporting elders. A common thread is the use of passive monitoring technology to recognize behaviour and raise alerts as needed. Early systems did not have the alerting capabilities, but have a clear path to this capability. Another common thread is the integration of multiple sensors.

Togawa *et al* [160; 179] was one of the first projects to use passive sensing of everyday activities to monitor subjects. Their main focus is to monitor physiological parameters, but they also monitor, for example, sleep hours, toileting habits, body weight and computer use. The systems collect data for analysis by a caregiver, and do not raise alarms or automatically respond to the data in any way.

Celler *et al* [28] collects data for measuring the behaviour and functional health status of the elderly, and assessing changes in that status. Data analysis is off-line, and reports are generated for participants who have demonstrated a consistent change in functional health status.

Inada *et al* [76] was perhaps the first system to incorporate the capability to contact emergency personnel whenever there is a sudden change in the patient's condition, and the patient initiates the call. The system collects biological information, physical activity, and subjective information such as complaints.

Richardson and Poulson [138; 139] describe installments of assistive home control technologies for supporting independent living. The main focus of this work was to make devices more supportive and easier to use by creating a common framework for controlling and monitoring devices, both from within the home and externally. One of the installed bases includes medical monitoring devices and raises appropriate alarms, and they call for systems that raise alarms for all appropriate 'supportive' purposes.

Glascock and Kutzik [63] similarly aims at using non-intrusive monitoring to detect functional activities of daily living. This system does not respond to the collected data in any way; the data is logged and later analyzed off-site. Their patent [90], however, covers the capability of generating a control signal in response to the collected information.

Alyfuku and Hiruta [9] also have a patent that passively monitors people and can control devices based on the monitored information.

Chan *et al* incorporate the results of machine learning to control environments and automatically raise alarms. A neural network is used to learn the habits of this group of people (temperature and location) [29]. The network is trained over a given period, and then used to control the temperature of a room based on expected occupancy. The authors extend this work to recognize behavioural changes and raise alarms [154]. A paper in this proceedings describes a real-time monitoring study [27].

Sixsmith [151] describes and evaluates results from an intelligent home system installed in 22 homes. The system raises alerts for "potential cause for concern" – namely when the current activity is outside a activity profile based on the average patterns of activity. The system was well-perceived by the elders and their caregivers.

Leikas *et al* [97] describe a security system for monitoring the activities of demented people at home, primarily through alarms on doors. The usability evaluation was quite thorough.

Huberman and Clearwater [73] built a agent-based market-based temperature controller. The Intelligent Home project [98] researches multi-agent systems in the context of managing a simulated intelligent environment. The primary research focus is on resource coordination, e.g. managing the hot water supply.

The Neural Network House [127] also used neural networks to 'self-program' a home controller. The system learned the users preferred environmental settings, and then controlled the house to meet those settings and optimize for energy conservation.

Pearl [136], a joint project between the University of Pittsburgh and Carnegie Mellon University, is a mobile robotic 'nurse' assistant. Pearl guides elders through their environments and reminds them about daily activities.

NASA JSC is developing a *cognitive orthosis* to support individuals who have difficulty planning, scheduling and carrying out tasks. The tool will monitor activities while the elder is performing them, provide additional assistance when an error occurs and provide mechanisms for intervention from third-parties [148].

The Georgia Tech Aware Home [47; 87] is a platform for a wide variety of research. A paper in this proceedings [1] describes the technological, design and engineering research challenges inherent in this domain. Research areas include computer perception, human factors, ubiquitous computing and extended monitoring.

MIT's House_*n* [121] is another research platform. It started as an architecture design project – how to design a more "elder-friendly" home. Now projects also include behaviour recognition, user interfaces, and networking. Another paper in this proceedings describes a monitoring system for "just-in-time" context-sensitive questioning to prevent congestive heart failure [77].

The University of Washington's Assisted Cognition [84] is a relatively new project with ambitious research goals. The paper in this proceedings describes a behaviour recognition and task prompting piece of the system.

The Independent LifeStyle Assistant™ (I.L.S.A.) is a Honeywell project with the goal of creating an umbrella system that monitors, supports, alerts and reports the activity of an elder. Haigh et al. [69] describe the overall architecture and vision, and several papers in this proceedings highlight different aspects and issues [61; 66; 68; 171].

Sincere Kourien, a retirement home in Japan, features robot teddy bears whose sole purpose is to watch over the elderly residents. A voice recognition system supports monitoring of patient response times to spoken questions, and raising alerts as appropriate [103].

Oatfield Estates, a residential care complex in Milwaukie, Oregon monitors and tracks medical data, weight via bed sensors, location via tags, and includes web displays for elders who can monitor their own health [16]. Vigil has fielded over 2000 dementia-care systems in multiple assisted living facilities. Their system focusses primarily on incontinence and wandering [169].

Few of these large systems have been evaluated for usability by elders; only [27; 97; 139; 151] can make this claim. Even fewer have achieved commercial viability [16; 103; 169].

Assistive Robotics

Robotics technology has been applied to and developed for many different applications to assist people with disabilities; these systems can also be used for elder care. This broad field of robotics is usually called *assistive robotics* or *rehabilitation robotics*. Robots have been built to assist people with personal care, to provide vocational assistance, to retrieve items and to provide safe travel. LaPlante [94] provides a comprehensive set of statistics on assistive device usage, although the article is dated.

Several earlier overviews of the assistive robotics field have been written. Dario, Guglielmelli and Allotta [43] discuss the use of robotics in medicine, covering topics from robot guided surgery to robotic arms to mobile robots for delivering items in hospitals. Dallaway, Jackson and Timmers [41] present the state of research in Europe. Harwin, Rahman and Foulds [70] review rehabilitation robotics with an emphasis on systems developed in North America. Miller [118] also reviews assistive robotics with an emphasis on mobility, manipulation and sensing.

Manipulation assistance

Robotic arms fitted with some type of gripper can be used to help people eat, assist with personal hygiene, fetch items in a home or office environment, push elevator buttons and open doorknobs. The arms can be mounted on wheelchairs, attached to mobile robots, on a mobile base, or fixed to one location as part of a workstation. An overview of rehabilitation research investigating robotic arms and systems can be found in [106].

Arms mounted on wheelchairs must not interfere with normal use of the wheelchair by increasing its size too much or causing the chair's balance to become unstable. The Manus arm [91; 140] is a five degree of freedom arm on rotating and telescoping base unit that is now available commercially. The Wessex robot [71; 67] is a wheelchair mounted arm that is currently under development. This six degree of freedom arm is mounted at the rear of the wheelchair in a fixed position.

While arms mounted on wheelchairs usually require that the user be seated in the wheelchair in order to use the arm, robotic arms mounted on mobile robots can provide assistance away from the user as well as in the user's presence. WALKY [19] is a mobile robot with an arm designed to assist its user in laboratory environments to conduct microscope work, blood group determination and culture analysis. It is designed to work with its user's own input device(s). The MoVAR project [167] also integrated a robotic arm and mobile robot base for vocational assistance. MOVAID [41] was designed for home use, to provide assistance with food preparation and house cleaning.

Handy 1 [162] is mounted to a (non-robotic) wheeled base. The robotic arm was designed to assist its users with personal hygiene and eating. Different trays can be attached in front of the arm to allow specific tasks to be accomplished: a tray for eating and drinking, a tray for washing, shaving and teeth cleaning, and a tray for applying make-up. A tray for art called the Artbox is currently being prototyped to allow the robot to assist with recreation in addition to necessary care.

Alternatively, robotic arms may be fixed to one location as part of a workstation. Workstations can be used for vocational assistance, where its user can perform his work duties with the assistance of the arm and its supporting interface. Workstations can also be used for eating, reading and personal hygiene.

The RAID workstation [19; 41] was designed to work in a vocational environment. The robot arm was mounted on a track and could access materials like books and disks on a bookshelf and printouts from the printer. The end effector could also turn pages for the user. The EPI-RAID workstation [41] is an extension of the work on the RAID workstation, requiring less complexity in programming tasks. The EPI-RAID workstation would also be useful in a home environment, which has more variation than an office workspace.

The DeVAR workstation [167] was also designed for vocational assistance. It included a robotic arm for manipulation, telephone control and environmental control. ProVAR [170] introduces a user interface that is easier to use.

The MUSIIC system [85] allows for telemanipulation of objects using speech and gesture. For example, a user can point to a straw and say "That's a straw" followed by "Insert the straw into that" while pointing at a cup. This system allows the environment to change and include new objects.

Electronic travel aids

Electronic travel aids for the blind or elderly infirm take many forms. All attempt to provide the user with assistance to compensate for the user's lack of sight. Some take a passive role, suggesting a safe travel direction through tones and allowing the user to walk as he wishes. Some systems are more active, guiding their users on a path as the user holds on to the system's handle. For the elderly, the support provided by a walker is probably more useful than tone output from a cane-type system.

The guide dog robot MELDOG [157; 158] was developed to emulate the assistance that a guide dog provides to a blind person. The robot was built to execute the commands of the user while providing intelligent disobedience if the command would cause the user to be put into harm's way. The robot communicated with its user through electrodes placed on the user's skin. This electrocutaneous communication was determine to be preferable to an audible warning to allow the person to use his hearing to help guide his travel without noise from the system.

HITOMI [123; 124] was designed as a travel aid for people who lost their sight later in life and have trouble remembering routes. This system uses a powered wheelchair as its base. The user walks behind the wheelchair, holding on to its handles. The system uses vision, ultrasonic sensors, tactile sensors and GPS to guide its user in outdoor environments. HITOMI acts like a guide dog, taking its user safely across streets and down sidewalks.

PAM-AID [93; 92] was designed as a mobility aid for elderly people who need support while walking and have limited vision. In addition to providing physical support, the robot also provides obstacle avoidance using ultrasonic sensors, infrared detectors and bumpers. The user commands the robot using a joystick and a single switch. The robot was designed for indoor environments such as hospitals or nursing homes where its users would be bed-ridden without a caregiver or the robot for guidance and support.

Dubowsky [50] describes a robotic walker that can detect obstacles and guide users to a desired location. The system monitors location by reading ceiling posts. The walker has different modes to allow the user to control walker or to let the walker control the direction of movement. Field trials suggested minor problems but a very high acceptance by users.

Another robotic walker is described in [176]. It can detect objects, infer paths, and adjust to a person's mobility.

Electronic travel aids do not need to be robotic. The Navbelt system [145], also meant for the blind, is comprised of a portable computer carried as a backpack, a belt with 8 ultrasonic sensors worn in a manner similar to a fanny pack, and stereo headphones. It uses the same algorithms for sonar firing and direction computation as the NavChair system described below [99]. The travel direction computed is converted to tones played in the user's headphones. The system was tested indoors and outdoors, but fails to detect steps, holes, edges of sidewalks and overhanging objects. Plans for future work include the addition of sonars to detect these missed objects.

Robotic wheelchairs

Research in the field of robotic wheelchairs seeks to address issues such as safe navigation, splitting control efficiently between the user and the robot, and creating systems that will be usable by the target population. The focus is not on improving the mechanical design of the standard powered wheelchair. Thus robotic wheelchairs are usually built with standard powered wheelchairs for their bases.[3] Field [55] presents a literature review covering many aspects of powered mobility and Cooper [35] discusses issues for engineering both powered and manual wheelchairs.

Many robotic wheelchairs were designed only for indoor environments. However, a survey of powered and manual wheelchair users found that 57% used their wheelchair only outside and 33% used their wheelchair both inside and outside [86]. Even considering that some of the target population may be institutionalized which may increase the number of people using their systems indoors only, a large number of users still need a system that will work outdoors.

An early system provided collision avoidance [143]. The wheelchair was driven using a joystick and provided collision avoidance using three ultrasonic sensors The chair would slow down if an obstacle was less than one foot away on either side or less than six feet away in the front. The chair would hit an obstacle at a maximum speed of 1/4 foot per second, allowing a user to pull up to a desk.

The Ultrasonic Head Controlled Wheelchair [79; 80; 81] uses two ultrasonic sensors to measure forward/backward and left/right components of the motion of a user's head. This information can be used to drive a powered wheelchair with no navigation assistance or can be used with the assistive mode that was developed. In assistive modethe chair slows or stops if an obstacle gets too close, can follow a slow moving person at a fixed distance, can follow walls, and provide a cruise control where the system maintains the last set speed. The user can switch between the system's modes by moving his head to the rear and then to one of the four quadrants.

The OMNI project [22; 72; 25; 21] uses a custom-designed omnidirectional wheelchair as its base. The chair can rotate around its center point, allowing it to move in tighter spaces than a standard powered wheelchair base. The system uses ultrasonic and infrared sensors to provide assisted control through obstacle avoidance, wall following and door passage. The project also includes a custom user interface that can be simplified for a row/column scanning mode.

Another custom designed omnidirectional wheelchair was built in the Mechanical Engineering department at MIT [159]. A behavior-based architecture for semi-autonomous control has been designed for the wheelchair, but has not yet been implemented. Plans call for the user to drive the system using a joystick. The system will use ultrasonic sensors to provide semi-autonomous control and autonomous control where the chair could follow a guide or wander randomly.

A system built by Connell [33] also follows a horseback riding analogy. The user would sit on a chair on

[3] A few projects have custom built bases (e.g., [22; 159].)

a mobile robot base. A joystick was used for driving the system. A bank of toggle switches were used to turn on or off the ability of the robot to perform some tasks autonomously. These behaviors included obstacle avoidance, hallway traversal, turning at doors and following other moving objects. The overhead involved with selecting behaviors and toggling switches would most likely be prohibitive for our target group.

An autonomous robotic wheelchair was developed at Arizona State University [105]. The purpose of the system was to transport its user to a specified room in a building using a map of the environments and planning. It used a scanning Polaroid ultrasonic range finder for obstacle avoidance and a digital camera. The system used only a restricted amount of vision processing to locate and verify known objects such as room numbers, look at elevator lights and keep the wheelchair centered in the hallway.

TinMan II wheelchair [119] uses infrared, bump and ultrasonic sensors to provide semi-autonomous control. In their semi-autonomous control mode, the user can drive using a joystick with obstacle avoidance that will override the user's commands. In addition, the chair can be driven by pushing one button to turn while avoiding obstacles and by pushing another button to move forward while avoiding obstacles.

The goal of the TAO project [64] is to develop a robotic module for navigation that can be interfaced with standard wheelchairs. The behavior-based navigation module has been put on two different commercially available wheelchairs. The system uses computer vision and infrared sensors to navigate in its environment. It is primarily an indoor system, although it has been tested outdoors in limited situations such as a snowy sidewalk with 1 meter high walls of snow on either side. The TAO wheelchairs navigate in an autonomous mode, randomly wandering in an unstructured environment or performing landmark-based navigation. The user can override the robotic control by touching the joystick. In joystick mode, no assistance is provided.

Like the TAO Project, Alanen [6] has developed an add-on system with sensors to be placed on the wheelchair by its manufacturer. Like NavChair (described below), its collision avoidance is based upon the virtual force field (VFF) method [20]. The wheelchair slows down when there are obstacles, but still moves toward the obstacle, allowing the user to pull up to tables and open doors.

The Hephaestus project [147] also aims to build a navigation assistant that can be added to any powered wheelchair. The system would be installed between the wheelchair's joystick and motor controller. The first prototype has been tried with one powered wheelchair base to date. The navigation assistance provided is based on the NavChair system described below.

The NavChair [150] navigates in indoor office environments using a ring of sonar sensors mounted on the wheelchair tray. The height of the sensors prevents the system from being used outdoors since it can not detect curbs. The system has three operating modes: general obstacle avoidance, door passage and automatic wall following. The system can select a mode automatically based on the environment or the environment and location [149]. People who are unable to drive a standard powered wheelchair have been able to drive the NavChair using sensor guidance with either a joystick or voice commands as an access method.

Vocomotion [11] is another voice controlled wheelchair. The system provides no driving assistance.

Senario [83; 15] can be operated in a semi-autonomous or fully autonomous mode. The system informs the user of risk and takes corrective measures. The user can override in semi-autonomous mode. The wheelchair will stop moving if an emergency situation is detected. The user can command the system using voice control or the joystick.

The UMIDAM Project [112] developed a wheelchair that includes sensors pointing downward to detect stairs. The wheelchair can be commanded by voice in semi-autonomous or autonomous mode. The autonomous mode provides obstacle avoidance and/or wall following with the speed controlled by voice. In semi-autonomous mode, the voice commands are executed using the sensors to provide safe navigation (if the user has not elected to turn off the sensors). Face tracking can also be used to control the wheelchair [17].

A deictic navigation system has been developed for shared control of a robotic wheelchair [36]. This system navigates relative to landmarks using a vision-based system. The user of the wheelchair tells the robot where to go by clicking on a landmark in the screen image from the robot's camera and by setting parameters. Deictic navigation can be very useful for a disabled person, but a complicated menu might be difficult to control with many of the standard access methods. However, it could be adapted for a scanning system, perhaps in a row-column scanning pattern.

Wakaumi [172] developed a robotic wheelchair that drove along a magnetic ferrite marker lane. A magnetic lane is preferable to a painted line due to its ability to continue to work in the presence of dirt on the line. This type of system is useful for a nursing home environment to allow people to drive around without the need for being pushed by a caregiver.

A wheelchair developed at Notre Dame [181] provides task-level supervisory control; the user can select the nominal speed, stop and select a new destination or stop and take over control. The system is taught "reference paths" during set up that are stored in memory. The system does not include obstacle avoidance. If a trash can is put in the wheelchair's path, the user needs to take over control to maneuver around the trash can and can then pass control back to the system. The philosophy is in direct opposition to many others; we believe that fine navigation control required to navigate around small obstacles is more difficult for our target group than traversing a known route.

PSUBOT [133; 153] was designed to navigate indoors between rooms of a known building. Commands are given to the robot using voice recognition. The robot is taught where landmarks are in images in a learning mode and then navigates autonomously using this information.

Wang [174] designed a wheelchair system that uses ceiling lights as landmarks to self-localize. The system performs autonomous navigation, taking commands of the form "travel from node x to node y."

The VAHM project [24; 23] operates in an assisted manual mode and an automatic mode. In assisted manual mode, the system can provide obstacle avoidance and wall following. In automatic mode, the system performs globally planned paths with obstacle avoidance of non-modeled objects. Their philosophy is that the person supervises the robot in automatic mode, overriding robotic commands that are unwanted, and the robot supervises the person in assisted manual mode, overriding commands that put the user in danger. The project has developed a user interface for single switch scanning.

A system developed at Carnegie Mellon University [137] uses a vision system with a 360 degree field of view to localize on a topological map. The system currently works only in an indoor environment, but there are plans to implement the system for outdoor environments. The navigation system is running on a wheelchair platform built by KIPR [119], but no access considerations are included at this time.

The Intelligent Wheelchair Project [65] also uses a base built by KIPR [119]. The research on this system is addressing spatial knowledge representation and reasoning. The structure of the environment is learned over time through local observations. The system uses stereo color vision, in addition to ultrasonic and infrared sensors.

A system developed at Osaka University [2; 89; 88] controls the wheelchair's direction by observing the direction of the user's face, under the assumption that a person will look where he wants to go. They use ultrasonic sonars to choose the sensitivity of the program to a user's head movement. For close obstacles, they smooth over a large number of frames, making the system ignore small head movements since the user may look at the close obstacles. For long readings from the sonars, smoothing is done over a smaller number of frames to allow for finer control in open spaces.

The CALL Centre Smart Wheelchair [129] is a configurable system that can be modified for each individual user. It uses a standard powered wheelchair base, but the joystick is removed and replaced with a "Smart Controller." Bumpers detect collisions; several behaviors can be selected to correct the bump for the user. A line following behavior can follow reflective tape on the floor. Several access methods can be selected. Several case studies are discussed where the system starts out doing most of the work through bump behaviors and line following, then users learn to take on more of the task themselves. In some cases, the users can end up driving a conventional powered wheelchair, when they could were not successful learning to drive it without assistance from this project.

The Wheelesley robotic wheelchair system [180] was designed for both indoor and outdoor travel, making it the first to travel in general outdoor environments. The wheelchair was a shared control system, where the user gave high level commands such as "left" and "straight" while the robot took over low level control such as path following and obstacle avoidance. The wheelchair was designed with an easily customizable user interface that was adapted for single switch scanning and for an eye tracker.

Human Factors

Arguably, one of the greatest challenges for systems in this domain is to provide an interface for potentially technophobic users with varying capabilities and constraints. Older adults have more difficulty learning new computer skills [38; 125], and interfaces that are poorly designed cause devices to be abandoned [5; 45; 62].

Numerous different ideas have been tried to improve interfaces. Lighthouse International publishes a pair of very enlightening pamphlets on designing interfaces for people with vision problems [13; 12]. McCoy [113] summarizes many of the technologies supporting interfaces for people who have disabilities that make it difficult for them to communicate using spoken language. Pieper *et al* [135] performed a usability evaluation to improve the accessibility of the Internet, and SeniorNet [58] was a successful, early attempt to bring elders into the computer revolution. Mann *et al* [110] studied four different TV remote controls to test preferences. Ones with larger buttons, fewer functions, and higher contrast were preferred. They are currently designing a smart phone for centralized coordination of smart home devices [107]. Icon selection also can dramatically improve interactions [144; 173].

Multimodal interfaces seem to be effective [166; 102], as does modelling emotion seems to be a useful technique [75]. Another creative method of communicating information is through cartoon characters with facial expressions [78], although trust levels increase through a *text-based* interface, contrary to author expectations [168]. Elders also have more problems with speech [126; 152; 164], notably short term memory.

Training is also a key factor for elders [108], but the type of training is critical as well – online training is the least effective method for older adults [40].

Conclusion

Advances in technology are creating systems that will assist in the care of the elderly. These systems can remind people to take medicine, monitor the health and safety of people who live alone, and help them move safely through the world. The design of these devices must account for a population that grew up before the dramatic boom in computer technology for the home and workplace.

Technology is increasingly either occupying or sharing the role traditionally occupied by human caregivers. As this role increases, we need to understand better the moral and ethical implications of this progress. Beyond the legal issues of privacy and liability, some of the issues include the dependency of technology to the extent that it leads to reduced personal care, reduced funding for state run care, reliability of such systems and user control of systems [116; 165; 178]. In this proceedings, Miller *et al* [117] discuss the obligations of intelligent systems to elders.

It will be important to understand the interplay of these issues so that intelligent automation can be appropriately and effectively integrated into the caregiving network.

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