Increasing the Opportunities for Aging in Place

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ABSTRACT

A growing social problem in the U.S. and elsewhere is supporting older adults who want to continue living independently as opposed to moving to an institutional care setting. The "Aging in Place" project strives to delay taking that first step away from the family home. Through the careful placement of technological support we believe older adults can continue living in their own homes longer.

The goal of our research is to take a three-pronged approach to understanding the potential of such environmental supports. The research team combines expertise in human-computer-interaction, computational perception, and cognitive aging. Together the team is assessing the feasibility of designing environments that aid older individuals in maintaining their independence. Based on our initial research, we are dividing this work into three parts: recognizing and adverting crisis, assisting daily routines, and supporting peace of mind for adult children.

Keywords: aging, awareness, cognitive aging, home, computational perception, ubiquitous computing

INTRODUCTION

There can be no denying that America's population is aging. Baby boomers approaching late middle age ask: "How does one care for a population that lives many years longer than any of the preceding generations?" The "Aging in Place" project strives to delay taking that first step away from the family home. Through the careful placement of technological support we believe older adults can continue living in their own homes longer.

The average age of the world population is increasing rapidly. According to the U.S. Census Bureau, in 1996 there were approximately 550 million adults over age 60 and this number is expected to approach 1.2 billion by the year 2025. In the U.S. alone, there were nearly 44 million adults over age 60 in 1996 and the projected number for 2025 is approximately 82 million (over 20% of the total population).

Most older adults live in independent households; it has been estimated that only 5% of the older population reside in nursing homes [6]. However, the number of people in nursing homes does increase with age such that 20% of individuals over age 80 live in nursing homes. For economic reasons alone, increasing the length of time that individuals can avoid nursing home care is valuable.

For more than just economic reasons, a primary goal of many older individuals is to maintain an independent lifestyle [18]. Thus, many older adults live in private homes, typically either alone or with family [17]. According to the Administration on Aging (1997), there are many factors that contribute to the independence of older individuals including marital status (married or not), living arrangements (alone or with others), household status (head of household or not), education, economic dependency, and income. A variable that has not been studied is the degree to which the house itself is supportive of the functioning of the individual.

Interdisciplinary Approach

The goal of the our research is to take a three-pronged approach to understanding the potential of such environmental supports. The research team combines expertise in human-computer-interaction, computational perception, and cognitive aging. Together the team is assessing the feasibility of designing the environments that aid older individuals in maintaining their independence.

The field of cognitive aging has made substantial progress in understanding the basic cognitive changes that accompany the normal aging process. Some abilities do decline, yet other abilities remain intact well into the seventh or eighth decade of life. Of course there are substantial individual differences in the rate of decline and the amount of decline. However, in general, aspects of memory (e.g., keeping a lot of information active in working memory), online reasoning ability, and aspects of attention such as attending to more than one source of information all show age-related declines. On the positive side, abilities that tend to remain intact into old age include some aspects of memory (e.g., recalling well-learned information), verbal abilities such as vocabulary and reading, and some aspect of attention (e.g., focusing on a single source of information). Designers must recognize and accommodate those abilities that do decline while at the same time capitalize on the abilities that remain intact.

The goal of our HCI[1] work is to leverage computational capabilities to enhance day-to-day activities by focusing on a continuously present environment [2]. Instead of viewing the computer as a tool that is picked up, used, and then set aside, it is viewed as a constant partner in daily activities. For example, the computer could notice when a person is interrupted and help him or her regain a task upon return. It could monitor an elderly grandmother's environment, informing her of hazardous situations. It could help an adult child assess an elderly parent's long-term behaviors to detect positive or negative trends. In all of these examples, the key challenge is designing interfaces that reflect and support the on-going activity of daily life, without being inappropriately intrusive or complex.

The primary goal of our research in computational perception is to develop intelligent machines, interfaces, and environments that can perceive, recognize, anticipate, and interact with humans. Towards this end, we are developing signal understanding and pattern recognition techniques for analyzing sensory signals from scenes and environments. We explore methods for perceiving where people are, recognizing them, understanding their actions, and interpreting the communicative stream. To provide an environment with such perceptual abilities requires instrumentation with sensors that are non-invasive and unobtrusive, so that the sensing and computing is transparent to the user. We instrument spaces with sensors such as eyes (cameras), ears (microphones), and touch (contact sensors). In addition, we also instrument various artifacts of in a space to measure usage. Analysis and interpretation of the signals captured from these sensors make the system aware of the events and activities in its surroundings.

FRAMEWORKS FOR AGING IN PLACE

Many factors contribute to the growing problem of supporting older adults who want to continue living an independent and rewarding life, but who need some assistance due to declining cognitive or physical abilities [5]. In this section, we briefly describe the multiple frameworks that inform our analysis. We then describe the three problem areas that we are investigating.

One traditional assessment of everyday functioning provides a good starting point for looking at the everyday activity of older adults. People living independently must be capable of performing basic activities of daily living (ADLs) such as bathing, toileting, and eating. In addition, successful independent living requires the capability to carry out instrumental activities of daily living (IADLs) such as managing a medication regimen, maintaining the household, and preparing meals of adequate nutrition [9]. Existence as an independently-living, active older adult may require much more; specifically the ability to adapt to a changing environment. The willingness to accept these new challenges and to learn may be key to staying fully functional in a changing environment. These additional behaviors have been labeled enhanced activities of daily living (EADLs)[16].

All of the activities (ADLs, IADLs, and EADLs) can potentially be aided by augmented environments.

ADL: Bathing could be aided by systems that assist in temperature regulation and monitoring the vital signs of the bather for signs of problems.

IADL: Reminder devices and medication organization have potential for computer augmentation.

EADL: Use of the WWW as a means to communicate with the outside world such as family, friends, and even local community.

In 1995, there were 1.56 million residents in nursing homes accounting for 71% of the $90.9 billion spent for long-term health care[8]. There are also an estimated 20,000 to 30,000 assistive living centers housing one-fourth of the currently 2.2 million Americans who live in senior housing[3]. Although there are now more choices available, many of these options are prohibitively expensive, costing on average $2000 per month and often requiring a substantial entry fee. Additionally Medicare and Medicaid funds often cannot be used in these non-regulated assistive care centers [7]. Since the inception of nursing homes to support physical ailments, there is an increasing emphasis on supporting cognitive ailments. Approximately two-thirds of nursing home residents suffer from dementia [3] and this percentage is almost certainly larger if those with "normal" cognitive declines are included. Given this evolving picture of elder care in the U.S., we are hopeful that in-home solutions could be much more economically feasible for a wider spectrum of older adults in the long-term. We are also paying increasing attention to the effects of declining cognitive abilities in hampering independent living.

In addition to understanding current assessment techniques and the economic impact of caring for an aging population, we wanted to gain an insider's perspective via ethnographic observations and interviews of local assistive care centers. This study focused on understanding *why* people chose to leave their homes for an institutional care setting. We were impressed by the dominant role of adult children and their need for day to day assurance of their parent's well-being. We were also concerned by the negative effects of institutional life, e.g. decreased motivation for self-care and increased isolation and depression.

From this complex backdrop, we are addressing three key problem areas. In each area, we are using prototypical scenarios to drive our design and evaluation efforts.

- **Recognizing crisis**: From the immediate crisis of a fall to an impending crisis of a broken heater in the winter, we are designing systems to recognize potential problems and to notify home occupants and outside support (family, EMS) as appropriate.
- **Supporting everyday cognition**: Declines in memory capabilities of older adults lead to difficulties in remembering tasks (e.g. taking medication) and

1. This research program in HCI is called "everyday computing."

handling interruption [14][15]. We are working on systems to recognize forgotten or interrupted tasks and to assist the occupant in resuming these tasks.

- **Providing awareness of daily life and long-term trends:** Some potential problems cannot be as easily detected as a crisis or forgotten task, but may still be significant for the long-term health and happiness of the occupant. Additionally, daily contact between family members, as opposed to the lack of an alarm, can help provide a sense of security, peace of mind, and lower barriers for more direct communication.

This paper is structured according to these three primary issues in Aging in Place. In each area, we provide more detail regarding the problem, our interdisciplinary approach and scenarios that are guiding our research. The purpose of this paper is to convince the ACM community as to the importance of this problem and the opportunities inherent in an interdisciplinary research approach. Results of this research are summarized elsewhere. Where appropriate, we provide pointers to those summaries.

THE BI RESIDENTIAL LABORATORY

A key resource for this research is the Residential Laboratory building on the Georgia Tech campus managed by the Broadband Institute (BI). The facility is shown in Figure 1.

Initial funding for the building of this house came from the State of Georgia's Georgia Research Alliance. Construction was completed in April, 2000. The house is about 5000 gross square feet, and has two identical floors, each equivalent to a typical three bedroom apartment. This house is built with all the functional and design requirements of a normal home as well as with the facilities for instrumenting each and every room with sensors and displays to support ubiquitous interactions between the residents and the house.

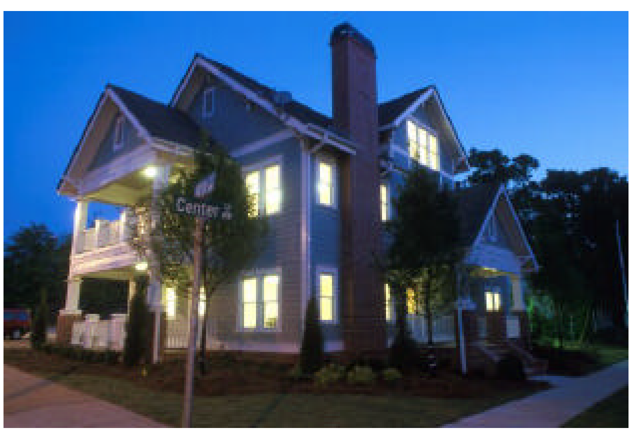


FIGURE 1. Broadband Institute Residential Laboratory

Researchers including us are installing a wide range of sensing equipment (cameras, microphones, IR, RF, sonar, tactile), including general metering on utilities as well as specific instrumentation on appliances. The goal is to automatically and unobstrusively measure activities of the residents and provide support for their daily needs and activities. Research is also underway to equip this home with an advanced computing and networking infrastructure to support the wide array of sensing and display equipment. It should be noted that there have been previous efforts at building a smart and adaptive home. Similar to our efforts, Mozer [12] built a neural net-based home that he himself lived in, where the home learned his patterns and attempted to control lighting and other environmental sensors according to his daily routines. Our interest in the Residential Laboratory is more ambitious as we aim to support informal human activity via sensing, computing, networking, HCI, and machine learning.

This house is serving as “living laboratory” for various research projects that combine technological innovation with the study of how these technologies can enhance the everyday activities of the residents. We are beginning to deploy our research systems in the Residential Laboratory for experimentation and eventual long-term use.

CRISIS SUPPORT

The first concern that comes to mind is a potential crisis: a person has fallen and is immobile, a car is left running in the garage. For a variety of reasons, an elderly person may be unable to attend to a potentially life-threatening problem. Not all of these crises are instantaneous such as a fall, but may be a gradual threat such as inadequate cooling on a hot summer day. Additionally some events may not be life-threatening in the near term, but may be terrible to experience such as being unable to get out of the bathtub and waiting until someone discovers the problem.

There are currently a number of technological and social approaches for guarding against a potential crisis. A popular system called Lifeline™ is a wearable device that can trigger a phone call to the Lifeline center [1]. The intent is that the user can still communicate through a speaker phone. The Lifeline center can then notify emergency assistance or family members as needed. A common social strategy is *calling circles* where each member of the circle is responsible for reaching another member on the phone each day just to make sure that everything is ok with them. Emergency call buttons and pull cords in bedrooms and bathrooms are frequently seen in assistive care institutions.

There are obvious limitations to these current strategies. Most technological solutions require the elderly individual to initiate the call for help although they may be physically unable or too confused to do so. Human-only solutions are fallible as humans are fallible, by forgetting to call, as well as being unable to recognize a looming potential threat. Most certainly, these solutions are incomplete.

As we envision an augmented environment that can recognize potential crises, the interaction between the user (occupant) and the system is straightfoward and often implicit. When the system recognizes a potential problem, it should attempt to notify the occupant. If the occupant responds in a satisfactory way, either directly by indicating that there is no crisis, or implicitly by remedying the situation, then the system reacts by downgrading or removing the crisis alert. If the occupant does not respond, then depending on the immediacy of the crisis, the system continues trying to contact the occupant and initiates contact to appropriate outside agencies such as emergency response and family members.

From a cognitive aging and HCI perspective, the challenge is designing alerts that are appropriate and effective for the given situation and for the user's perceptual and cognitive capabilities. For example, audio cues must take into account the occupant's perceptual capabilities and the level of ambient noise. The content of the cues should help convey the context of the concern (e.g. the running car in the garage) as well as its urgency.

As with the rest of this work, we are designing sensors in the home that can detect simple events (e.g. a falling person) to more complex routines (e.g. preparing a meal). For the focus on crisis, our design, implementation and evaluation work is driven by the following scenarios:

- A person is immobile, either from a fall or from collapse. Recognized visually as a prone human in an awkward position or in an unlikely location. Also potential to recognize an impact sound. If the occupant does not respond, neighbors or emergency response is notified.
- A car is left running in the garage. Recognized by the accumulation of carbon-monoxide. This capability is available in stand-alone technology. We are integrating this capability into our design including notifying the occupant with an appropriate signal and notifying neighbors or emergency response if the situation is left unattended.
- The house is becoming dangerously hot or cold. Recognized with environmental sensors.

Working in combination with existing technologies that provide security and connection to emergency services, this first level of defense addresses infrequent, but potentially life-threatening events. Supporting day-to-day activity, however, is a more common problem.

COGNITIVE SUPPORT

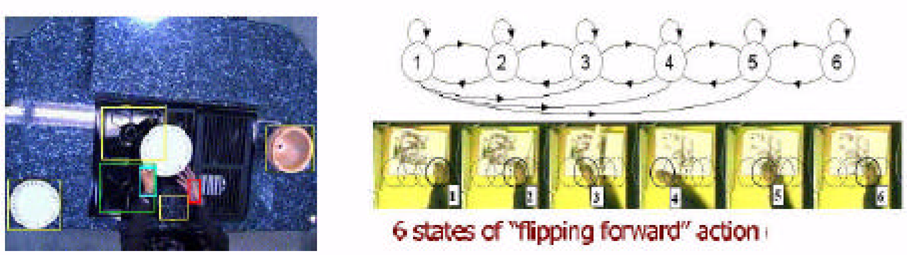
In our initial inquiries we have uncovered seemingly universal concerns about the effects of aging on memory. In discussions with elderly parents and their adult children we commonly hear stories of water left running or cook stoves left turned on. Technologically this problem appears simple to solve. Leave the stove on for x minutes and the house can turn it off. But technology of this nature does not support a person's ability to stay at home so much as it exerts control over their life. Self-reliance and personal dignity are closely aligned. Cognitive changes, such as memory loss that accompany aging (see [4]), could be tempered by creating a computational environment that supports remembering, both by observing and learning patterns of human activity, and by creating effective displays within the home that create a context for remembering.

As we envision an augmented environment that can recognize daily routines, the interaction between the user (occupant) and the system is generally self-contained, only involving other people if a potential crisis is recognized. The system attempts to monitor, support and not impede the flexible execution of daily activities. A primary concern is an activity forgotten or left incomplete. A design strategy could follow an "out of sight, out of mind" maxim. Thus the system would present auditory and visual reminders to stimulate re-acquiring a task.

From a cognitive aging perspective, our goal is to understand what basic activities are key to independent living and what are typical human errors that the system could guard against. Although ADLs through EADLs provide a framework of human activity, to inform our sensor design efforts, we must understand how these activities are enacted on a day-to-day basis and how these routines are interwoven. One key concern is managing a medicine regimen.

From an HCI perspective, the challenge is designing interfaces to support remembering, especially when the context for the memory may be out of sight. Another design concern in this work is to develop systems that aid human remembering in order to *maintain* cognitive abilities, instead of fostering the *decline* of cognitive abilities by off-loading the effort to the computer.

From a computational perception perspective, one challenge is recognizing the many variations of common activities. In all areas, we focus on managing the negative



Recognizing cooking actions

Recognizing flipping forward using a 2-state HMM [10][11]

FIGURE 2. Using HMMs to Recognize Cooking Actions

effects of interruptions in informal daily activities such as preparing meals.

For the focus on everyday cognition, our design, implementation and evaluation work is driven by the following scenarios:

- A medicine regimen that includes pills taken three times a day with meals. Visual sensors help determine if the pills have been taken from the box and swallowed with the meal. Visual ambient displays help remind the occupant to take their pills. If forgotten, more insistent alerts notify the occupant of the potential mistake.
- The occupant is preparing a meal and is interrupted by a phone call or person at the door. Following the interruption, the cooking task appears forgotten. Depending on the potential severity of the error (e.g. a pot left on a hot stove in contrast to slicing cold cuts), the occupant is reminded of the unattended task with visual or audio ambient displays. (See Figure 2)

PEACE OF MIND

One common milestone is when adult children are faced with the death of one parent and the difficult question of whether their remaining elderly parent should live by themselves. No longer can they have the peace of mind that derives from knowing that one elderly parent can support the other. Based on our initial research, we believe that peace of mind for adult children encompasses a range of information from knowing when a crisis has occurred,to maintaining an awareness of the long-term health and emotional well-being of an elderly parent.

Therefore, in addition to recognizing a potential crisis and supporting daily routines, we are interested in supporting awareness of long-term health and social issues, answering questions such as “Has she been eating enough?” and “Is he active or sedentary?” for extended family members and other care-givers. For example, a display on the kitchen refrigerator of an adult child could provide a qualitative sense of the activity of his elderly mother. One advantage of this long-term awareness is that it keeps the channel of communication between the parent and child open. When a crisis notification does occur, it may be more comprehensible given a larger surrounding context. Additionally the open channel assures the users that the system is up and running.

Typically people living in an assistive living complex are assessed according to their ADLs. This metric is used to gauge when a person might need to move to a more advanced care facility. One opportunity of computer augmentation of a person’s home is sensing activity in the home and generating these ADL metrics. In many ways, continuous sensing by computers should provide a more robust picture over time in contrast to information gathered during an on-the-spot interview while preserving more privacy for the occupant. These metrics could be translated and shared with other family members concerned about an adult person’s well being.

Designing a “Digital Family Portrait”

We are designing a “digital family portrait” that creates a visualization of a person’s day at home from available sensor information. From general measurements of activity to indications of the weather, the portrait attempts to capture the observations that would naturally occur to someone living in the same home. Leveraging a familiar household object, the picture frame, our current design populates the frame with iconic imagery summarizing 28 days of daily, household life.

We have combined field observations and interviews, iterative design, empirical evaluations and field trials with the prototype interface to create an interface that conveys salient aspects of everyday life, compliments existing communication practices, creates an emotionally-engaging experience, and respects self-presentation and privacy needs. [13]. Our first and current designs are shown in the following figures.

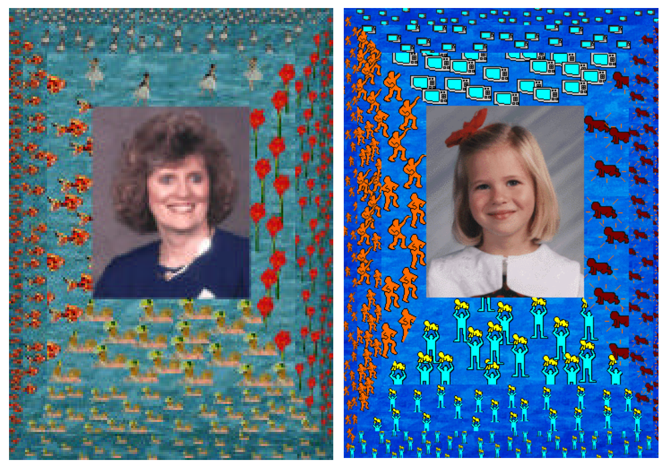


FIGURE 3. Our First Design

In our first design, there are four categories of information each depicted on one side of the frame: health, relationships, activity and events (clockwise from the right). Each category is divided into three bands with the most recent information in the inner band to the least recent in the outer band. A typical photograph rests in the center. The density of icons in a band represents the measurement for that category for that time period. The greater the density of icons, the higher the measurement. For example, in the grandmother’s portrait above, there are few recent events although there are a greater number of events in the past. Activity and health are fairly consistent with slightly higher than median ratings. In relationships, there is a recent concentration of interaction in contrast to less interaction in the past.

Based on informal evaluations and a field trial with the users pictured above [13], we modified the design by splitting the information categories across multiple frames. In Figure 4, the activity of a woman is indicated by daily butterfly icons. In this design, the level of activity is mapped to the size of the icon.

FIGURE 4. Our Current Design[1]

While the initial pilot study indicated that users wanted historical information to help them identify trends as well as to help them interpret the current day's icon, the goal of having older information slowly fade to the edge of the frame did not seem tenable. Borrowing a different metaphor for time, in this design, the icons are ordered around the frame in a clockwise motion. Instead of aggregating information, 28 days (4 weeks) are arranged on the four sides of the frame. We try to reinforce this clockwise motion using multiple cues. The current day is colored white making it distinct. The current day and the recent past is highlighted using a gradient of background color, creating a "wave" of the forward progress of time. Additionally the color gradients of all but the current day icon match the clockwise motion. (See Figure 4[1])

An augmented home that can monitor long term trends has the ability to create an interface (connection) between physically separate family members. The visualizations of long-term trends may also be an important tool for self-reflection about one's personal well-being. In this way, the visualization acts as a digital mirror.

An unresolved question from a cognitive aging perspective is understanding what trends are important, which ones are expected and what is a baseline for normal daily activity. With respect to supporting awareness between family members, the primary challenge is designing the visualizations of long-term sensor data that paint an accurate and socially appropriate picture of life within that home. In contrast to quickly recognizing an event, such as someone falling, the goal of the computation perception efforts is to summarize sensor data over time, recognizing long-term patterns and minimizing the effects of "noise" created by less-than-perfect sensors.

1. This photograph is used with permission by PhotoDisc, Inc.

Scenarios that are guiding this portion of the research are:

- Due to increasing health problems, a person is eating less and is moving around their home less each day. Multiple sensor streams (e.g. use of kitchen appliances, floor sensors, optical sensors) are combined to form the picture of overall decline. This information is visualized in the digital family portrait and is also available to share, in a less abstract form, with the family doctor.
- A person sleeps well if he has a sufficient amount of social interaction during the day, such as talking to a family member on the phone or having a friend come to visit. Without these interactions, he sleeps fitfully. Over time, the system is able to correlate these two streams of sensor data. Before then, the visualizations of these two primary components of daily life depict this pattern.

CONCLUSIONS

In this project, the synergy between cognitive aging, HCI and computational perception should be clear. From cognitive aging, we understand which cognitive abilities show age-related changes and how such changes can impact the key activities that are crucial for independent living. From HCI, we learn how to create a continuously present interface for the home that reflects and supports daily activity and from computational perception, we design systems that are aware of the inhabitants and their needs, both on the long and the short term. These computational systems hold the potential of more economical and higher quality care for our aging population.

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