Designing and Evaluating Technology for Independent Aging in the Home

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Summary

We are developing technology and design strategies to support aging in place. To design and evaluate our solutions, we have created new tools that can be used to study behavior *in actual homes*. Our goal is to evaluate solutions *in context*, taking into account the complexity of real-world behavior that is often missing from laboratory environments. Two of our tools are described here: a portable kit of tape-on sensors for studying behavior in existing homes, and the PlaceLab, a residential observational facility with ubiquitous sensing technology. In both cases, the tools are used to study behavior outside of a typical laboratory in a natural home setting. We propose one scenario that illustrates how the portable sensors can be used to create a new device to support aging in place. We then discuss how the portable sensor kit and the PlaceLab can be used to study the technical and social challenges that must be overcome to realize the scenario.

Background

The home ideally provides a safe, comfortable environment in which to relax, communicate, learn, reminisce, and be entertained. Homes become places of special meaning over time because so many important events in life are experienced in them. For these reasons, Americans consistently express a desire to remain in their own homes as they age, and changing residences can induce a tremendous amount of stress. Moving in with loved ones or relocating to an assisted living facility are often seen as undesirable options that are only acceptable when the home can no longer support the changing needs of the occupant. Caregivers, meanwhile, are often placed in uncomfortable situations where they are forced to move a loved one from an independent existence in a cherished home to a group living situation where the person feels that he or she is being continuously monitored.

Our multi-disciplinary research team at the Massachusetts Institute of Technology is developing new design strategies and technologies that will help people *proactively* improve their own health and living situation (House_n, 2002). Our aim is to transform existing home environments into spaces that meet the physical and cognitive needs of their occupants during the aging process. The spaces we envision seamlessly merge digital information with the physical environment. The four overarching goals of our project are to create supportive technologies that (1) help people create and customize environments and technologies that reflect their unique needs and values, (2) help people to live longer and healthier lives in their homes, (3) help people reduce resource consumption, and (4) help people integrate learning into their everyday activities in the home. Although we are creating strategies for building new types of physical structures that better accommodate changes through various stages of life, in this paper we focus on some of the tools we have developed that can be used to invent and test new technologies for existing homes.

Our goal is to create technology that can be cost-effectively retrofitted into existing homes and that can accomplish two things: (1) allows researchers to study how to create new technologies and devices for homes, and (2) allows researchers to create and test technologies that will support people as they age without requiring them to move to new environments.

It is common for technologists to assume that technologies supporting aging in place should either automate domestic tasks or monitor an occupant to automatically detect medical problems and call for help. Interviews with physicians, nurses, patients, pharmacists, and other healthcare participants, however, have led us to focus our efforts not on developing technology primarily to automatically control and monitor the home environment but instead on developing technologies that help people learn how to control their environments on their own (Intille, 2002). Further, we feel technologies that are perceived as communication tools rather than monitoring tools will be more effective at supporting independent living in the home.

Aims and Objectives

Our vision is one where computer technology is ever-present in the home but in a subtle way -- information is presented to people at precisely the time and the place when they need it so that they can learn how to take better care of themselves, remain independent, and maintain a mentally and physically active lifestyle as they age. Medical experts tell us that the old adage, “use it or lose it,” is applicable to sustaining both physical and mental health. We want our pervasive technologies to empower people with information that helps them make independent decisions; we do not want to strip people of their sense of control. Loss of control has been shown to be psychologically and physically debilitating (Rodin & Langer, 1977). Further, we do not want to create technologies that make people perceive themselves as sick or as though their privacy is being invaded. In short, we want technology that helps the home occupant to learn how to take control and stay mentally and physically active while also providing the caregiver with peace of mind – a measure of comfort as to a famy member or friend's well being (Mynatt & Rogers, 2002).

A Scenario

As the Baby Boomer generation ages and people live longer lives, an increasing number of families will be forced into care giving situations. By 2030, for example, nearly 50% of households will include someone who needs help performing basic activities of daily living (*Chronic Care in America: A 21st Century Challenge*, 1996). Consider a scenario where an elderly person ("Sue") has been living independently for many years without assistance. One day, Sue experiences a traumatic disruption in her life caused by a car accident, a fall, a medication compliance slip, a home maintenance emergency, or a friend moving away. The disruption causes concern for Sue's family, who live a long distance away. Suddenly her family feels uneasy about Sue living independently. Sue does not wish to move, and her family does not have space for Sue in their own home or money to support Sue in a suitable assisted living facility. The family caregivers believe they need some way to monitor Sue's status if she continues to live independently in her home. Sue is resentful of her family's intrusion into her independence, notwithstanding their good intentions.

The family may look for technologies that can help them monitor Sue and provide them with some assurance that Sue is functioning well. Most devices on the market, such as necklace emergency call buttons, stigmatize Sue and make her feel as though she is sickly and frail. They also require that she proactively wear the technology, even when she is alone in her own home causing a physical and emotional impingement to her autonomy.

The average yearly costs of placing Sue in a nursing home ($41,975) or providing home care ($31,025) (*How much does elder care cost?*, 2002) are extraordinarily high relative to the U.S. median income ($42,209 in 2002 (DeNavas-Walt, Cleveland, & Webster Jr., 2003)). Technology that would extend the period of time that Sue can remain in her home would result in a huge cost savings to Sue and her family. The challenge is to develop technology that will economically comfort the caregiver that Sue is healthy while not unduly stigmatizing Sue or placing additional burdens on her activity.

Suppose the family purchases two sets of small, tape-on wireless sensor kits. These tiny devices can be easily "installed" by taping them on the bottoms of chairs, on the backs of doors, on the base of dials, and on other objects in the home. They are simply tiny switches that detect when the object they are attached to is moved. The family members can place the sensors in the home with only a few hours of labor, and the devices run for years on a single battery and require no maintenance. They are placed not only in Sue's home but also in the home of her concerned caregiver. After a few weeks, these sensor devices automatically learn to recognize typical patterns, or routines, of occupants in each home. The software compares "typical" days with each new day of data and detects changes from the typical patterns. When an event is dramatically different in either household, a message is left on the answering machine of the other household with the notice that "something has changed, give them a call."

Both households utilize the devices. The technology does not reveal details about what is happening in another location, only that something changed. This affords each household privacy. The devices are used as communication devices, not monitoring devices. Family members do not need to remember to carry gadgets that make them feel stigmatized, and the technology does not use microphones or cameras to detect what people are doing, which could make the family members feel uncomfortable. Other computer devices that provide new forms of entertainment and education, including applications that empower the home occupant to learn how to stay healthy and active in fun and enriching ways, can utilize the sensor system.

Realization of the Scenario

To achieve the scenario presented above requires that technology be developed and tested that is embedded into actual homes where people are living. As designers, we must not only evaluate the technical capabilities of the technology (i.e., can it detect changes in activities or changes in specific activities of daily living) but also the social acceptability of the technology (i.e., will end users find the technology acceptable in terms of privacy and use it as anticipated?). In all cases, testing the technology can only be accomplished in a limited way in a laboratory setting. Just simulating the type of data that would be acquired from the sensor system when installed in a real home is difficult.

Therefore, we have designed two tools to test home-based technology in context. Our goal is to develop tools that can be used to study not only the technology but also *the response of people using that technology in context*. The first technology is a portable kit of tape-on sensors for studying behavior in existing homes. The second is the PlaceLab, a residential observational facility with integrated, ubiquitous sensing technology used to develop and test technologies in a sensor-enabled home.

Tape-On Portable Sensor Kit

We have developed a portable kit of tape-on sensors for studying behavior in existing homes. The sensors are small switches that detect movement of objects that can be easily taped onto any object in a room that is moved or manipulated. The devices passively collect data without requiring any conscious effort of the occupants of the environment.

The sensors we have created are sufficiently robust so that they can be installed into complex, non-laboratory environments such as real homes and workplaces to collect data about activity. This data could be used to create new applications, such as the application for peace-of-mind health monitoring described in the scenario or to study the impact of a technology or health intervention on behavior in the home. Manual and automatic analysis of the data will provide a better understanding of activity in naturalistic settings and create new opportunities for development of proactive health technologies.

In prior work where sensors have been ubiquitously installed into home or workplace environments, typically only a small number of sensors have been used or the studies have been conducted in controlled research settings such as the homes of the researchers themselves or close affiliates (e.g. (Barger et al., 2002; Mozer, 1998)) or in special homes where researchers work (e.g. (Kidd et al., 1999)). The sensors are tricky and time-consuming to install.

Our system utilizes ``tape on'' sensors that can be quickly installed in a complex natural environment to measure just a few or several hundred object states, depending upon how many sensors are used. A small team of researchers can install the system in a one-bedroom apartment containing a typical amount of clutter and complexity in about 3 hours. The devices have been used to continuously and passively collected data for two-week blocks in multiple subject homes. These subjects have had no affiliation with our research project.

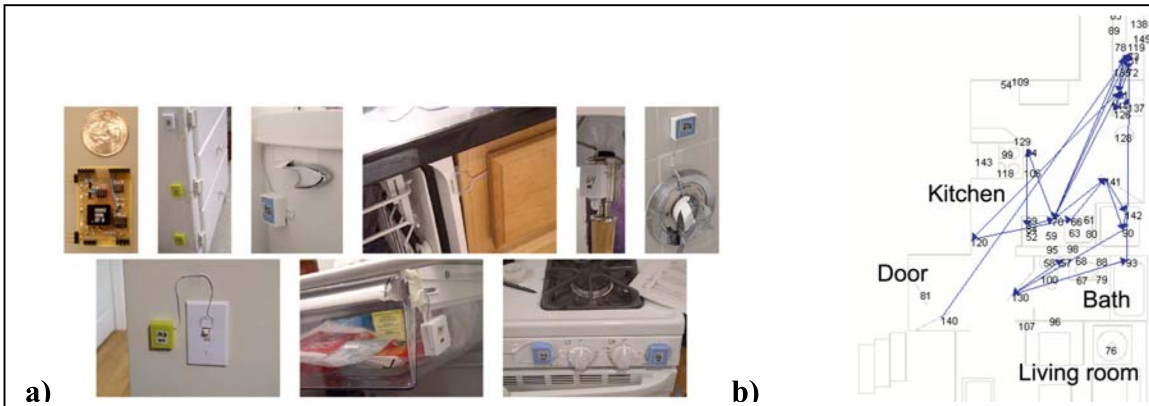

Figure 1: (a) Sensors that can be installed ubiquitously throughout an environment such as a home. Each device consists of a data collection board and a small sensor to detect movement, and the components are taped to objects and surfaces for the duration of the data collection period. These images show the data collection board outside of the protective case and 11 of the 85 sensors installed throughout one subject's home. (b) The data acquired from the sensors can be used to automatically recognize everyday activities (e.g. see (Munguia Tapia, 2003)) or, as shown here, presented in ways that help home occupants understand their behavior, such as how effectively they use their physical space (Beaudin, 2003).

Our design goals were to permit several hundred low-cost sensors to be installed in an environment for at least two weeks, left unattended, and then recovered with synchronized data. Figure 1 shows a sensor device, which consists of the sensor itself connected by a thin wire to a 27mm x 38mm x 12mm data collection board. The devices are robust and easy to use. Each fits snugly in a plastic case of dimensions 37mm x 44mm x 14mm. They use either reed switches, which are activated when brought into contact with a small magnet, or piezoelectric switches, which detect movement of a small plastic strip. The plastic cases are taped onto surfaces using a non-damaging adhesive. The sensor components (e.g. reed and magnet) and wire are then taped to the surface so that contact is measured. Figure 1 shows 11 of 85 sensors that were installed in the home of one subject. They can be attached to many devices in the home, including light switches, containers, and furniture. The sensors in this subject's home operated for 16 days. We have measured the synchronization between sensors to be +/- 2 seconds. The boards can record up to 3 activations and deactivations per second and can record a total of 2666 events in memory.

The total cost for parts and fabrication (in quantities of 150) for each data collection board as of February, 2003 was $24.66, where an additional $2 is required for each sensor (e.g. magnetic reed). When sensors are installed, each data collection board (which has a unique ID) is marked on a plan-view of the environment so that when the sensor data is collected the location and function of each sensor is known. We are sequentially installing and then removing the sensors in different subject homes, enabling us to use the same sensor kit to study many real homes. The hardware and software specifications for the devices are available on request.

Although other portable sensing systems for ubiquitous computing applications have been developed (Hollar, 2001; Kahn, Katz, & Pister, 1999; Kasten & Langheinrich, 2001; Mainwaring, Polastre, Szewczyk, Culler, & Anderson, 2002), we are unaware of prior work where 100+ of these devices have been rapidly deployed in multiple homes as ``tape on and forget'' devices and where data was collected from non-researcher occupants in real homes for several weeks. Several groups have hard-wired cabinets and mats (Abowd, 2002) and some kitchen appliances (Alwan, 2002), but these systems have not been deployed throughout entire homes because of the difficulty of installation and maintenance. The simplicity and small size of our data collection boards make it possible to cost-effectively deploy large numbers in non-laboratory settings. Although our boards are much simpler than distributed network devices such as the Berkeley motes, they are also significantly less expensive in parts and can operate for substantially longer time periods.

Direct study of the sensor data may be useful to some researchers. For instance, the total number of activations or frequency of activations of particular sensors may be of interest for specific inquiries (e.g. a sensor in a cabinet or drawer may offer clues about medication adherence or a light switch in the bedroom may offer clues about sleeping patterns). The data can also be transformed into representations used by researchers in qualitative interviews to help people learn about their own behavior. For instance, the data from the sensors has been used to help people understand how they use their own homes and how they might redesign them (Beaudin, 2003). Figure 1 shows one sequence of activations in a subject's home, where the arrows indicate sensors that triggered after each other. This representation permits a researcher to study patterns of movement about the environment.

The sensor data collected, however, is most useful when the sensor readings can be correlated with self-report or observational data about what people in an environment were actually doing at the time when objects in the environment were being manipulated. These activity labels are particularly important if the observation system is to be used to automatically collect data about behavior. With such labels, it becomes possible to create algorithms that recognize context automatically from the ubiquitous switch sensors using pattern classifiers customized to the individual using supervised learning (e.g. (Barger et al., 2002; Munguia Tapia, 2003)). We are exploring multiple strategies to obtain labeled training data using the toolkit. One strategy is to use mobile computing devices that periodically ask the user about his or her activity via multiple-choice questions (Intille, Rondoni, Kukla, Anacona, & Bao, 2003).

Based upon our experiences using these portable sensors, we are currently creating a second-generation sensor system. The devices will be smaller, even easier to install, and, unlike the current devices, permit real-time recognition of activities or changes in activities. We will continue to install the toolkits in real homes, studying both the technology itself and the way that the technology impacts occupant behavior.

The PlaceLab

To complement the portable sensor kit, we have designed a residential observational facility called the PlaceLab that will serve as a "living laboratory" to study how people respond to new proactive health technologies. Figure 1a shows a rendering of the living room of the facility, which is located a few blocks from MIT's campus in a residential condominium building. The facility will open in 2004 and is currently under construction. The 1000 sq. ft. home will (1) demonstrate how low-cost sensing technology can be embedded within the architecture of an environment in an aesthetically pleasing way, (2) provide an environment in which life in the home can be scientifically studied, and (3) provide a means for evaluating whether new pervasive computing interventions have a long-term and meaningful impact on proactive health behavior in the home.

The PlaceLab will be occupied by volunteer subjects who agree to live in the home for periods of days, weeks, or months, depending upon the studies being run. Researchers will have the capability to monitor nearly every aspect of life in the home using a cabinet-based integrated interior infill system (Larson) that permits hundreds of sensors to be inconspicuously placed in the environment and easily upgraded over time. Figure 1b shows a prototype cabinet. Fifteen variations of this cabinet will be distributed throughout the apartment. Every cabinet will contain the same suite of sensors for acquiring data on the movement of objects, the state of the environment, and auditory/visual imagery. Biometric data can also be obtained from wireless mobile computers worn by occupants. Figure 1c shows a control panel for the prototype.

Since the PlaceLab is a single apartment, experiments using the facility will be restricted to small sample sizes. However, the facility will complement the capabilities of the portable sensor kit. Studies can be run where multiple people are studied in the same environment or where the goal is to study how people adjust their behavior when they move into a new environment. The portable sensors could be used in combination

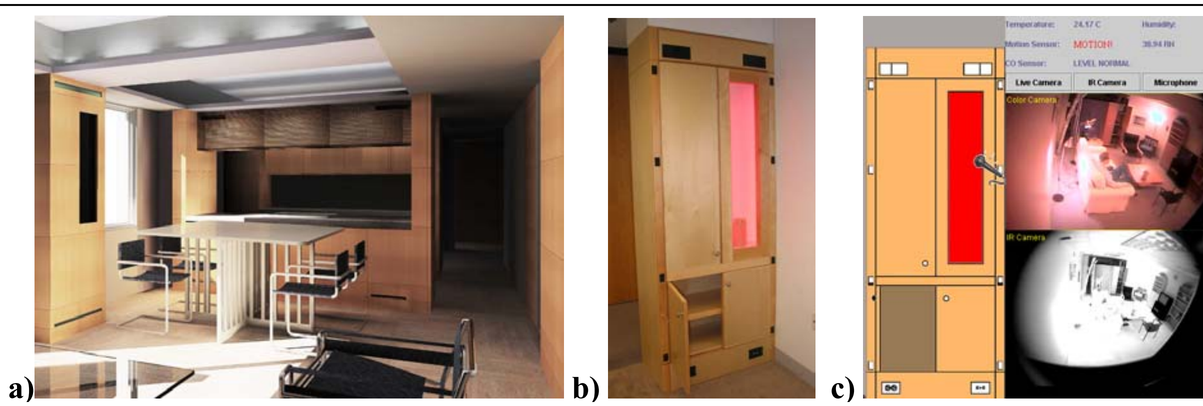

Figure 2: (a) A rendering of the living room of the PlaceLab, showing one cabinet on the left. (b) A prototype of that cabinet. Each cabinet has sensors for color video, infrared video, temperature, position, motion, doors, audio, and air quality. This cabinet also has audio output, 24-bit color output (red nook), and infrared floodlights. (c) A display showing the state of the doors, lighting, environmental sensors, and the two video streams from the prototype cabinet, updated in real time.

with the PlaceLab to study behavior in a subject's home before and after the subject stays in the PlaceLab. Most importantly, the PlaceLab has been designed so that subject responses to new computer-based "just-in-time" interventions can be observed, where the extensive sensor environment is used by algorithms to determine the best time to provide information.

The facility will be managed as a multi-disciplinary shared scientific tool in the tradition of other scientific facilities such as telescopes and microscopes developed to study unique environments. Researchers from many fields will submit proposals to a multi-disciplinary review board. High quality proposals will be those that (1) can only be accomplished with the facilities of the PlaceLab, (2) will fundamentally increase scientific understanding of issues related to life in the home, and (3) consider the long-term implications of the technology, system, or architecture being studied and potential to create societal change. The PlaceLab will be used to investigate questions relevant to designing proactive health technologies such as: (1) Can proactive technology remain effective over time without becoming annoying or invading privacy boundaries? (2) Can technology and architectural design motivate life-extending behavior changes? (3) Can technology help people proactively manage chronic disease and age-related dysfunction to support aging in place? We will begin running studies in the PlaceLab in 2004.

Conclusions

We are currently using our portable kit of sensors to study behavior in real home environments and to develop ideas and technologies to support proactive health care. In particular, we are developing and testing the technology necessary to realize the scenario for a peace-of-mind proactive health communication device described in this paper. We invite researchers who may be interested in using either the portable sensor toolkit or the PlaceLab in their own work to contact us.

Acknowledgements

The PlaceLab is collaboration between MIT and TIAX, LLC. T.J. McLeish, T. Lawrence, D. Moore-Pitman, and J. Hyman contributed to the design and construction of the prototype cabinet and control software. This work was supported, in part, by National Science Foundation Grant #0112900.

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