DigiSwitch: A device to allow older adults to monitor and direct the collection and transmission of health information collected at home

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Abstract Home monitoring represents an appealing alternative for older adults considering out-of-home long term care and an avenue for informal caregivers and health care providers to gain decision-critical information about an older adults' health and well-being. However, privacy concerns about having 24/7 monitoring, especially video monitoring, in the home environment have been cited as a major barrier in the design of home monitoring systems. In this paper we describe the design and evaluation of "DigiSwitch", a medical system designed to allow older adults to view information as it is collected about them and temporarily cease transmission of data for privacy reasons. Results from a series of iterative user studies suggest that control over the transmission of monitoring data from the home is helpful for maintaining user privacy. The studies demonstrate that older adults are able to use the DigiSwitch system to monitor and direct the collection and transmission of health information in their homes, providing these participants with a way to simultaneously maintain privacy and benefit from home monitoring technology.

Keywords Aging in place, Home monitoring, Home, Older adult, Privacy.

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Introduction

Advances in medicine and technology, improvements in healthcare access, and increases in economic resources have contributed to the growing numbers of older adults worldwide. In the United States alone, there are 38.8 million people over age 65 and the projected future older population is expected to reach 88.5 million by 2050 [2]. By that year current demographic estimates indicate that older adults will comprise more than 20% of the projected total population in the US.

A key challenge facing older adults is the ability to live independently. Almost universally, older adults want to age in place [34]. In addition to older adults' preference for familiar surroundings, living independently is considerably more cost effective for individuals, their families, and society, than institutionalized care. However there are a number of challenges facing older adults who wish to live independently, including the inability to perform activities of daily living [24], cognitive impairment [19, 24], functional dependence [24], medical burden [20], and even characteristics of caregivers [7, 8]. One hope is that medical systems may be able to reduce or eliminate some of these threats [30]. Specifically, human factors research can inform the design of medical systems that give older adults the support they need to remain in their home and maintain independence [28]. In this paper, we focus on the use of a medical system in the form of in-home monitoring to support older adults and their caregivers, enabling aging in place.

While traditional medical systems are designed for clinical settings, or are perhaps portable systems for targeted medical functions (e.g., insulin pumps), there is a strong move towards developing systems that empower patients and their informal caregivers such that they become more self-sufficient with their own care [35]. Under this new model, a system that supports patient-oriented, independent living is indeed a medical system. However, the design of such a system is very different than traditional medical devices and applications meant for clinical use. In particular, lay people (patients and their family members), who may have little computer experience or specialized education/training, are meant to use such systems. Thus, such systems require an additional focus on usability and safety.

To give one example, patients are currently screened very carefully when being considered for certain medical devices, such as home dialysis, to ensure they have the capacity and dedication to use such a system regularly and properly [36]. With aging in place technologies however, the patient is an older adult who may be unfamiliar with technology, and who is expected to eventually experience the mental or physical declines that the device is meant to counter. The design of a system that empowers older adults and their informal caregivers without undo burden requires user-centered design techniques that will result in systems that truly support independent living by taking advantage of older adults' capabilities and minimizing their limitations. Such techniques include contextual observations and interviews, focus groups, shadowing, participatory design sessions and in-situ evaluations. In this paper, we utilize a user-centered design process to investigate the design of DigiSwitch, a display allowing older adults to see and control the data collected about them by a home monitoring system.

1.1.1 Benefits of Home Monitoring

Home-based systems have the potential for a variety of health applications, from delivering information to monitoring individuals with chronic conditions [37]. Home monitoring offers a number of benefits to different stakeholders, ranging from the economic to the emotional. First, older adults benefit from home monitoring as it offers them the option to "age in place" rather than move to an assisted living facility. Aging in place is desirable to older adults for a variety of reasons. For instance, it provides an opportunity to live in familiar surroundings [25] and potentially preserve older adults' principal financial asset, the home. Caregivers benefit emotionally when a loved one ages in place because the decision to put a loved one in assisted living is often related to caregiver guilt [7]. Other economic stakeholders, (e.g., insurers, taxpayers, and family members paying out of pocket) benefit because aging in place is often a less expensive option than assisted living [15]. Finally, the larger community could benefit if the information from home monitoring were used for population level research.

1.2 Concerns about Monitoring

Despite the multitude of potential benefits of home monitoring, there are concerns to be addressed. Many barriers to the successful design and use of health technologies are directly related to privacy. In one large survey, 67% of participants reported that they were "very concerned" or "somewhat concerned" about the privacy of their health records [6]. Thus, privacy is widely considered to be a major barrier in the adoption of Personal Health Records [31], which may contain information collected from personal monitoring devices (e.g., in a non-home setting, pedometers).

Besides general concerns over the automated collection and dissemination of health information, there is a more specific concern about privacy when monitoring devices are used in the home [9]. This specific concern about monitoring in the home has two parts. In the case of smart or aware home, where the goal is to create a ubiquitous computing environment where processing and sensing are invisible or inaccessible to users, older adults may not be fully aware of what information is being collected about them [16]. Second, it is important to maintain the special privacy affordances of the home. Therefore, monitoring in that particular context requires special consideration. Many researchers have pointed specifically to the need to understand the impacts on perceived privacy when introducing technology into the home environment [3, 5, 10, 11, 28]. Going even further, Beckwith [39] suggests that it is part of designers' responsibility to align perceived and actual privacy by integrating conservative, understandable, and well-defined mechanisms for data use and retention.

In addition to a designer's responsibility to privacy, the designer must also consider other variables such as the age of the user. Although previous research shows that older adults are concerned about privacy in monitored home environments [5, 11], they, like people from many other age groups, may underestimate how much information they reveal when interacting via computer mediated channels [1]. One reason older adults underestimate privacy risks may be that they are unaware of the information being compiled about them when they use any of the myriad of technologies available to them. Thus, one barrier to overcome in the design of home monitoring technologies is *transparency*.

While transparency is an issue for everyone in managing their privacy, older adults may be subject to additional considerations that affect their privacy decisions. For example, older adults tend to prioritize health, safety, independence, and their perceived needs for technology over privacy concerns [3]. While older adults may lose relatively less privacy to home health care technology compared to a move into a nursing home [29], this does not mean that privacy in a monitored home can be neglected. In a home that is constantly monitored, older adults may feel that they are never in a position to be let alone (cf. [40]). Once a user understands what data are being collected about him or her (i.e., the system is transparent), the ability to impact a sense that one may be let alone, or control, can be enabled by allowing the user to determine if and when those data are collected and shared. Thus, a second barrier a home monitoring system must overcome is control.

1.3 Previous Approaches to Overcoming Privacy Barriers

Previous research has proposed approaches to overcoming privacy barriers in other contexts of use. For the purpose of providing background, we discuss two of these approaches below.

1.3.1.1 Obfuscation

Many approaches to preserving privacy within the home involve collecting video data and then augmenting it so as to obfuscate the activities (e.g., eigen-space filtering) [14]. However, obfuscation techniques have been shown to be insufficient for preserving a sense of privacy among users [26]. In their study of home based video conferencing, Neustaedter et al. [26] found that there were no levels of obfuscation that balanced privacy and awareness across all situations.

1.3.1.2 Feedback

The idea that feedback is important in awareness systems—especially media spaces—is not new. Bellotti et al. [4] pointed out the challenges in providing appropriate feedback to users so that they may be aware of the "system's attention" and questioned how best to direct feedback to "the zone of user attention." More recently, Tsai et al. [31] demonstrated that providing feedback in a location-sharing application allayed users' privacy concerns and increased their comfort levels.

1.4 Our Approach to Overcoming Privacy Barriers

Clearly, it is critical to address privacy barriers in the design of home health monitoring systems. We recognize and acknowledge that data flows across physical boundaries (such as the walls of homes) and among individuals who are close (such as an older adult and a family caregiver) and propose that, for many of the reasons we have outlined, home-based computing offers challenges that are best met by bridging data privacy (where privacy rests upon the management of data collected and used by large organizations) and personal privacy (where privacy is an interpersonal concern).

Given these requirements the designers of monitoring systems often struggle to balance flexibility with privacy protections for personal data. While regulations, law, and limiting the number of people who have access to medical data help address privacy issues with respect to data in the clinical setting [38], home-based systems are by their nature less regulated, and potentially expose data to more individuals. Our argument is that technologies such as these require a different overall approach to privacy.

Building upon these prior findings and approaches, our approach to reducing privacy barriers was threefold. First, we recast obfuscation as data type. Because obfuscation has been shown to be an insufficient technique for preserving a sense of privacy [26], we hypothesized that collecting different types of data (e.g., video, motion, sleep pattern), rather than simply making one data type less information rich, would reduce privacy concerns. Thus, we designed each prototype in our system to capture different kinds of information about everyday activities. For example, one device captures motion data while another collects video images.

The second prong of our approach builds on existing ideas of feedback (e.g. [4, 31]). In our system, we wanted users to be aware of data that were being collected about them. We sought to make the flow of data—and thus the privacy risks—visible [33] so users could see what was being collected and transmitted.

Finally, we propose that, in addition to the previous approaches of data type (i.e., obfuscation) and data awareness (i.e., feedback), control over the distribution of data is critical for user privacy. Thus, in our system we put users in control of whether and when information about them is collected and transmitted to others (in this case, a non-co-located caregiver). Each prong of our approach is described in detail below.

1.4.1 Data Type

One solution to the problem of preserving privacy when using monitoring systems in the home is to transmit data that are rich in some types of information (e.g., safety information), while impoverished in other types of information (e.g., identity). Arguably, collecting motion sensor data, for example, should be considered less privacy-invasive than collecting video data because motion sensor data, while providing activity level information, does not provide identity information. Indeed, it was found that older adults considered visual sensing data such as images from a blob tracker to be less concerning from a privacy standpoint than video data [10].

In our system, we were interested in collecting a variety of types of data to test whether different types of data (e.g., motion sensor vs. video) would result in different levels of privacy concern. Thus, we designed three devices that each collected different data types.

The devices include a Presence Clock, a Beacon Strip, and video cameras. The Presence Clock consists of a pair of devices that collect and display presence information using a motion sensor [17]. The Presence Clock resembles an old-fashioned wall clock but is enhanced with LED lights and motion sensors and requires a second Presence Clock, not co-located, to function fully. When the clock senses nearby motion, LED lights on the partner clock (located in another home, potentially that of a caregiver), light up to indicate that motion. This function is reciprocal, so both owners of the clock can view the other owner’s presence near the clock. The Beacon Strip is a dual function device that both assists users in finding their way to the restroom at night and simultaneously gathers sleep pattern data. Sleep pattern data is collected by a pressure sensor placed under the mattress and is visualized as a simple line graph showing weight in the bed at different times of the day. A flat line would indicate no change in pressure while several peaks would indicate movement while in bed (e.g., Figure 1). Finally, the video camera collects video images from the home of an older adult user.

1.4.2 Data Awareness

Increasing data transparency can increase awareness of data compilations and thus may enhance older adults' understanding of the potential privacy risks associated with the devices in their home monitoring system. Transparency requires more than that no data compilation about an individual be kept secret from that individual. While it is implicit that an older adult will be aware that monitoring technology is being installed in his or her home, we propose that the user must also be able to see and understand what data are being compiled and transmitted in order to be transparent.

In our system, we wanted to ensure that users were aware of exactly what data a caregiver would be able to access. In addition, we wanted the content of the data awareness be presented in a way that was easily understandable by the user. We sought to keep data flows transparent [33] to facilitate a sense of participation, rather than a sense of being invaded upon. Thus, we designed the DigiSwitch, a touch-screen computer integrated into an everyday object in the home, a digital picture frame. Within the DigiSwitch, we include a "Friend's View" screen which allows the user to see exactly what his or her caregiver is seeing. One goal of the DigiSwitch is to increase data awareness and thus provide a key step towards transparency.

1.4.3 Data Control

Determining information a user considers particularly sensitive has proven to be difficult. One problem is that the sensitivity of information is often a function of the recipient of the information [13, 22, 23]. In addition, it seems that individuals have different privacy concerns and sharing tolerance [21]. An alternative to determining an individuals' perception of the sensitivity of a specific piece of information a priori is to allow the individual to regulate what information is captured and transmitted.

The key innovation of the DigiSwitch, or digital switchboard (named as a reference to the original switchboard which routed telephone calls), is that it gives users the ability to cease transmitting data with the flick of a digital switch. Thus the users of the technology can easily retain complete control of the information provided to a particular recipient. An older adult user can control the flow of information collected about them by the devices in their home monitoring system via the DigiSwitch interface without having any particular technological expertise.

In addition to controlling the flow of information collected via sensors in the home (e.g., video data), we also designed DigiSwitch to preserve state privacy. State privacy or "device state privacy" refers to information transmitted from a particular device about how and if it is currently functioning. For the DigiSwitch to preserve state privacy, we needed to provide a way for the older adult user to be able to turn off a device, but not have the state of the device (i.e., off) be leaked to the caregiver. Thus, we needed to have a setting where no real time data was collected about the older adult, yet the caregiver was not aware that this was the case. To accomplish this, we designed a function that did not transmit real time data, but instead transmitted cached data for a certain period of time. For the purposes of the study, we used previously archived data and transmitted that to the caregiver in place of real time data transmission. This allowed a participant complete temporary privacy in that the caregiver would be unaware of any activity in the home while simultaneously unaware that the user had paused real time transmission (i.e., providing state privacy). The idea that to ensure complete privacy requires not only the ability to temporarily cease transmission, but also to avoid leaking device state information to the caregiver is another key innovation of the DigiSwitch.

1.5 Evaluating DigiSwitch: Three Studies

In the remainder of the paper, we present three studies we conducted to evaluate and refine DigiSwitch. First, we present findings from a study with three focus groups. These focus groups were designed to elicit perceptions and ideas regarding the concept of a central control device for home monitoring systems. Second, we present findings from a survey conducted with the same participants, related to the technologies they had discussed previously. Third, we describe the development of a DigiSwitch prototype based on these findings. We then present results of a study that examines whether older adults could use DigiSwitch effectively. Finally, we conclude that mechanisms that allow data subjects to be aware of information compilations, and control the transmission of that information to others, holds tremendous potential to resolve the conflict between the promise of health information technologies and threats to privacy.

2. STUDY 1: FOCUS GROUPS

2.1 Participants

Participants were 48 older adults (28 female) between the ages of 53 and 83 (M = 70.02 SD = 7.87) who volunteered to be part of the study. Potential participants were recruited from the local community through flyers and by word of mouth. Participants did not receive monetary remuneration, but were provided with a meal during the study.

2.2 Procedure

All participants visited the Ethical Technologies in the Homes of Seniors (ETHOS) Living Lab [17] located on the campus of Indiana University. The Living Lab is a lab inside a historic home equipped with working prototypes of many technologies being tested for use in the homes of older adults. The house also has lab space for user testing, focus groups, and interviews. Participants toured the home in groups of 6-8 people. After a brief tour of the house, participants congregated for a focus group session that lasted one to two hours. Each focus group session was conducted by a member of the research team. A trained note-taker recorded the discussion from the focus group sessions. Each focus group session covered three main topics: 1) an overview of the functionality of DigiSwitch, 2) general concerns about the device, and 3) privacy concerns.

2.3 Results

The notes from the three focus group sessions were examined for thematic content by two members of the research team. Themes that emerged related to the DigiSwitch are discussed below.

2.3.1 Control Over Devices

One overall theme that emerged was that participants wanted to be able to turn devices on and off individually rather than turn off the system as a whole. Participants suggested that the ability to turn off individual devices would increase their ability to manage privacy. One participant suggested that users would want to be able to turn off the video recording devices in particular (FG1). This was in contrast to other devices where it might be preferable for them to be on all the time. For example, other participants suggested that some devices, such as those that merely indicated presence (i.e., presence clock) should be left on all the time (FG1 & FG3).

2.3.2 Simplicity

A second theme that was woven throughout the focus group discussion was the importance of simplicity. Participants stressed the importance of keeping technology simple for older people.

Several participants mentioned that a simple on/off mechanism would be more useful than a more complete, but more complicated set up: “on or off would be enough of a choice” (FG1). Participants likened the on/off functionality to familiar models of on/off devices used in everyday life: it should work like a “light switch” (FG3). Finally participants suggested that even if the technology had additional options, older adults might not use them: “There is a limit to how much fine-tuning” older people will want to do (FG2).

3. STUDY 2: SURVEY

3.1 Participants

Participants were the same participants described in Study 1.

3.2 Materials

3.2.1 Survey

The survey contained three sets of questions: demographic questions, technology experience queries, and a home monitoring poll. For the purposes of this article, only questions related to DigiSwitch (a subset of questions about monitoring technologies) will be discussed. The DigiSwitch questions enquired about participants’ anticipated use of the DigiSwitch prototype:

1. “Would you turn off any of the devices [using DigiSwitch] from time to time?” with responses including “very likely” “somewhat likely” “not likely” “no” and “don’t know”;

2. “If you turned a device off, would you like it to re-start automatically at a set time or would you prefer to turn it back on manually?” with responses including “re-start automatically” “turn it on manually” and “don’t know”;

3. “Would you like to be able to keep a caregiver from knowing a device was off?” with responses including “yes” “perhaps” and “no”.

3.3 Procedure

Participants were asked to take a survey related to the same technologies they had discussed previously in the focus group.

3.4 Results

3.4.1 Intention to Use DigiSwitch to Turn off Devices

As shown in Table 1, the majority of participants reported that they would be likely to turn off monitoring devices in their home from time to time to protect their privacy. The largest percentage of participants reported that they would be very likely to turn off at least one device, while few participants (9%) reported that they would not turn off any of the devices.

3.4.2 Automatic Restart of Monitoring

As shown in Table 2, most participants reported that if they turned off a device they would want it to resume transmitting automatically. Slightly less than a third of participants reported that they would want to manually restart the recording/transmitting, while 13% did not know which option they would prefer. One participant created his own option indicating he would want both options (i.e., manual and automatic resume).

3.4.3 Caregiver Knowledge of Device Status

As shown in Table 3, a slight majority of participants reported that they would (or perhaps would) like the ability to hide the status of devices from a potential caregiver. Forty-eight percent of participants reported that they would not want this functionality.

4. DISCUSSION OF STUDIES 1 & 2

4.1 Control Over Devices

When asked about whether they would like to have control over the collection and transmission of monitoring data in the home, most participants reported that they would like to have such control. This suggests that in addition to data awareness and data type, data control may be an important aspect of preserving privacy in a monitored home.

4.2 Device Simplicity

The need for simplicity in an interface to control multiple home monitoring devices was consistently present in both the survey and focus groups. The majority of participants reported that they would want a device to automatically resume collecting/transmitting after it had been turned off or "paused" for some period of time. This automatic feature could increase device simplicity in that it would not rely on participants to actively restart the data collection. Technology that assists in areas where users have difficulty (e.g., the prospective memory task of remembering to turn a device back on) may also enhance ease of use.

In addition, participants felt it was especially important to focus on a simple, easy to use interface given the user population. While technology use among older adults has been increasing, older adults still use fewer technologies compared to younger adults [25] and therefore may gain additional benefits from easy to use designs.

5. IMPLICATIONS FOR DIGISWITCH

5.1 DigiSwitch User Interface

Based on the findings from the user study, we developed a prototype of DigiSwitch (see Figure 2). This prototype was implemented on a touch-screen capable panel PC, which also acts as a digital picture frame. The choice to implement DigiSwitch as a digital picture frame had two inspirations. First, we wanted the device to function both as a normal household object (i.e., digital picture frame) as well as a ubiquitous computing system that could provide users with full control over the home health monitoring devices in their home. The touch-screen capability also removes the need to have extraneous computer peripherals such as a keyboard and mouse. Second, we expected that having a device that only served as a digital switchboard might be a privacy risk in and of itself; a highly distinctive DigiSwitch interface might inherently communicate the existence of a home monitoring system, while a digital photo frame would not.

5.1.1 The Main Screen

Prior to v1 of the interface, the naming scheme for the text on the buttons was "On, Off, and Hide" which reflected our original plan to allow users to turn on and off all devices as a group. However, in the focus group, participants told us they wanted to be able to turn each device on and off individually (e.g., turn off the video camera while leaving the clock on). In addition, in the survey, the majority of participants reported that they would be likely to use the DigiSwitch to turn at least one device off from time to time. Thus, we needed a naming scheme that reflected that devices could be turned on or off individually or as a group. For the group function, we chose to use "Start All, Stop All, and Pause" respectively reflecting the familiar Stop-Start-Pause model from other technologies likely to be familiar to older adults (e.g., VCR, camcorder).

The Start button allows the user to turn on devices, while the Stop button turns off the devices. The Stop function also allows the user to choose how long they want the device(s) to stay turned off before they are automatically turned back on. The device buttons toggle devices between on, off, or paused; pressing once will change the status to Pause mode and two presses will change it to Stop mode. The color of each button changes according to the mode; green corresponds to Start, red to Stop and yellow to Pause.

The buttons on the left hand of the screen change the status of all devices and the buttons on the right change the status of each device individually. The design decision to allow users to control the status of each device individually was driven by findings from Studies 1 and 2. The design was intended to maximize both simplicity and control.

5.1.2 The Pause Feature

The Pause feature allows users to pause the device(s) so that no additional real time data are collected and transmitted to the caregiver (see Figure 4). This design feature reflects findings from the survey where a slight majority of participants reported that they would like to have the ability to hide the status of devices from a potential caregiver. The Pause feature allows the user to cease data transmission while keeping device status private from the data recipient (i.e., state privacy).

5.1.3 Timer

The timer interface was designed to allow the user to set a specified pause time for all devices or for each device individually (see Figure 5). The default Pause time is set to 30 minutes with up and down arrows added to allow the user to easily change the time. When the specified time set by the user expires, the device(s) would return to the On state. Similarly, the Stop function also allows the user to choose how long they want the device(s) to stay turned off before it is automatically turned back on.

5.1.4 Spatial View

Because previous work in the area of monitoring devices in the homes of older adults shows that users have different levels of privacy tolerance in different rooms of the house [11], in addition to different levels of privacy tolerance according to type of device, we created a Spatial View, which allows the user to view the devices according to the space in their home. As shown in Figure 3, the devices in Spatial View are organized according to the rooms in the home. The device(s) that is installed in each room is listed under that room. Users can switch between Spatial View and Device View using the toggle button.

5.1.5 Friend's View

The Friend's View panel was designed to allow the user to see exactly what their caregiver is seeing (see Figure 6). The design goal of this feature was to provide data awareness to the older adult. Both the older adult and their caregiver are able to view this screen. However, neither the caregiver nor the older adult can make any changes to the settings from this screen. If the older adult wants to make a change, he or she must return to the main screen and change settings from there. The background of the friend's view is blue to differentiate between the old adult's own view and their caregiver's view. There are two buttons at the bottom of the screen. The Main Panel button takes the user to back to their home screen. The Exit button returns the user to the digital picture screen.

The stoplight metaphor is used again here. Red means the device(s) is Stopped and data are not transmitted. Green means the device(s) is On and data are transmitted. However, when a device is Paused, it is not shown in yellow. Instead, the device is shown in green as if it is transmitting data. Recall that when a user chooses to Pause a device, the device is not actually transmitting real data;n the Friend's View the caregiver is shown archived data. By allowing the user to see the friend's panel, they can be fully aware of what data are or are not being transmitted in real time. This enhances transparency by providing a visualization of the caregiver's view.

In the next section, we evaluate many of these interface features.

6. STUDY 3: USABILITY STUDY

We conducted a usability study of DigiSwitch with 7 older adult participants. The goal of this study was to determine whether older adults were able to use DigiSwitch to manage their privacy. Specifically we were interested in the following research questions:

1. Task Completion: Can participants complete privacy management tasks including access sharing functions and modify device states?

2. Comprehension: Did participants understand the visual representations and metaphors used in the prototype?

3. User Preference: What were users' preferences about control panel options including setting timers, view options, and pausing vs. stopping?

In terms of task completion, we were interested in whether users were able to access device functions, including access the DigiSwitch interface from the initial screen, access the view that a caregiver would see, alter the state of each device (e.g., Start, Stop, and Pause all devices, turn off only one device, turn on only one device), and adjust the amount of time a device (or devices) is/are to be paused.

In terms of comprehension, we were interested in assessing how well the visual representations and metaphors we chose for DigiSwitch were initially understood by users. Our goal was to make the interface immediately usable by participants, thereby requiring little to no training upon installation. Specifically, we were interested in assessing whether participants recognized what each icon represented and sought to determine to what degree the participants understood the state of each device, the red/yellow/green stoplight metaphor, what information was shared, and with whom.

Finally, in terms of participant preference, we were interested in understanding user preference with respect to setting a time for a device to return to the sharing mode (e.g., 9 PM) versus setting an amount of time (e.g., 30 minutes) after which the device would return to the sharing mode; preference for a "room view" or a "device view" (described in Section 7.3.2); and preferences about ceasing transmission (both temporary and permanently).

6.1 Method

6.1.1 Participants

Participants were recruited from an existing database of older adults who had previously expressed interest in taking part in research studies. Of the 7 participants, 4 were women. Participants were between the ages of 67 and 84 (M = 73.57 SD = 6.32). All participants lived independently in their own homes and reported that they used computers and the internet frequently. Despite reports of frequent use, participants reported different levels of skill with using computers (see Table 4). Three participants reported experience using a touch screen device while 4 participants reported no experience using a touch screen device.

6.2 Materials

6.2.1 Prototype

The goal of the initial prototype was to create a touch screen interface that older adults could use to control monitoring devices in their home. The first iteration (v1, see Section 2.1) was informed by a focus group and survey, and the final iteration (v2, see Section 5) was informed by the current study.

6.2.2 Procedure

All usability study sessions were conducted at the ETHOS house at Indiana University [17].

First, participants gave informed consent. Next, participants were given a tour of the home. During the tour, participants were shown the devices described in Section 1.4.1 (Presence Clock, Beacon Strip, and video camera) and given a brief description of how each device worked. Next, participants were seated at a table in the living room of the ETHOS house. The moderator introduced the goals of the study and explained the general procedure, and instructed participants to interact with the prototype as if it were a working touch screen device. In addition, participants were instructed to think aloud as they completed tasks.

7. RESULTS AND DISCUSSION OF USABILITY STUDY

For ease of presentation and discussion, results are organized by research question.

7.1 Task Completion

7.1.1 Could Users Access Device Functions?

Access to control panel interface. No users had problems touching the personal digital photo to elicit the main control panel screen.

Access to the view that a caregiver would see. While most users did not have trouble touching the Friend Panel button (see Figure 2) to access the view that a caregiver would see, one participant was confused as to how to access the caregiver's view. Instead of touching the button to access the Friend Panel, he touched the Spatial View button. When the prototype screen showed the Spatial View with the devices arranged according to the home spaces (that would have appeared given this selection), he touched the Room View button. Although other users did not experience similar problems, other participants did express related concerns. One user noted that using the caregiver's name instead of just "Friend Panel" would make it more personal, more memorable and more immediately obvious that this button would lead to the caregiver's view.

Based on this feedback we changed the title of the button from Friend Panel to a more personalized <name of caregiver>'s View to clarify with whom information would be shared (see Figure 7). Here the text inside of the < > would contain the name of the caregiver. For example, if the caregiver's name is "Dorothy" the button would read: "Dorothy's View". Next, we changed the color of the friend view button so that it was consistent with the background color on the Friend View display. Finally, we extended the length of the button, though this decision was primarily driven by the addition of a tabbed view for device state status (see Section 7.3.2).

7.1.2 Could Users Alter the State of Each Device?

Start all devices. All users were able to Start all devices by pressing the Start All button.

Stop/Pause. All users were able to Stop/Pause all devices by pressing the Stop or Pause button.

Altering the state of one device. All participants were able to Stop and Start devices individually by pressing the icon within the device frame.

Based on the successful completion of all device state altering tasks, this portion of the interface was retained in the final version.

7.1.3 Could Users Adjust the Amount of Time a Device Was Paused?

In the initial design, as shown in Figure 5, once the participant pressed Pause, an alert was displayed asking the user for confirmation of a default time setting (30 minutes).

Although we did not measure the precise time on task, users spent a greater amount of time reading this dialogue as compared to other tasks. Study participants were confused about whether to press “yes” or “no” in response to the dialogue. Therefore, we removed the alert screen altogether and instead provided users a screen with a default pause time of 30 minutes, which was adjustable to their preference (see Figure 8).

7.2 Comprehension

In this section we examine how well participants appeared to understand the aspects of the interface.

7.2.1 Device Names

Despite being shown the Beacon Strip during the tour of the house (where the tour guide called the device the Beacon Strip), two participants did not realize that the Beacon Strip was the device designed to light their path to the restroom at night. Based on this feedback, we changed the name of the Beacon Strip to Nightlight.

7.2.2 Icon Recognition

Two participants expressed that they did not understand what the lighthouse icon had to do with the Beacon Strip. Based on this feedback, we changed the icon for the Beacon Strip to a light bulb to coincide with the name change from Beacon Strip to Nightlight (see Figure 9; see also 7.2.1).

Finally, we changed the exit icon from a large red X to an arrow pointing through a door (see Figure 10) because 2 participants thought that pressing the X would turn off the DigiSwitch completely.

7.2.3 Intuitive Understanding of Device State

Upon initial inspection of the device frame, all participants but one were able to immediately understand that all devices were on (see Figure 2). The one participant who did not understand upon immediate inspection, did understand after she saw the second screen (which contained paused devices indicated by the color yellow – see Figure 4). Because all participants were able to understand the device state with minimal interaction with DigiSwitch, we did not make any changes to the device state display.

7.2.4 Understanding of Shared Information

Upon encountering the Friend's View, all participants were able to articulate that the information being displayed to them was the same information that a caregiver would be able to see. The one area of confusion on the friend/caregiver view was how to return to the main screen. Participants were unsure whether to press My Panel or Exit. Based on this confusion, we changed the name of the button to return to the main screen from Main Panel to My Panel (see Figure 11).

Similar to the change we made in "access to what a caregiver would see" as described in Section 7.1.1, we also changed the hard coded title Friend's View to the more personalized <caregiver>'s View.

7.2.5 Stoplight Metaphor

All participants easily understood the stoplight metaphor and were able to explain all three states. Recall that devices were on when the background was green, paused when the background was yellow, and off when the background was red. Based on this finding we retained the stoplight metaphor.

7.2.6 VCR Metaphor

In v1, the main controls to start, stop, or pause all data gathering and transmission were called "start all", "stop all", and "pause". These controls, while differently named are similar in function to the controls on a VCR. On a VCR the functions are "play", "pause", and "stop". Similar to play, "start all" begins transmission of all devices. Similar to stop, "stop all" stops transmission of all devices for a specific period of time. Pause is also analogous to the pause function of a VCR in that it temporarily stops transmission. However, in the case of the DigiSwitch, pause has the additional feature of transmitting archived data to a caregiver to preserve state privacy.

When we asked participants to describe each of these functions the results were mixed. All participants understood "start all" to mean that all devices were on, capturing and transmitting real time data. However when we asked participants to describe "stop all" all participants thought that this function would stop all devices from collecting and transmitting data permanently (recall, in our design, this function only stopped transmission temporarily). On a related note, participants thought "pause" would cease collecting and transmitting real time data, but for only a specified period of time at which point real time data transmission would resume automatically. Additionally, participants did not express an understanding that "pause" included transmitting archived data to the caregiver.

Based on these findings, we understood that we needed to change the metaphor for the stop and pause function. However, we still felt it was important to allow users to cease transmission of real data, but keep the fact that they were not transmitting real time data to the caregiver. So, we renamed the function "me time" to reduce confusion with the idea of "pausing" being one of stopping recording for a short period of time, as well as to enhance users' understanding that the “me time” function would allow them to cease transmitting real data to a caregiver, and maintain state privacy. In concert with this change, we renamed “stop all” to “pause all” to reflect that the original “stop all” command would only cease data transmission for a specific period of time, rather than for good, or until the user turned the devices back on. Thus, as shown in Table 5 in v2 of the control panel interface we changed “stop all” to “pause all” and “pause” to “me time”.

7.3 User Preferences

7.3.1 Pause “For” vs. Pause “Until”

We tested two alternative default Pause function dialogues. The first dialogue was a Pause For dialogue (see Figure 8) where the user could control the amount of time the device or devices were paused using number of minutes. The second dialogue was a Pause Until dialogue (see Figure 12) where the user could set a specific time at which they wanted the device or devices to resume transmission.

Regardless of which dialogue they encountered first (we counterbalanced dialogue introduction), all participants preferred the Pause For to the Pause Until dialogue. Participants reported that they did not want to have to check a clock to determine the current time in order to utilize the Pause function. They thought that it would be easier to simply input the amount of time they wished devices to wait to resume transmission.

7.3.2 “Room View” vs. “Device View”

During the focus groups, participants expressed that they liked being able to control each device individually rather than having to turn on/off all devices. Thus, we developed an interface to allow users to turn off individual devices by device and by room.

Removed unused rooms from device view. In the initial iteration (see Figure 2) of the Device View, the interface showed all devices in the home. In the case where a device was not installed in one of the default rooms, the room title was grayed out. However, 3 participants tried to press the grayed out rooms to, we assume, toggle the devices in said rooms to Start, Stop or Pause (see Figure 2). So, in the final version, we removed rooms where no device was installed.

We also tested two alternative default device frame views. The first device frame was Device View (see Figure 13). In the device view, the buttons are arranged according to the type of device. On the other hand the Room View" (see Figure 14), the buttons are arranged according to the space in the users' home (i.e., by room). Participants were able to use both device frame view successfully.

When showing users the initial device frame, we counterbalanced room view and device view. Regardless of device frame view, participants preferred the view they encountered first (so, if Mary saw Room View first, that was the one she reported she preferred). Based on this finding, we determined that the Room View and Device View were similar in terms of usability and preference, and thus needed different criteria for choosing which view to use in the final version. We examined existing literature on privacy in smart homes, and found that previous formative work showed that participants expressed the desire to be able to control devices in specific rooms of the house [5][11]. Based on this previous research we chose the Room View as the default view for the final iteration. Device View is also available as a tabbed selection (see Figure 14).

7.3.3 Digital Photo Frame to Panel Transition

As described in Section 5.1, DigiSwitch usually functions as a normal digital picture frame, with a rotating display of personal photos. In our initial prototype, we designed the photo frame such that DigiSwitch screen would appear when motion was detected near the screen.

However, during usability testing, users resisted this idea for privacy reasons. Users stated that they would not want the panel screen to be automatically displayed when motion was detected because they worried someone other than them would create motion near the photo frame, and therefore trigger DigiSwitch screen and become aware of the dual purpose of the device. Rather, participants said they wanted to be able to access DigiSwitch, but keep visitors to the home unaware that DigiSwitch existed.

In light of this finding, we redesigned the photo frame transition to be an "on touch" transition instead of an "on motion" transition. Therefore, only a user who touches the photo frame will see the DigiSwitch interface.

8. CONCLUSION

In this paper we describe the design and evaluation of DigiSwitch, a device designed to allow subjects of home health monitoring technology to see and control what information is collected about them, including temporarily ceasing transmission of data for privacy reasons. Overall, we found that users were able to complete most privacy management tasks. Participants understood many of the metaphors, names and states in the device, but were unclear about Room View vs. Device View. Participants uniformly preferred a "pause for" functionality over a "pause until" option. Our results illustrate that when designed appropriately, older adults can use Digiswitch or a similar device to successfully manage their privacy in a home equipped with health monitoring equipment.

As the older adult population, particularly the 85+ age group, continues to grow, supporting independent living in later life is a critical concern for older adults, their families, and private/public third party payers such as Medicare. Technologies to support aging in place are one potential approach to supporting health and quality of life while reducing costs and caregiver burden. Technologies like the Digiswitch have potential not only for individuals wishing to age in place, but for community living arrangements including assisted living, retirement communities, and long term care. But it is essential that these technologies be empowering; they should not force one to cede one's privacy; specifically, the right to be let alone. Furthermore, the choice to use such technologies should not be seen as a choice to forego the ability to maintain control over if and when monitoring occurs. Rather, technologies like the DigiSwitch suggest an ethical approach to home monitoring, where the aging adult retains a sense of the home as a haven. This represents an approach to design for older adults that is grounded in respect for autonomy, relationship, and privacy.

8.1 Contribution

To date, much of the research on technology to support aging in place has not been adequately informed by models or theories of aging; we see this as a critical gap in the literature that hinders the field. Interdisciplinary theories from the fields of gerontology, human computer interaction, and privacy can and should address the intersection of aging, technology, and the home. Theories of aging suggest that older adults' perceptions of privacy are contextual, individualized, and influenced by psychosocial motivations of later life [23]. One size fits all approaches to technologies in the home overlook the highly individual experience of aging, the nature and importance of relationships in later life, and the desire for personal autonomy. Technologies like the DigiSwitch, informed through interdisciplinary research, are designed to satisfy user preferences including those for data type, data awareness, and data control.

The contribution of this paper is three-fold. First, we described the design of a suite of technologies for monitoring the health and well being of older adults in their homes and some of the literature-driven motivations for their design. Second, we presented DigiSwitch, a complementary device that allows users to both maintain awareness of what information is collected and regulate the flow of information to others. Finally, we presented the results from a user study suggesting that older adult users are able to use DigiSwitch effectively. Thus, the system may provide older adults, their caregivers, and healthcare providers with a way to monitor at-home health and well-being while simultaneously maintaining privacy.

In addition, the work described here has implications beyond the design of a monitoring system for use in the homes of older adults. More broadly, this work is an important first step in designing a range of privacy-enhanced health systems. For example, lessons learned in this study, such as the need for a simple interface that allows users to control who has access to their data, while simultaneously maintaining state privacy may be well suited to the design of privacy enhanced electronic health records (EHRs) and patient health records (PHRs). A key element of such systems will be providing usable privacy management options specifically designed for the user population.

8.2 Future Work

In the future, we plan to deploy the DigiSwitch-enabled suite of devices to further assess usability, usefulness, and acceptability. We expect to learn more about older adults' ability and propensity to use the DigiSwitch (or a similar device) to monitor collection and control transmission of information to caregivers and health care providers. We are also interested in exploring the effects on perceived privacy, and effects on the older adult–caregiver relationship when the DigiSwitch is used in situ. Finally, we hope to explore how the lessons learned in this study may inform the design of other privacy enhanced health systems.

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