An Action Design Research of a Sensor-Based Elderly Monitoring System for Aging-in-Place

Short Paper

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Abstract

In recent years, in-home Sensor-based Elderly Monitoring Systems (SEMS) have penetrated the healthcare domain as cost-effective assisted living solutions to ensure safety and wellbeing of community dwelling elderly. Such systems are favoured by the elderly due to the unobtrusive and passive nature of monitoring. Building on a situation-awareness perspective, this research proposes a set of principles for the design of elderly monitoring systems. By adopting an Action Design Research (ADR) method, we analyzed the case of SHINESeniors project, a successful SEMS implementation in a natural community setting. This research is arguably the first to explore the design principles of a sensor-based monitoring system. When completed, our study is envisioned to shed light on challenges in implementing digitally assisted aging-in-place care models.

Keywords: Sensor-based Elderly Monitoring Systems, Action Design Research, Aging-in-place, Situation-awareness

Introduction

In view of the global population aging, digitally assisted aging-in-place has gained increasing attention as a home and community-based care delivery model that can serve as an alternative to the costly and labor intensive institutionalized elderly care system (Chan et al. 2009). By 2050, the number of people aged 65 and over is projected to grow from 617 million (2016) to 1.6 billion, nearly 17% of world population (National Institute of Health 2016). Along with this, are the upward trend toward the elderly living alone (Tai 2015) and the demand for cost-effective digital solutions to ensure the safety of elderly who prefer to continue living in their own homes. Sensor-based elderly monitoring systems (SEMS) is fast becoming a solution that preserves freedom of movement and independence in life (Demiris et al. 2004).

Compared to mobile technologies, surveillance cameras and wearable technologies (e.g., watches, body worn tags), in-home sensors enable unobtrusive and continuous monitoring of elderly at their homes (Demiris and Hensel 2008). The feeling of stigma associated with surveillance technologies can be alleviated (Niemeijer et al. 2015) and little is required of the elderly (such as remembering to wear the watch) to ensure the solution’s workability (Bakkes et al. 2011). Regardless of its promising opportunities, most projects are still in the pilot stage of testing and evaluation, e.g., Oregon Center for Aging and Technology (Petersen et al. 2014) and City4Age Project (Mainetti et al. 2017). There is limited evidence to support its widespread implementation in practice (Reeder et al. 2013). While the elderly’s concern of privacy may
remain a barrier, it is critical not to overlook the emergency response function considering that the value realization of such care delivery services must involve multiple stakeholders such as the caregivers (often the first responders) (Sherer 2014). To deliver the value it promises, the design of SEMS has to consider both behavioral monitoring and personal emergency response functions.

However, there has been limited theoretical development which directly informs the design of SEMS. This study proposes an action design research (ADR) to examine the design principles of SEMS, arguing that the design of digitally assisted care delivery requires an “interaction of design efforts and contextual factors throughout the design process” (Sein et al. 2011 p. 38). The method allows us to generate prescriptive design knowledge through concurrently building and evaluating IT artifacts in a specific context. The Smart Homes and Intelligent Neighbours to Enable Seniors (SHINESeniors) project in Singapore provides a rare opportunity for us to learn from the interventions in real settings. Building on a situation-awareness model, this study proposes a set of design principles for behavioral monitoring systems that requires personalized, time-critical responses. This research, when completed, will shed light on challenges in implementing digitally assisted aging-in-place care models and provide an empirical ADR case.

Technologies for Aging-in-Place

A wide variety of assisted living technologies have emerged to facilitate remote monitoring and care provision. Wearables and mobile devices that measure one's health vitals (Schwenk et al. 2015) and mobility or the performance of physical activities (Fontecha et al. 2013) have proliferated the market and the research arena as viable options for continuous health monitoring. Furthermore, body worn tags are also used, enabling caregivers to monitor elderly's movement in the house or neighborhood and to understand their behavioral patterns (Hayes et al. 2007). Despite the many benefits, these technologies pose challenges to seniors who are unfamiliar with technology (Bakkes et al. 2011). An illustrating example would be that seniors may forget to wear or charge them on a continuous basis.

In view of the difficulty in shaping one's habits, ambient technologies that can be embedded in elderly's daily living environment are proposed. Several studies have investigated video and computer vision-based solutions as feasible options for in-home monitoring (Starner et al. 2000). Video cameras installed at key areas of a house can be used to identify in-home motion patterns, to detect falls and to assess various gait parameters (Heath and Guibas 2008). Researchers also experimented with smart furniture-based solutions that can measure gait, balance or weight to derive measures of physical health of the elderly (Chang et al. 2013). However, a widespread adoption of ambient technologies remains challenging and arduous mainly due to the perception of privacy, high cost and the operational difficulty.

More recently, non-wearable in-home sensor technologies began to gain attention. “Smart homes” with networks of low cost and reliable sensors installed in various locations can unobtrusively monitor in-home activities (Chan et al. 2009; Reeder et al. 2014). Motion sensors can capture movement patterns, sleep sensors can assess the quality of sleep and magnetic contact sensors can be installed on the doors for tracking going-out. Sensors are more favorably perceived compared to wearable technologies or video cameras because they require little maintenance and they impose minimal changes in habit. Hence, they are more practical for long-term monitoring (Bakkes et al. 2011). The systems can even be used to capture clinical data such as loneliness (Goonawardene et al. 2017) and cognitive impairment (Urwyler et al. 2017).

Given the potential of SEMS, studies have delved into factors that influence the elderly's intention to use the technology. When applied in the context of aging-in-place, adoption can be positively associated by a felt need for safety (Mahoney 2011) and autonomy while negatively affected by concerns for personal and data privacy (Townsend et al. 2011) and a stigma related to the surveillance technology (Niemeijer et al. 2015). Taken together, these studies (not limited to IS) demonstrate clearly that the implementation of digitally assisted aging-in-place solutions is context-dependent because it involves “a social process, even more than a technical matter” (Yusif et al. 2016 p. 114). The values of these studies notwithstanding, they place a heavy emphasis on a single group of actors in studying a digital solution that requires integrated efforts of multiple stakeholders (Schulz et al. 2014). As technologies give rise to this new care delivery model, it is imperative to examine the design of SEMS, specifically on how it can be seamlessly integrated in the work practices of various relevant stakeholders (Carroll et al. 2016). Amongst other, Marcelino et al. (2018) has considered in their pilot study the predefined alerts to caregivers and family members.
Also, although many projects have piloted SEMS, there has been limited evidence to support its widespread implementation (Reeder et al. 2013). Many prior studies are stalled in the evaluation phase (Yefimova 2016). Other SEMS projects which promotes elderly’s independent living are being piloted in controlled environments such as in aged care facilities like CSIRO Smarter Safer Homes. Although more closely related to the context of our study – in-home monitoring, the Oregon Center for Aging and Technology (Petersen et al. 2014) and City4Age Project (Mainetti et al. 2017) are more technology-centric with a greater focus on the sensors compared to the emergency response system. Together, the evidence indicates an imperative practice-driven need for research which explores the means of integrating the technology and various stakeholders of the aging-in-place care model, and the design principles which enable such a model.

Methodology

The design of the SEMS is at the intersection of design-oriented design research and organization-oriented action research as it involves both an innovative application of technology and an implementation of IS in a specific context, one that involves an unconventional group of users. Therefore, we adopt an action design research (ADR) to generate the design principles of SEMS. In particular, the method bridges the technological view of IT artifact and the shaping by context by integrating the previously separated and sequenced steps of artifact building and evaluation. The integrated view of Building, Intervention and Evaluation (BIE) in ADR allows us to surface intended as well as unintended consequences of usage on the (re)shaping of the artifact (Sein et al. 2011). Table 1 summarizes the stages of an ADR and principles.

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<tr>
<th>Stages &amp; Principles</th>
<th>Operationalization</th>
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<tr>
<td><strong>Stage 1: Problem Formulation</strong></td>
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<td>Practice-inspired Research</td>
<td>The research was driven by a need for better design of an innovative application of sensors and IS implementation in a specific context of elderly.</td>
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<td>Theory-ingrained Artifact</td>
<td>The theory used (user-oriented model) was the overall behavioral, economic and data analysis guiding the existing healthcare IS design and implementation.</td>
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<td><strong>Stage 2: Building, Intervention and Evaluation</strong></td>
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<td>Reciprocal Shaping</td>
<td>The issues of design and implementation were influenced by the domains of IT artifacts and user context. Feedback were regularly gathered from the elderly and caregivers to continuously reshape the design.</td>
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<td>Mutually Influential Roles</td>
<td>An ADR team consisting of researchers, a project lead and representatives from the technical team and caregivers was formed such that theoretical, technical and practical perspectives were incorporated.</td>
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<td>Authentic and Concurrent Evaluation</td>
<td>First evaluated within the ADR team and then in the wider setting of caregivers and elderly, the ongoing evaluation contributes to the (re)shaping of the IT artifacts.</td>
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<td><strong>Stage 3: Reflection and Learning</strong></td>
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<td>Guided Emergence</td>
<td>The ADR team maintained a constant sensitivity to signals that indicate refinements to the artifact and to unanticipated consequences for the generation of new practices.</td>
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<td><strong>Stage 4: Formalization of Learning</strong></td>
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<td>Generalized Outcomes</td>
<td>Three design principles for the SEMS were generated and subjected to further validation in the next step following this research-in-progress.</td>
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The selection of SHINESeniors project is based on three reasons. First, the project has significant values considering Singapore’s rapidly aging demographic. According to the United Nations’ (2017) report, the country had almost the same number of elderly and youth in 2017, and by 2050, the percentage of elderly will make up almost half of the population (47%). Considering the growing number of elderly who are staying alone (from 35,000 in 2012 to 83,000 by 2030 (Tai 2015)), the iCity Lab jointly established by Singapore Management University and Tata Consultancy Services initiated SHINESeniors, a SEMS project. Second, SHINESeniors allows interventions in authentic settings, a necessary condition in conducting an ADR study. Rather than in laboratory settings, the sensors were implemented in real home settings. The case is unique considering that few projects have piloted smart home infrastructure in the dwellings of the elderly and their community over long periods of time (Yefimova 2016). Lastly, the engagement of two of the authors as the leader and researcher who work closely with the stakeholders provides a rare, propitious opportunity for us to study up-close the building and intervention throughout the project.
SHINESeniors involves the caregivers from three voluntary welfare organizations (VWO) and the elderly. Since early 2015, the SEMS was deployed in 75 flats in Singapore. Participants were selected on a voluntary basis if they were aged 65 or above, living alone in government-subsidized flats and affiliated with a VWO. Prior to the installation, all the participants gave their consent to access their data. The sample size remained stable, but reduced to 69 because 3 subjects moved to nursing homes due to health declines and 3 subjects passed away; one elderly died of a stroke and the other two due to cancer. Over a span of three years, the SEMS went through two major changes with the first version (V1) implemented in Jun 2015 and the second (V2) in Aug 2017. In addition to the inquired contextual understanding of the authors, data collection was conducted through 4 rounds of face-to-face interviews with 48 elderlies, quarterly meetings, 4 face-to-face interviews and 1 focus group discussion with caregivers. Secondary data was obtained through records maintained by two coordinators who collected elderly feedback and information pertinent to the system use on a weekly basis, and through other sources (including newspaper, online articles, reports, website etc.). These data were further supported and contextualized with the researchers’ deep engagement over time via meetings, observations as well as data gathered through the sensors.

Case Overview

The SEMS deployed by iCity Lab allowed caregivers to remotely monitor the elderly and attend to in-home emergencies detected to ensure their physical safety. In 2014, Singapore’s Ministry of Social and Family Development organized the community-based social services within each neighborhood to better support vulnerable seniors. In neighborhoods with higher number of community-dwelling elderlies, Voluntary Welfare Organizations (VWO) oversaw the caregiving and social services for elderly. This setup enabled a distinct environment for the SHINESeniors project to deploy the SEMS in a real-world community-care network by partnering with VWOs. Elderly under three VWOs participated in the project and 2 caregivers of each VWO were given mobile phones and allocated to attend to the alerts triggered by the system. The system connects elderly and their formal caregivers, who are the primary responders for elderly needs and emergencies. Because the SEMS is unobtrusive in nature and passively monitors in-home activity of elderly, it allows privacy-preserving monitoring that is preferred by the elderly (in contrast to video-surveillance systems which are widely popular in remote monitoring).

The SEMS constitutes four components: 1) in-home sensor network, 2) web portal/mobile app for real-time data visualization, 3) alert component and 4) data analytics component. As shown in Figure 1, the in-home sensor network consists of a set of passive infrared motion sensors in the living room, bedroom, kitchen and toilet, a door contact sensor and a gateway for data receiving. The motion sensors function by firing a signal at 10 seconds intervals to indicate whether motion is detected. The door contact sensors fire a signal when the two magnets are apart to indicate a door opening or closing event. Each elderly was also given a panic button to call for help when there is an in-home emergency.

The web portal/mobile app for data visualization and alert component were deployed for the formal caregivers of the VWO. Web-portal displays sensor readings in real time. The alert system notifies the caregivers of two types of alerts 1) panic alerts once an elderly presses the panic button and 2) inactivity alerts when prolonged inactivity is detected. The inactivity threshold is personalized for each elderly based on their in-home behavioral pattern. Once an alert is received, the VWOs evaluate the situation and respond accordingly through their formal or informal caregivers (i.e. neighbors) who provide service on a voluntary basis (Liu et al. 2016). Figure 1 shows an example of an alert from V2, which will be illustrated later. Since its deployment, VWOs have attended to 17 elderlies due to panic alerts triggered by elderlies and over 300 suspected emergencies triggered by sensor-detected prolonged inactivity (i.e. combining both V1 and V2 over 36 months). All prolonged inactivity alerts were either false-positive or true-positives (i.e. there were no false-negative alerts), of which 3 were true-positives. In view of their manpower constraint, the VWOs have requested to minimize the number of false-alarms to be below 7 in a given month.

SHINESeniors’ SEMS differs qualitatively from other behavioral monitoring technologies for its unobtrusive nature. For the level of personalization required in the response, it is also hard to apply in SEMS the design principles of other response systems such as the fire emergency response (Yang et al. 2012). Our team suspected that the existing design theories may not adequately serve the requirements of this nascent design situation. This suspicion forms the impetus to the formation of our practice-inspired research project to not only design a problem-solving artifact but also learn from the interventions. By doing so, we aim to conceptualize design principles for SEMS. This 3-year project, albeit still on-ongoing,
has seen some drastic changes across the two versions of the system (V1 and V2) and improvements in user adoption. During the process, the SEMS was revamped to incorporate features based on the inputs of multiple stakeholders, i.e. caregivers, elderly and the technology providers. In the following, we present our analysis in accordance with the four stages of ADR method.

![Figure 1. Layout of the Sensor-based Elderly Monitoring System and a sample alert from V2](image)

**Preliminary Findings**

After the successful deployment of V1 in 2015, a number of unanticipated issues related to sensor alerts, communication and data presentation surfaced. In Stage 1 of ADR (**problem formulation**), our diagnosis identified a few core issues which are summarized in Table 2. Although the ADR team has managed to overcome a number of critical issues in SEMS design including the participation of elderly and the accuracy of sensor data and real-time alerts, the system was ineffective in assisting the decision-making and subsequent action taking of the caregivers.

While appreciating the accuracy of the data, caregivers highlighted concerns over the high frequency of “false alarms” upon reflection. To obtain a better understanding of the situation, they had to manage three separate information channels: SMS-based alerts, data visualization component for verification of alerts and a WhatsApp group (with other caregivers) for coordination. Although the caregivers largely welcomed the introduction of technology to the intimate human-based care delivery model, they shared worries about data returned by individual sensors which could have diverse meaning across scenarios (and across individual elderly due to their habits). An example was the interpretation of a prolonged inactivity alert; in some occasions, false-positive inactivity alerts were triggered due to failure to detect certain activities such as sleeping or out of the home.

From our literature review and data, we subsequently identified the underpinning issue. To shift away from the focus on technological capability, the team had initially made a conscious decision to adopt a user-oriented design. However, the focus was heavily placed on the elderly being the beneficiary. This is reflected in, for example, the data analysis algorithm that generated highly personalized alerts based on individual behaviors and daily habits. Consequently, the team decided to explore a new direction. The **Building, Intervention and Evaluation (BIE) stage** was initiated by projecting a SEMS that adopted a situation-awareness (SA) oriented model (Endsley 1995). In comparison to the user-oriented model which, in this case, led to a heightened attention on a single group of actors, this model focuses on information required for the formulation of response (Yang et al. 2012). Our study is arguably the first study that looks at designing such SEMS. The class of field problems that the resultant findings will address is hence the behavioral monitoring systems that require personalized, time-critical responses.

SA provides a design guide to monitoring systems that aim “to maximize the person’s ability to perceive needed information, comprehend what that information means, and use it to predict the future state of the system” (Yang et al. 2012 p. 767). With this model, we cater for operational and informational requirements of a situation, rather than for an individual or elderly in particular. To operationalize SA, we build on the three levels of the SA model – Perception, Comprehension, Projection (Endsley 1995). Perception is about the ability to perceive the status of relevant elements, comprehension refers to the ability to understand the significance of those elements in light of the actor’s goal, and projection is about the ability to project the future state of the elements, including those that are only acquirable over time (Endsley 1995).
Table 2. Problems with Pre-Existing SEMS (V1)

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<th>Problem</th>
<th>System in Use</th>
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<td>Desensitization of caregivers due to the system’s data-driven personalized alert threshold setting</td>
<td>The V1 adopted an accurate, data-driven approach to determine the safest threshold for sending prolonged inactivity alerts. Thresholds were determined based on individual elderly’s past living pattern. Although it ensured elderly’s safety, with the inevitable noise picked by the sensors, false-positive alerts were generated. “...if it beeps too often, it also lowers down our guard. Because if there are twenty beeps and all are not emergencies and the twenty-first beep is of emergency and we chose to ignore it, I’m not saying that we will, but it will lower our guard...” [a formal caregiver]</td>
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<td>Inability of caregivers to react quickly after the system alert, due to a delay in retrieving information from the fragmented components</td>
<td>Upon receiving an alert, the caregiver would login to the data visualization component (i.e., web portal/mobile app) to obtain elderly’s last seen location in the house. To determine if the alert was a true-positive, caregivers had to manually search and filter the visualization component for the elderly’s past behavior pattern. The caregiver would also initiate a conversation in the WhatsApp group. After resolving the case, the caregiver would update the status in both WhatsApp and web portal/mobile app. “...downside of WhatsApp is, its unable to consolidate same conversation in the same thread, there can be many conversations going around at the same time once an alert is received.” [a caregiver who has 3 years of experience with the system]</td>
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<tr>
<td>Inability of caregivers to interpret the sensor data due to data presentation in raw form</td>
<td>The V1 system displayed real-time activity charts of the elderly i.e. raw sensor readings of each sensor while the SMS alert displayed only the type of alert (i.e. panic or inactivity) and inactivity threshold of each elderly. Caregivers expressed the concern of wanting to see more higher-level representations of data, for example to be able to compare weekday vs weekend living patterns, typical sleeping hours of the elderly or going-out habits etc. “One improvement I thought we could have is that if we are alerted that someone is away, and if it can display somewhere in the alert that this person is away then we don’t have to recall to know if the elderly is away from when to when.” [a caregiver]</td>
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Through an ongoing reflection in the BIE stage, the ADR team identified three principles that would realize situation awareness, in correspondence to the three levels: interpretive accuracy of alert threshold, integrated response interface and user learning facilitation. By adjusting the data-driven alert threshold according to each individual’s situation (e.g., active elderly may have a low threshold and frail may have a longer one), it relaxed the provision of the “most accurate data-driven threshold” in communicating the information to the caregivers, thus lowering the frequency of “false alarm” and alleviating the issue of desensitization. The integrated response interface principle would enable the caregivers, upon receipt of an alert, to quickly retrieve necessary information needed to comprehend the real situation without having to lose the time critical for reaction. The last principle about user learning facilitation emphasizes the importance of translating data from multiple sensors into information and knowledge of elderly’s behavioral patterns. This would address the problem in which the system was perceived limited in facilitating caregivers’ learning for their assessment of elderly’s behavior over time.

To evaluate the working hypothesis – that SEMS encapsulating these principles would be more effective than pre-existing system – these principles were translated into a new set of functions, interface, data flow and analytic algorithm. The new system, V2, was implemented through a comprehensive intervention. It replaced the old system and was made available to all the users, particularly the caregivers. Continual participant observation and biweekly evaluations with the elderly and caregivers have been conducted since V2 (to date) by the ADR team. The 69 elderlies and 3 VWOs remained active participants till date. With the representation of key stakeholders (i.e. caregivers, elderly and the tech team), the building of artifact, intervention in organization and evaluation of artifacts and problems were concurrently conducted.

The ADR team’s intervention of introducing changes in the system was assessed, constituting a formative evaluation that disclosed both expected and unexpected consequences (Table 3; unexpected consequences are in italics). Though the caregivers were familiar with the V1 of the SEMS, the V2 introduced several substantial changes to the communication channel and user interfaces. The situation awareness of the caregivers has improved as a result of 1) a refined alert threshold, 2) a new response interface that integrated the alert components and WhatsApp channel and 3) a refined data visualization component that presented elderly behavioral patterns in a more organized way. However, some unexpected consequences emerged.
The users found that the number of alerts were not reduced to the level that reflected the real emergency situation. Since V2, numerous requests have been made to the technical team to consider the complicated data pattern of living habits. For instance, by discerning whether one is inside or out of home, the caregivers believed that real emergencies could be better reflected. Also, although the integration of alerts and WhatsApp in a single platform (i.e., Slack) has improved the organization of information sharing and coordination of caregivers on the ground, the Slack system displayed only information relevant to inactivity alerts (e.g., usual sleep time and inactivity threshold – see Figure 1). To access other behavioral data, caregivers would still have to log in to the data visualization component. Moreover, the system was limited in providing insights beyond reactive care, such as early detection of physical frailty accelerations for preemptive care needs of elderly. Lastly, while the data visualization component incorporated functions for users to explore the data (e.g., searching, filtering), it placed a high demand on the experience and knowledge of users to generate a meaningful health assessment of an individual, especially when the concerns spanned across physical, social and mental aspects of health.

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<th>Design Principle</th>
<th>Consequences</th>
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| Interpretive accuracy of alert threshold | • Improved the sense of urgency to alerts generated by SEMS due to the reduced false-alerts  
  “There are less false alerts... a lot lesser... last time the system [V1] had a lot of false alerts... it utilized a lot of manpower to check on everybody, and we had to go down on weekends to check on them [the elderly] and make sure they are ok, and I think the system is more reliable now.” [a formal caregiver who has experience in V1 and V2]  
  • Detection of other sources of false positive e.g., daily going-out habits |
| Integrated response interface | • Streamlined information sharing and facilitated an organized action coordination at the communication and interface level  
  “Recently there was an inactivity, the system actually prompted that. There was no door contact and the last motion detected was in the living room. For a layperson like me, it was easy to see and interpret [from a single Slack interface]. I didn’t have to ask too much questions for confirmation and we managed to save the senior.” [a caregiver]  
  • Because of the attention of the interface was about ensuring responsiveness to the alerts, the system neglected the potential value of longitudinal data collected by the SEMS to assess and preempt other health issues |
| User learning facilitation | • Improved user learning with an open sharing of elderly behavioral patterns derived from aggregated and interpreted data  
  “I can filter to see persons activity per weekday or per weekend. I think that helps because I have seniors reporting to me certain activities [and] I do track back on the sensors if they are providing consistent information. It can be due to dementia that they are not providing consistent information.” [a caregiver with 4 years of experience]  
  • High demand on individual capability to generate insights beyond safety and physical health in order to assess overall social and mental wellbeing of elderly |

### Subsequent Work and Potential Contributions

In preparation for the next stage of this study (reflecting and learning), we refined the design principles to reflect changes of the system that cater for the unexpected consequences. The revised design principles are summarized in Table 4 (changes are in italics) and our further analysis involves investigation of other stakeholders (i.e., technical team and family members) and insights from the sensor data. In particular, the emphasis of V1 and V2 were primarily on the delivery of reactive care. The system has not exploited its fullest potential to offer a preventive care delivery. For example, to identify groups of elderly that are socially isolated for early interventions through building predictive models with the longitudinal sensor data collected on elderly’s in-home behavior patterns. In the near future, these changes will be instantiated in the next iteration of the artifact for further evaluation by the users. Upon the completion of this iteration, we will continue the reflecting and learning stage, followed by the last stage of ADR for formalization of learning that focus on articulating the class of problems and the generalization of design principles.

This ADR aims to propose a set of design principles for behavioral monitoring systems that requires personalized, time-critical responses. Specifically, the boundary condition of the study includes in-home elderly monitoring systems that 1) apply the use of unobtrusive technologies (sensor versus obtrusive ones like camera, wearable and video surveillance technologies), and 2) serve the function of safety monitoring.
(versus physiological monitoring, functional monitoring, security monitoring, social interaction monitoring, and cognitive and sensory assistance (Demiris 2015)). Although the analysis and the project are still on-going, our study is envisioned to make contributions to theory, practice and methodology on challenges of implementing digitally assisted care models for elderly who are living alone.

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<tr>
<th>Design Principle</th>
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<tr>
<td>Dynamic interpretive accuracy of alert threshold</td>
<td>Setting of alert thresholds can be data-driven for accuracy at individual level. However, contextual information must be considered to continuously adjust the threshold for a better interpretive accuracy in users’ perception of the situation.</td>
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<td>Integrated response for predictive and reactive care</td>
<td>The response interface should be integrated for informed decision-making and timely coordination. However, the system should also expand the data use for preemptive care delivery (e.g., toilet use frequency to forewarn nocturia).</td>
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<tr>
<td>Explorative and exploitative user learning facilitation</td>
<td>The system should facilitate user’s data exploration for immediate risk assessment and physical health assessment. However, the system should also exploit the existing data by translating the raw data collected over time into assessment of elderly’s overall wellbeing including mental and social health.</td>
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Theoretically, this ADR study generates design knowledge for behavioral monitoring systems that require personalized, time-critical response. In addition to deriving a set of design principles, this study expands the boundaries of Situation Awareness Theory by showing the demand for situation awareness in designing behavioral monitoring systems. Practically, this study empirically presents the challenges of applying sensors (or Internet of Things technologies) for digitally assisted aging-in-place, and how these challenges may be alleviated via a continual adaptation of systems. Unobtrusive behavioral monitoring systems that could enable preventive medical care are increasing becoming a key focus in healthcare. Our study is one of the initial attempts to explore the design of a sensor-based monitoring system for elderly care delivery in a community setting. Methodologically, this paper provides an exemplar study that adopts action design research in the context of healthcare. This practice-inspired research allows us to learn from the interventions while addressing problematic situations in the healthcare industry where significant time lags are not unusual before values become evident (Sherer 2014). The research will be continued by evaluating the next iteration of the system to address the issues identified at the current stage.

References


