Designing a Human-centered Intelligent System to Monitor & Explain Abnormal Patterns of Older Adults

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ABSTRACT

Older adult care technologies are increasingly explored to support the independent living of older adults by monitoring their abnormal activities and informing caregivers to provide intervention if necessary. However, the adoption of these technologies remains challenging due to several factors (e.g. lack of usability). In this work, we present a human-centered, intelligent system for older adult care. Our proposed designs of the system were created based on the findings from a focus group session with caregivers. This system monitors the abnormal activities of an older adult using wireless motion sensors and machine learning models. In addition, unlike previous work that only notifies an outcome of activity recognition and abnormal detection models to a caregiver, the system supports interactive dialogue responses to explain the abnormal activities of an older adult to a caregiver and allow the caregiver to elicit additional information about the older adult and the older adult to proactively share his/her status with the caregiver for an adequate intervention.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Empirical studies in collaborative and social computing**; • **Applied computing → Health care information systems**.

KEYWORDS

health/assistive technology, remote monitoring, quality of life, aging, caregivers, older adults

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1 INTRODUCTION

Researchers have explored older adult care technologies [20] to support their independent living and improve their quality of life. These technologies [20] range from a personal alarm system worn by an older adult for raising the alarm in the case of an emergency situation or providing reminders, technologies that provide companionship [12], physical or cognitive assistance [20] on daily activities [7] or exercises [10], and intelligent systems that analyze sensor data to detect abnormal activity patterns of an older adult for independent living [20].

Among various technologies [12, 20], this work focuses on an intelligent system that analyzes sensor data to recognize activities of daily living [5, 16, 17], detect a dangerous or abnormal situation (e.g. being idle for a long time, leaving home and wandering at abnormal hours, etc.) that may be indicative of changes in health status [22], and alert an older adult's abnormal situation to a caregiver to provide an intervention if necessary [3, 20]. Previous studies of intelligent systems for older adult care have shown the value of reviewing observations of activities of daily living [13] and providing contextual information [23] to improve the self-awareness of older adults and the potential of a conversational agent to assist daily activities (e.g. alarms during cooking, getting weather information) [25]. However, the adoption of such technologies remains challenging due to several issues [9, 12, 24]: lack of usability and trust [24].

In this paper, we present the design of a human-centered, intelligent system for older adult care. First, we conducted a focus group session with family caregivers to specify the design spaces and use cases of a system. Based on the findings of the focus group session, we implemented an intelligent system that can monitor abnormal patterns of activities of daily living and provide interactive dialogue responses that explain an abnormal event to a caregiver and allow older adults to proactively share their status for a personalized intervention.

Even if prior design works engaged with older adults or/and caregivers to discuss design considerations for various applications (e.g. mobile fitness [8], assistive kitchen [11]) and the importance of improving communication between care providers and adults with chronic conditions [2] or dementia [6], and controlling older adult care technologies [1, 15], it remains unclear about detail design specifications of an intelligent system to monitor abnormal patterns of older adults. Thus, we conducted the focus group session with caregivers to identify high-level designs of a human-centered intelligent system to improve the practice of older adult care and implemented it to demonstrate its functionalities.

Compared to the previous work with one-directional communication that only notifies the outcome of activity recognition and abnormal events to caregivers [20], this work proposes to utilize interactive dialogue responses that explain the outcome of activity and abnormal events of an older adult to a caregiver, allow the caregiver to further elicit additional information from the older adult

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and the older adult to determine the information to be shared. Our work contributes to the growing body of research in older adult care technologies and human-centered designs of an intelligent system to monitor and explain abnormal patterns of older adults.

2 STUDY ON A HUMAN-CENTERED, INTELLIGENT SYSTEM FOR OLDER ADULT CARE

In this work, we engaged with caregivers to design a human-centered intelligent system for older adult care. Specifically, we conducted a focus-group session with four family caregivers to understand the practices and challenges of caregivers and specified the design spaces of the system. Based on the findings of the focus-group session, we implemented the high-level system prototype to illustrate its functionalities.

2.1 Focus group session with caregivers

The objectives of a focus group with family caregivers were to learn about their experiences and challenges during the care services of an older adult and specify the design spaces of an intelligent system. For the focus group session, we recruited four family caregivers, who have had experience of providing caregiving for their parents or grandparents. Among four caregivers, three had experience of being a primary caregiver for both parents and one had experience of being a primary caregiver for both parents and a secondary caregiver for grandparents.

A researcher then moderated a semi-structured focus group session with the following three questions to center conversations on learning practices of the care service for an older adult: (1) What is the process of determining whether an older adult is okay or not?; (2) What signals that you use to make a decision for an older adult?; (3) How do you react to those signals and what's the process of interacting with an older adult?

For the data analysis, we transcribed the audio recordings of the focus group session and followed an iterative, reflexive coding process [4]. First, we generated initial codes from the structured topics of the interviews. After reviewing transcripts, the researchers individually generated codes and findings and iteratively improved the codes of the transcripts with the research team. Following the practice of a reflexive thematic analysis, we do not calculate interrater reliability as we iteratively discussed disagreements and ambiguities in the codes to refine and make consensus on our codes [4, 14].

In the following subsections, we described the thematic analysis and findings of the focus-group session: practices and challenges of providing a care service for an older adult and high-level requirements of an intelligent system for older adult care.

2.1.1 *Practices and challenges of the care services.*

The care services of an older adult broadly start with checking the status of an older adult and providing an adequate intervention if necessary.

For checking the status of an older adult, caregivers mainly **rely on phone calls or visiting**. *"What we do is just regular check-ins by speaking them on the phone and getting a sense of how things work"* (C1). Also, caregivers need to visit an older adult periodically and spend time together to understand the activities of an older adult as *"it is hard to get an older adult on the phone"* (C2).

During phone calls or visiting, caregivers typically **speculate on the daily activities of an older adult to check the status of an older adult** and determine the necessity of intervention. Especially, caregivers get a sense of when an older adult *"wake up, eat foods, spend spare time, and leave the house"* (C1). Caregivers then check any deviations of activity that occur, such as *"canceling the regular dinner"* (C2). Once a caregiver observes any deviated situation (e.g. *"older adults cannot have a meal themselves"* - C2), caregivers will then figure out what services they could provide an older adult from social workers or a hospital.

All caregivers in the focus group session highlighted the importance of **preserving the independence and dignity of an older adult**. *"You really think this isn't a pet that you are just trying to keep alive. This is a person"* (C1). *"Most problems that older adults would get embarrassing"* (C3). Some older adults become *"stressful about receiving a service from a different person each time"* (C4). Thus, it is critical to make a balanced decision to provide an adequate intervention that preserves the independence and dignity of an older adult.

2.2 High-Level Designs of a Human-Centered, Intelligent System

Based on our findings from the focus group session, we identified high-level designs of a human-centered, intelligent system to improve the care practices of an older adult (Table 1).

First, the system should recognize the daily activities of an older adult and detect abnormal events to supplement the caregiver's check-in visits or phone calls. During the focus-group session, we identified daily activities that are commonly used to check the status of an older adult. These activities include *"Waking up, Sleeping, Eating (Breakfast, Lunch, Dinner, Snack), SpareTime, Leaving, Toileting, and Idle/Falling"*. In addition, we specified five use cases for detecting abnormal events. These use cases include 1) too frequent toilet usage, 2) abnormally leaving, 3) abnormal sleeping, 4) being idle for a long time, and 5) abnormal eating. Our five use cases based on the focus group are not an exhaustive list of use cases for an intelligent system that monitors activities of daily living for older adult care. Instead, the goal of specifying these use cases is to demonstrate the functionalities of our system.

In addition, as an older adult might have different life patterns and preferences on what information can be shared, the system should be able to provide a means of personalization and control. Specifically, we observed that a caregiver usually engages in a conversation and asks a specific, tailored question to an older adult to seek out further information on an older adult for analyzing his/her status and determining an adequate intervention while preserving his/her dignity. Thus, the system should provide a way to facilitate communication between an older adult and a caregiver for a personalized intervention.

To preserve the independence and dignity of an older adult, the system should *"reduce the installation of a camera everywhere"* (C1) and prioritize the usage of non-visual sensors.

Table 1: List of findings from the focus group and the corresponding high-level designs of a human-centered, intelligent system for older adult care

Findings from the focus-group	High-Level Designs of a system
F1. Limitations of regular check-ins on the phone or visiting	R1. Recognize the daily activities of an older adult and detect abnormal patterns - Waking up, Sleeping, Eating, SpareTime, Leaving, Toileting, Idle/Falling
F2. Analyze the status of an older adult through conversations	R2. Provide a communication method between a caregiver and an older adult to assess the status of an older adult through a personalized question
F3. Preserve the independence and dignity of an older adult	R3-1. Reduce the usage of a camera and prioritize non-visual sensors to monitor activities R3-2. Allow older adults to control the system (e.g. what information to share)

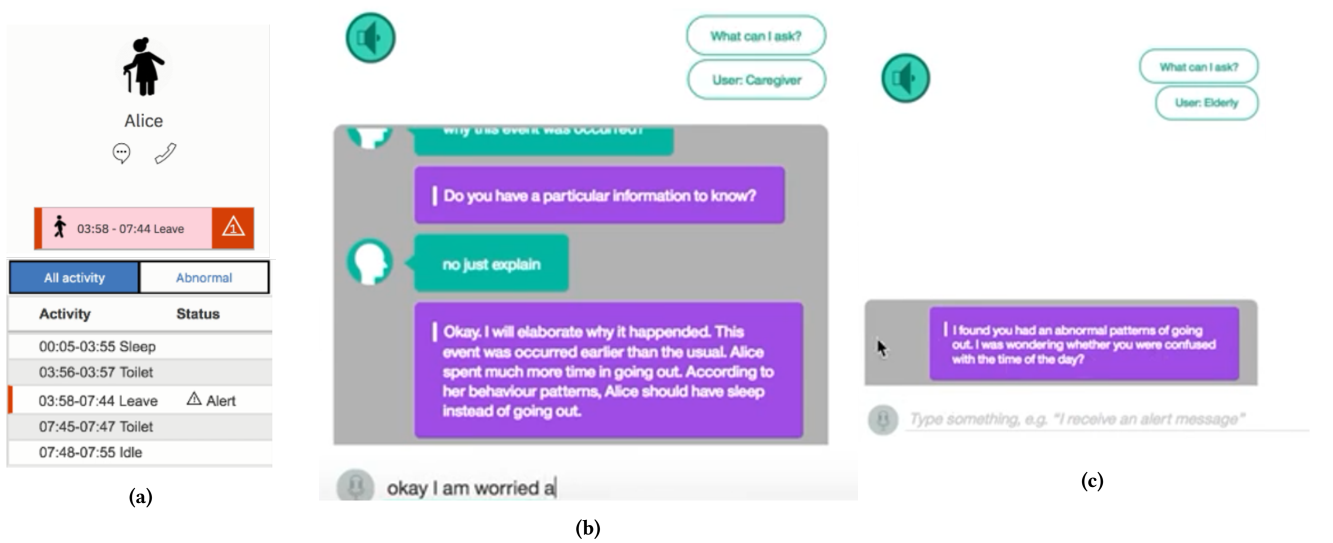

Figure 1: Interface of the System: (a) Notification about an abnormal event, (b) Dialogue responses to explain an abnormal event for caregivers, and (c) Dialogue responses for older adults, in which they will receive a follow-up question by the caregiver and determine what information to be shared.

2.3 System Implementation

We build upon the high-level designs of a human-centered, intelligent system for older adult care (Section 2.2) and develop the system to demonstrate its functionalities. The system consists of four major components: (a) wireless sensors, (b) a monitoring module, (c) interfaces of notifications and interactive dialogue responses, and (d) a database. In contrast to previous work that only notifies an outcome of monitoring models (i.e. activity and abnormal detection) to a caregiver [20], our system with interactive dialogue responses explains the outcome of monitoring modules, allows a caregiver to elicit additional information from an older adult and the older adult to proactively share information with the caregiver. Due to space limitations, we focus on sharing the main functionalities of the system (Figure 1) along with the descriptions of necessary technologies.

2.3.1 *Wireless Sensor Data.*

This work prioritizes the usage of non-visual sensors (e.g. wireless motion sensors) to the usage of a camera for preserving the privacy of an older adult. Also, this work assumes the installation of wireless motion sensors in the house of an older adult or an older adult care center for the system implementation. The sensor readings indicate the presence of a single inhabitant in a specific area (e.g. sitting on a couch) or the occurrence of a particular event (e.g. toilet being flushed) [17].

2.3.2 *Monitoring Module.*

The monitoring module of the system utilizes wireless sensor data and a machine learning model to recognize the activity of daily living of an older adult and detect whether the recognized pattern of activities is abnormal or not.

We utilized the dataset [17] that includes the recordings for 21 days of activities using 12 wireless motion sensors with the labels of 11 activities of daily living (ADL). We selected this dataset as it includes major daily activities that most caregivers leverage to understand the status of an older adult (Table 1). For activity recognition, we utilized the Hidden Markov Model (HMM) [18, 19] by learning the parameters using the maximum likelihood [19] and achieved 0.85 accuracy.

For anomaly detection, we utilized the following four contextual features of an activity: (1) transition, (2) duration, (3) frequency, and (4) starting hour of activity, which can be clues for caregivers to understand abnormal events (Section 2.1.1). We assumed that the contextual features of an activity follow Gaussian distribution and utilized the 90% confidence intervals of corresponding Gaussian prior distribution to label an abnormal event [22]. For the contextual feature of the transition, we indicated the transition is abnormal if the transition probability of activity is below 0.05. We utilized a decision tree as our model, which has not only high performance (i.e. an average of 0.89 accuracy and 0.88 F1-score) but also model interpretability [21].

As the focus of this work is to design a human-centered, intelligent system of older adult care based on the focus group session with caregivers and demonstrate its functionalities, this work does not explore other complex algorithms to improve the performance of the monitoring module.

2.3.3 *Interfaces of notifications and dialogue responses.*

We implemented the user interface using HTML and CSS to (1) provide a caregiver with the notification of an abnormal event and (2) support interactive dialogue responses with a caregiver or an older adult.

When the monitoring module of our system detects any abnormal event of an older adult, the system will send a notification to a designated caregiver (Figure 1a). As shown in Figure 1a, a caregiver can review the list of recognized activities of an older adult and only brief information about an abnormal event: which kinds of an abnormal event is detected and when it has occurred (e.g. the older adult abnormally left home at 03:58 until 07:44). To highlight the detected abnormal event, we included red background color.

Also, this system utilizes interactive dialogue responses to explain abnormal patterns (Figure 1b) and allows caregivers to seek additional information about an older adult while an older adult can share any necessary information about his/her status (Figure 1c). Our interface utilized the Watson Cloud Speech-to-Text (STT) and Text-to-Speech (TTS) services to support both chat-based interactions and voice-based dialogue responses.

As the abnormal notification does not provide sufficient information on the status of an older adult (Table 1), our system can explain the contextual information of an abnormal event to a caregiver (Figure 1b). If this explanation is still not sufficient, a caregiver can request our system to elicit any additional information to confirm the status of an older adult. Then, the system recognizes the activities of an older adult to determine an adequate moment for the interaction (e.g. taking a rest or being idle) and prompt dialogue responses (Figure 1c) to seek out the requested information from a caregiver (Table 1). Older adults can determine what information will be further shared through interactive dialogue responses (Figure 1c).

2.3.4 *Database.*

We implemented a Publish-Subscribe database with MongoDB to store processed data of our system and built a communication pipeline among the modules of our system. For example, after recognizing activities of daily living and detecting their abnormalities, the monitoring module will store its output and relevant data in the database. If an abnormal event is detected, the database will send the corresponding outputs to the notification interface or the dialogue module to support user interactions.

3 CONCLUSION & FUTURE WORK

This work contributed to the designs of a human-centered, intelligent system for older adult care. Specifically, we conducted the focus group session with family caregivers to understand the practices and challenges of older adult care. Based on the findings of the focus group session, we specified the design scope and use cases of the system and then developed the high-fidelity system prototype to demonstrate its functionalities.

This system can detect and explain an abnormal event of an older adult using wireless sensor data and machine learning models. Unlike the previous work that focuses on only notifying the results of activity recognition and abnormal detection to a caregiver[20], this work utilizes interactive dialogue responses that explain abnormal events to a caregiver and enable caregivers to seek out missing information from an older adult and older adults to proactively determine what information to be shared.

The main design recommendations for creating a human-centered intelligent system for older adult care are (1) providing a means of communication between caregivers and older adults and (2) providing additional contextual information on why the system detects an abnormal event through explainable AI techniques or an interpretable model [21]. Also, it is important to provide a way for older adults to control the system [1] for preserving their independence and privacy. Finally, it is necessary to conduct further investigation to understand the potential benefits and concerns of the proposed designs by showing the functionalities to caregivers and older adults and identify further refinement and design recommendations of the system for older adult care.

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