Doctoral Dissertation

Study on Participatory Activity Tracking and Risk Assessment for Anonymous Elderly Monitoring

Research Dawadi

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Abstract

The advancement in medicine and technology has led to subsequent increase in the life expectancy of elderly people. However, due to their children moving away, and loss of spouse, friends and relatives, most of them are forced to live in isolation. Hospitals, and care homes are crowded, uncomfortable and expensive, while caretakers are expensive and few in number. In this dissertation, we present an anonymous monitoring system through which it is possible to check the completion and duration of various daily basic activities such as medication, shower, and food intake, and analyze them to determine if there is any deviation from usual routine. Similarly, our intention is that our system, a smartphone application, will be used by volunteers and caretakers who can track such deviations and report if any risky situations are detected.

We designed our overall system and developed some technical requirements that had to be fulfilled. First, it is important that the activity details such as completion time and duration are shown in a clear and understandable pattern. We developed an Android based application with features such as candlestick chart visualization, color coding for state of activities and radio buttons for reporting. Second, we do not disclose any personal information of the elderly to the monitor, making our system anonymous. Third, we used two different notification techniques: abN (activity based notification) that is sent every time an activity was completed, and rN (recurring notification) that is sent periodically

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every two hours, to frequently remind the monitoring person to check the application. And finally, we analyzed if using the application, and reporting about activities regularly will cause a burden to the monitoring person or not.

We used data collected from a real life activity recognition experiment from the houses of the elderly residents in Japan. To evaluate our application, we included some situations where the activity deviated from usual routine based on completion time and duration. Similarly, to compare the effectiveness of our proposed method, we developed two different versions of our application with different activity visualization (using table instead of graph) and notification strategy (using rN only). Through the evaluation study, we found out that about 75.2% of the time, deviations were correctly identified using our proposed method compared to 68.5% & 65.8% of the other two versions. We also analyzed the time taken between opening the activity report of activities, and reporting them. We found that, on average, it took 28 seconds using our proposed method while it took 38 & 54 seconds using the other two versions. The proposed method also provided a better result for the timely reception of reports for activities with a median time value of 115.1 minutes, compared to 118.85 and 121.12 minutes. These results reveal that it is possible to effectively monitor activities of elderly people using a smartphone application, without causing a higher level of burden to the monitors.

Keywords:

Elderly Monitoring, Gerontechnology, Mobile Application, Human-Computer Interactions

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1. Introduction

1.1 Background

The statistical handbook of Japan released in 2021 by the Statistics Bureau, Ministry of Internal Affairs and Communications, Japan has revealed that in 2015, there were about 22 million households with residents aged 65 and above, including 6 million who lived alone, as shown in Figure 1. This is a trend that has been on the rise for a long period of time [1]. The number of people in the world has also been expected to be double by the year 2050 than at the start of the century [2] and is expected to keep on increasing in the upcoming years [3]. This has led to increase in the focus for research in healthcare and elderly monitoring [4].

(Thousands)

Type of households	1995	2000	2005	2010	2015
Private households	43,900	46,782	49,063	51,842	53,332
Elderly households	12,790	15,057	17,220	19,338	21,713
(percentage)	29.1	32.2	35.1	37.3	40.7
One-person households	2,202	3,032	3,865	4,791	5,928
Males	460	742	1,051	1,386	1,924
Females	1,742	2,290	2,814	3,405	4,003
Aged-couple households 1)	2,763	3,661	4,487	5,251	6,079

1) Consisting of a husband 65 years of age and over and his wife 60 years of age and over.
Source: Statistics Bureau, MIC.

Figure 1: Trend of elderly households in Japan [1].

Ageing can be normally associated with decline in cognitive ability in people, with symptoms such as forgetfullness, decreased problem solving capacity, decreased ability to maintain focus, and so on [3, 5]. Physical activities also get affected, with elderly most prone to chronic diseases such as cancer, diabetes, obesity, arthritis, etc.[2]. These situations thus give rise to importance in checking up on elderly regularly. With the boom in the information and technology industry and Internet of Things (IoT) enabling technologies and devices such as sensors, actuators, smart-objects, wearable sensors, mobile devices and so forth, it is now possible to assist and monitor daily activities of people in their living environment [3, 6]. An area of research and study, Gerontechnology, has been developed to predominantly deal with using technology to help, support and increase the quality of life of elderly people [7]. Along with that, integration of IoT, and other technological advances in healthcare, and everyday clinical practice has improved the society in terms of efficiency, time, and healthy living [4].

The number of smartphone users have rocketed in the recent years, specially since 2015 [8], and not just in developed but also in developing countries [9]. Smartphone usage have moved ahead from calling and messaging to an extended activities like personal health, work, news update, and keeping up with social circles [10]. These features have increased smartphone usage also among the 50 and above adults [8], who use it regularly to communicate with family and friends, making them feel less isolated, as well as updated with their loved ones [11]. With this increasing trend of use of smartphones and other technologies by the elderly, it can be fairly assumed that when the current younger generation will get old in the coming years, use of technology by elderly will be much more prominent [7]. Hence, technological devices and applications nowadays incorporate numerous health related goals into their systems, such as diagnosis, prevention, assistance, promoting healthy ageing, predicting negative health outcomes, etc.[7]. This makes smartphone a very convenient tool for research activities too, since it already occupies a space in the day to day life of people.

1.2 Elderly Monitoring

Nursing homes and care facilities are a common residential place for elderly people, but that also increases burden in the caregivers and health care officials in such places [12]. Moreover, residents in such houses often feel depressed due to lack of independence, unfamiliarity with the living environment, and quality of services received [9, 13]. In addition to the burden of work for heath care officials, nursing homes are also financially unfavorable to elderly people, who would prefer to live in their own home, rather than spending money elsewhere [13]. Hence, substantial amount of research has been conducted to provide health care, and support to elderly people inside their own homes [9, 14]. Taking care of the elderly in the home is important because of economic reasons as well as due to the preference of elderly people to be in their own house [15]. If elderly are assisted in their living environment, it can reduce the burden on healthcare officials, and also maintain the individuality of elderly.

Since, with age, it becomes necessary to check if the elderly have completed their daily basic activities or not [2, 16], the inclusion of IoT and monitoring facilities insures that family members, relatives, and health care officials, who are living afar from the elderly, can easily check completion of activities by the elderly, and get assured of their safety and well-being [17]. Inclusion of technology in the lives of the elderly is also difficult. Many elderly regard new technologies as an invader of their privacy and security [13], and tend to accept technologies only if it is beneficial to them or it adheres to their day to day activities without providing any hindrance [7].

In the Human computer Interaction (HCI) community too, the acceptance of technology by the elderly has been regarded as a challenging aspect to overcome [18], which is why focus has been shifted to creating non intrusive technologies that can help to improve the quality of life of elderly people. Use of camera to monitor their activities is not a favourable option for the elderly in terms of security and privacy [13], and on the other hand using wearable sensors can often be regarded as a hindrance and uncomfortable. Hence, researches have been carried out to monitor activities of people inside the house in non-obtrusive manner as much as possible [12, 17, 19, 20].

1.3 Problem Statement

As people get older, there is a prominent decrease in the level of mental and physical prowess. They leave house only when necessary, their engagement in mental and physical exercises such as reading and exercising declines, and they lose communication and social bonding with their friends and family members. They also have to deal mentally with their diminished physical and mental strengths, and get familiar with in-activeness, taking medication regularly, and taking better care of their health. Thus, it becomes more important to monitor if the elderly have carried out their basic daily activities or not [2].

To monitor the elderly remotely, systems such as Mimamori [21] and Canary [22] have been developed to be used specially by their children and close family members who live in a distant location. But their busy schedule can provide hindrance in continual monitoring of every day basic activities. There are also systems that include secure video communication between doctor and patients for regular or emergency situations, remote health monitoring, and emergency care services [23, 24]. Most of these applications are developed targeting the younger demographic of people [5, 11]. Therefore, in order to increase the usability across multiple demographics, it is necessary to make the interface design of the applications easy and intuitive [18].

1.4 Research Objectives

The aim of our research is to develop a system that can be used to monitor daily activities of elderly people, and predict or prevent any risky situations based on the time of completion or in-completion, and duration of basic daily activities like sleeping, eating, medication, shower and entertainment. We developed an Android based application, PATROL (Participatory Activity Tracking and Risk assessment for anOnymous eLderly monitoring) that can be used to view the activities of elderly and deduce if their activity show any potential risks in their daily routine. To tackle the concerns regarding privacy and security of the elderly being monitored, we only disclose activity information, and any personal information about the monitored elderly is not disclosed to the monitoring person.

We focused on the visualizations of the activities, and the notifications strategies to be used in the application, to realise the following research questions (RQs):

- RQ1: Is it possible to identify daily routine of individuals using a smartphone application?
- RQ2: Can a monitoring person detect potential risks in day to day activities based on visualization of activities in our application?
- RQ3: Is constant notification and using the application a burden for the monitoring person?

1.5 Dissertation Outline

This dissertation is organized as follows. In Chapter 2, we present existing literature and related works on activity recognition techniques focusing towards elderly monitoring and the role of notifications in the usage of smartphone. In Chapter 3, we first describe our proposed monitoring system, and mention the major focus area of this research. Secondly, we mention the technical requirements required to achieve our desired result. Chapter 4 presents the implementation and evaluation of our smartphone application including details about the design of the application and its evaluation conducted through experiment. Finally, in Chapter 5, we conclude this dissertation and provide limitations of our study and mention recommendations for future works.

2. Related Work

In this chapter, we discuss related works on various home monitoring methods, along with different IoT based systems designed for the elderly, and their implications. We also discuss the importance of notifications and how it affects usage of smartphone applications. The works we review can be grouped into two (2) main categories: home monitoring technologies for the elderly, and smartphone notifications

2.1 Home Monitoring

Enhanced healthcare systems have led to an increase of average lifespan in several countries [16]. This has also caused increase in research concerned with taking care of the elderly and monitoring them in their own home environment [25]. Most of home monitoring methods utilize camera or video captured to learn about the activities of the elderly [16]. Video and microphone based monitoring can be time consuming for monitoring, burdensome and also intrusive [15].

Since there are concerns of privacy and security when camera and video technology are involved, Veronese et al. (2016) [17] used only movement and domotic sensors to collect information from the home environment which were used to determine when the elderly entered or exited a certain room and to identify the time of occupancy of various areas in the house. The system used only ambient sensors as it also mitigated concerns related to low recognition accuracy, and burden due to the use of wearable sensors.

Fall related incidents are considered as the most common problem encountered by old people [16], which is why research has been focused in fall prevention and detection. Moreover, in some cases if the elderly has had an experience with fall, they tend to be cautious in activities, impacting their confidence, activity completion and social interactions. Therefore, it is necessary to check if they are completing their activities properly or not [16]. This is where remote monitoring can be helpful in keeping update of the elderly. Implantable electronic devices, wearable devices, and non-invasive monitoring are the most common ways for remote monitoring [25]. Non-invasive monitoring provides the best option since it does not interfere with the elderly physically.

An activity recognition system was developed using energy harvesting PIR (passive infrared sensor) and door sensors with positive results [19]. Another system utilized motion sensors attached to devices, and their on/off state to determine ADL (activity of daily living) of the inhabitants [26]. The system had very low construction cost, and also used motion sensors to determine location, thereby reducing the need for location sensors. A study by Kashimoto et al.(2017) [20] revealed that activity and location of the elderly can be accurately identified by using Bluetooth Low Energy (BLE) beacon. This method was further utilized in nursing homes to generate daily activities of the elderly [27].

Another study used wireless accelerometers attached on everyday objects to analyze their usage pattern and detect anomalies [28]. It is possible to determine the type of activity completed by monitoring the ON/OFF state of various every day objects. Similarly, by using a novel energy harvesting sensor mechanism, Morita et al.(2018) [29] measured sensor data such as temperature, humidity, illumination, etc. from a smart home environment effectively. Measuring body temperature, heart rate, blood pressure, respiration rate are also vital for people suffering from critical conditions or chronic diseases. Combined with indoor positioning, these technologies can help people, especially elderly who suffer from falls, heart failure, etc. [30].

An activity recognition system was proposed using ECHONET Lite appliances, infrared sensors and ultrasonic position estimation system in smartphones [31]. This system recognised nine types of daily activities using the sensor data consisting of ON/OFF state of home appliances, infrared sensors, door sensors and environmental sensors. Similarly, deploying a system that uses motion sensors, environmental sensors, and a button to be pressed at the start and end of an activity, Matsui et al. (2020) determined daily activities of the elderly over a period of two months [32]. All these studies help to highlight that it is possible to collect activities in the house using sensors such as motion sensors, environmental sensors, etc. accurately without the use of any wearable sensors in a cost effective way and handling concerns for privacy and security.

Activity recognition systems also allow elderly to live an independent life in their own house whilst their activities are monitored remotely [33]. There have been measures to monitor vital signs and biomedical signals of adults with medical conditions [34] or people working in extreme conditions such as firefighters [35]. The Allocation and Group Awareness Pervasive Environment (AGAPE) system used on-body sensors to monitor the elderly and contacted nearby caregiver groups in case it detected an anomaly in sensor data [36]. Systems can also contact the emergency contact, or caregivers of the elderly if any anomaly in the collected data is observed, for example, when the data exceeds a predefined threshold [37, 38]. When it comes to elderly remote monitoring, fall recognition systems are also very important, with some systems recording the average response time of fall detection between 7 minutes and 21 minutes [39]. The systems can detect falls using various types of sensing strategies such as acoustic sensors [40], wearable sensors [41], or accelerometers in smartphones [42].

Many commercially available products are also available that are used to monitor the elderly remotely. Systems such as Mimamori [21] and Canary [22] are specially designed to monitor activities of elderlies by their children and close family members who live in a distant location. Another system, GreatCall Responder, uses a physical button, called responder, that the elderly can press in case they feel they have an emergency, and the system contacts their caregiver [43]. Similarly, there are systems that track numerous activities using motion sensors that remote caregivers can monitor using a private and secure webpage [44, 45]. There are also systems that include secure video communication between doctor and patients for regular or emergency situations, remote health monitoring, and emergency care services [23, 24].

Many elderly people however regard new technologies as an invasion of their privacy and security [13], and tend to accept technologies only if it is beneficial to them or it adheres to their day to day activities without providing any hindrance [7]. A study found that being monitored did not affect the behavior of the elderly [46]. Their extensive study requested elderly to answer online questionnaires weekly and included daily activities of sending, reading and deleting emails, along with tracking their total everyday activities, walking speed, and time spent outside their home. Thus, using sensors such as motion sensors, environmental sensors, etc. will not affect or disturb elderly, and can be used to accurately determine their activities.

These systems also provide some areas of concern. The alerts are sent to caretakers of health professionals via text, or email [39] or direct phone calls [37]. However, the number of false alarms, which can be as high as 5 in one hour [40], can cause annoyance to the caretakers. Similarly, even though the accuracy of fall detection systems is high such as 97.5% [39] or 94% [41], the information regarding the time it takes such systems to inform the caretaker or the time it takes caretakers to respond are not explicitly evaluated. In another system, the activities of elderly were divided into critical, stable, scheduled and overlooked, and alerts for them were generated in a smartphone application as per the type such as after 5 minutes of usual time for critical activity such as medication and after 30 minutes for other activities [47]. These alerts were first sent to the elderly, and if they failed to respond, the caretakers were alerted. However, it is difficult to determine the exact time the elderly might prefer to do their daily activities. Similarly, in case of emergency, the elderly may not be physically able to respond to alerts [47] or press the emergency button [43].

2.2 Smartphone Notifications

People require notifications from different sources to keep up with latest information or amongst their friends and family. Throughout history, people have used different means to get alerts ranging from carrier pigeons to smoke signals, from town cries to telegrams, from door-to-door salesman to calls from telemarketers [48]. Mobile notification, that were initially intended for SMS or emails, are now a major source of reminding users and are used by almost all of the applications to attract users attention [49]. Notifications are also used regularly to advertise products and deals by companies, and application manufacturers [50].

It was revealed that an average mobile user receives about 63.5 notifications per day [51]. Notifications use sound, vibration or visual prompts to attract user's attention [49, 51, 52]. However, notifications opening pattern depends upon context of notifications, time at which they are received, activeness of users and reaction time [53]. Shirazi et al. (2014) used about 200 million notifications from more than 40,000 users to break down what users like and dislike about notifications [54] . They concluded that users viewed each notification differently and preferred to respond quickly to those received from social networking sites over the ones received from email or system applications. Mehrotra et al.(2016) collected and analyzed responses to more than 10,000 notifications, and determined that the response time of the notification depended on the sender, type of alert and visual representation of the notice [52].

Smartphone owners interact with their phones an average of 85 times a day, including immediately upon waking up, just before going to sleep, and even in the middle of the night [55]. Prasanta et al.(2017) divided notifications into 2 categories: personal notifications like emails, SMS or those from social networking sites; and mass notifications like news and advertisements [53]. They concluded that people tend to attend to personal notification more quickly and frequently than the other. Relationship between sender- receiver, type and complexity of the task to be done through the notification affects response time and perception of disturbance caused by the notification [56].

Notifications can however lower task performance and affect attention of the user negatively [49]. Response time and response rate of notifications were determined by analyzing the current context of the user through audio from their smartphones [57]. They concluded that the present context of the user plays a very vital role in the response time as well as response rate of the notifications. Similarly, a systematic review on the effects of context aware notification management systems found that context aware notifications increase the response rate [58]. However, it is difficult to predict what time and context can be considered as appropriate for interruption. Since remote monitoring technologies can send multiple notifications in a day, it is essential to determine if such notifications will be viewed as disruptive. Similarly, to our knowledge, the effectiveness of smartphone notifications in remote monitoring systems, specially using multiple types of notification strategies, has not been investigated.

2.3 Summary

Increasing demands in safe, secure and smart home for the elderly has led to many research and advances in the field of home monitoring and home automation [20, 27]. We found out that there are many methods with which activities can be detected accurately. However, in case of elderly people, it is also necessary to monitor such activities on a regular basis [33]. A smartphone application, equipped with adequate notification strategies, can provide a quicker remote monitoring compared to most of the remote monitoring platforms that are currently web based [44, 24, 23]. The smartphone application, that we have designed, can be used to instantly monitor completed activities and receive quick feedback from the monitoring person. It is essential not only to track activities, but also check if any risks that have occurred, and predict or prevent any potential risks in the daily life of elderly. Hence, at first, it is necessary to determine what activities to monitor and if those activities can be properly visualised in the application, and furthermore, if any deviation in the routine of the elderly can be distinguished so that any potential risky situation of the elderly can be detected. Similarly, it is essential to identify that if using the application, and monitoring activities regularly will cause burden to the monitoring person.

3. PATROL System Design

In this chapter, we will explain the overall concept of our system PATROL (Participatory Activity Tracking and Risk assessment for anOnymous eLderly monitoring), followed by the key ideas in the content of the system. We will then explain the process of viewing activity and reporting in the Android based smartphone application.

3.1 Overview of the PATROL System

The term successful ageing is used to define the ability of the elderly people to cope with the problems that arises as they get older such as isolation, frustration and depression, along with physical and cognitive decline [59, 60]. In order to reduce various effects of isolation among the elderly, numerous elderly specific socialization events have been organized and communities have been developed [61]. Similarly, mental as well as physical well-being in later years has been related to maintenance of frequent social networks and interactions [62, 63]. However, it is also necessary to assess if the elderly people are completing their daily activities properly [16]. Our proposed system includes a smartphone application that can be used to monitor the activities and status of elderly people. We aim to identify, predict or prevent potential risks in the daily activities of the elderly, and create a secure environment for them.

Our overall system, shown in Figure 2, can be divided into 4 sections: Activity recognition, Monitor generation, Notification generation, and PATROL smartphone application, where we denominate the elderly being monitored as *Target* and the person conducting monitoring as *Monitor*. Our system can be installed and integrated into any houses that already have an activity recognition system. This feature enhances the scalability of our system as it is able to incorporate any available activity recognition system into it and also helps to reduce the overall cost of installing the system in the houses of elderly. Thus, when possible, we do not have to directly design and implement an activity recognition system, but rather integrate it and consider it as a part of our overall system. In the case where we consider installation of the system, we aim to use information from electricity meters combined with low cost motion/environment sensors to gather activity information. Thus we believe that the installation cost of such system will be considerably low on cost as well as effort.

3.1.1 Activity Recognition

For the purpose of our research, we assume that the Target is residing in a smart home which is equipped with numerous sensors that can be used to recognize activities of the inhabitants [17, 26, 32]. We have designed our overall system in a way that it can incorporate any available activity recognition systems. Therefore, it is easy to integrate in houses which already have an activity recognition system. We assume that the activity recognition system outputs events (i.e., start and end times of activities performed by the resident) which are utilized for creating activity graphs, changing activity interface and sending notifications in the smartphone application.

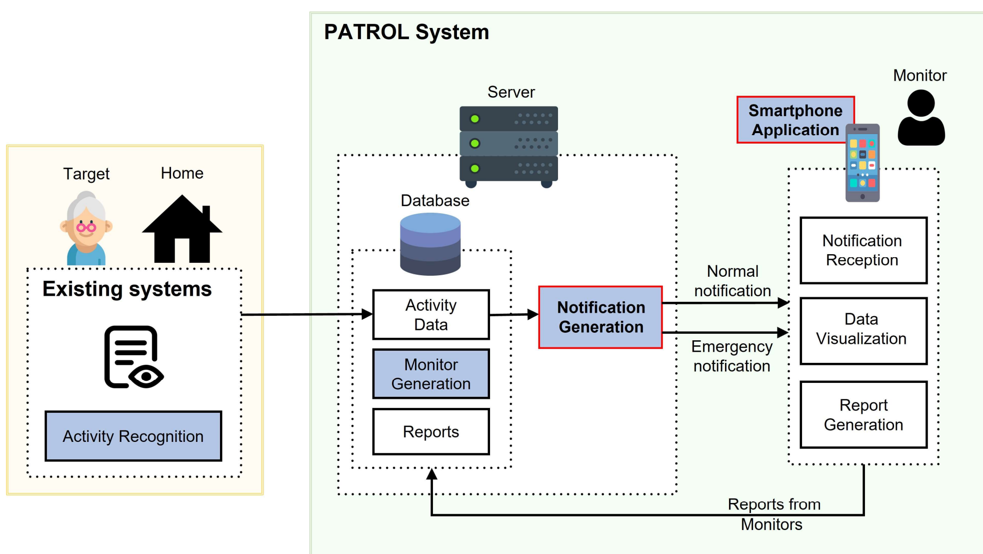


Figure 2: PATROL system.

Elderly people follow a fixed set of rules and routines in their daily activities [64]. For example, they have a definite time set for breakfast, lunch and dinner, medication, cooking, and so on. Recent technologies have made it possible to attach sensors to varieties of home objects [6] by the use of which it is possible to identify the activity performed by the elderly. With PATROL, our aim is to determine if the present state of the elderly can be identified with minimal information, in order to limit the amount of private data to be disclosed. Table 1 shows the activities of the elderly we want to monitor by observing the state of various home objects. These activities are basic day-to-day activities which are carried out normally. However, as people get older, it becomes more necessary to check if basic activities are completed or not [16]. Checking if these activities are completed or not can be helpful in determining if the elderly is in a risky situation or will potentially be in a risky situation later.

There can be instances when anomalies can occur whilst conducting activities that are not listed in Table 1. However, such incidences will subsequently impact the occurrence of basic activities that we aim to monitor. Therefore, our system can detect anomalies that can occur doing activities that are not directly monitored in our application. Since our aim is to disclose as less information about the Target as possible, whilst making it possible to determine their current status, we only use time of completion and duration of the activities to provide information about them.

Determining Routine of the elderly

With monitoring, there are also justifiable worries towards security and privacy. In some cases, the elderly may prefer to hide things in their house if there is a video based monitoring or surveillance system [15]. This shows that the elderly are concerned about privacy and security which is why we do not disclose the name, address or any other personal information of the elderly person to the monitoring person, making our system anonymous. We only show activity, completed time of the activity, and its duration. We also aimed to limit the number of data to acquire from the smart home in a way such that the monitoring results are not affected. We divide the areas of our concern into 4 specific areas of the house: kitchen, bedroom, living room and shower room. Below, we explain why inclusion of these areas, and activities inside them are important.

Table 1: Areas and activities to monitor.

Area	Home Objects with Sensors	Activities
Kitchen	• Stove • Microwave	• Breakfast, Lunch or Dinner
Bedroom	• Bed • Medicine Bottle	• Sleep time • Medication
Living room	• TV	• Entertainment
Bathroom	• Water consumption	• Shower

Kitchen

Reasons such as forgetfulness, physical declination, depression, or laziness can attribute to Target not eating or cooking regularly. To determine if the Target is eating properly and regularly, it is required to know if they are cooking regularly or not. Data from sensors attached to appliances such as stove and microwave can provide an insight into their cooking/eating activities. When monitored for a longer amount of time, the Monitor can have an idea about the eating schedule of the Target. Thus, any irregularity can be noticed in breakfast, lunch or dinner time and duration, and reported if required.

Bedroom

As people get older, proper sleep and rest becomes more mandatory than before. There can be physical as well as mental reasons because of which the Target might not be sleeping well or sleeping more than usual. By monitoring the time spent by the elderly on the bed, the Monitor can identify a difference in their sleep pattern. Similarly, Monitors can spot if the Target has been taking medicines regularly or not. If such variation continue for a longer time, then the Monitors can report it as a risky situation.

Living room

At any given day, living room can be considered as an area where the elderly spend most of their time. Isolation and boredom means that they might spend their day watching TV, or reading magazines or books. Entertainment through TV and reading can be considered essential for mental health of elderly. Lack of friends and social circles mean that the elderly should be entertaining themselves in some way or the other. Monitoring the electricity consumption of TV in the living room as well as the amount of time Target spent sitting on the couch, their activity can be recognized. If the TV has not been turned on or used for a varying duration of time than previous days, the Monitors can refer it as a risky condition.

Shower room

Regular personal hygiene is necessary for any individual. However, due to mental or physical decline, elderly people may not be regular in their hygiene activities. With regular monitoring, it can be identified whether appliances such as water heater or shower are turned on regularly or not and the time period of their use can also be determined. By monitoring the use of water heater or water consumption in the shower, Monitor can conclude whether the elderly is cleaning themselves or not.

3.1.2 Monitor Generation

Another important feature of our system is that we aim to use volunteers to monitor the elderly. Using volunteers for elderly care is a very common practice in Japan [65] where part-time civil servants committed by Minister of Health, Labour and Welfare as volunteers, locally known as minsei-iin, are assigned to regularly check the elderly people personally, have a conversation with them, etc. These part-time civil servants are people who volunteer themselves in the area of helping children, elderly people, people with disabilities, etc. and have no mandatory obligation to serve in such areas. The residential areas or communities usually consists of a secretary or a handling officer, usually someone with the responsibility of various activities or events within the community who will also act as the system administrator for our system. The task of assigning Monitors for Targets are also handled by such officers. Monitoring can be conducted in various ways. Figure 3 shows various patterns in which Targets and Monitors can be assigned in the system.

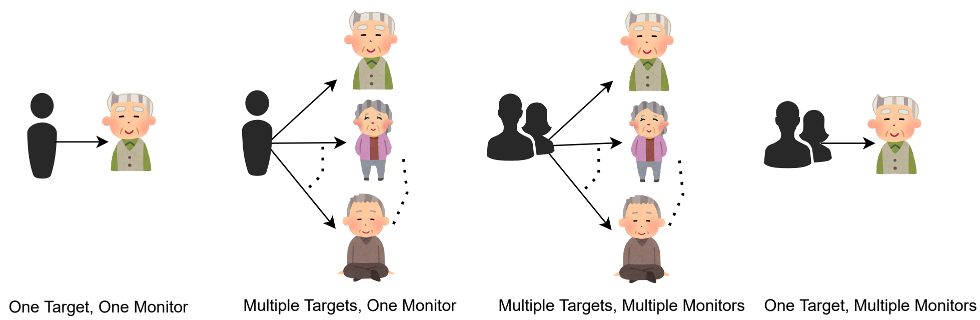


Figure 3: Various types of monitoring patterns.

The assignment of Targets is also dependent on the preference of the participants who agree to monitor the elderly people, which is why we term the monitoring activity as participatory. The volunteers (Monitors) can choose to monitor a single or multiple Targets. Hence, there can be times when one Monitor will check about only one Target. Similarly, one Monitor can be responsible to check for multiple Targets. Furthermore, multiple Monitors can be assigned for single or multiple Targets.

The system administrators have the responsibility of training the Monitors to use the smartphone application, assigning Monitors for each Target, assessing the performance of Monitors and determining if any change needs to be done. In case of changes in Monitors as well, the training of new Monitors is handled by the system administrators. Similarly, the initial testing and assessment of our application is handled by the system administrators as well who check if the system is working properly, and if the application is generating activity reports and notifications regularly. Since our application shows activities not just of the current day, but of a period of days (e.g., week), including previous days, a new user can still be familiar with start/end and duration of activities of a range of days and deduce a pattern or routine of the Target easily. Hence, to be assigned as a Monitor, one of the primary requirements is to be able to get familiar with the actions of the smartphone application. Similarly, they should be interested in elderly care and take the job seriously. They should also have the inclination to provide time and effort required to use the application and send reports properly. It is also a necessity to examine the monitoring capabilities of the Monitor, in order to ensure that the abnormalities or irregularities in the activities of the Target are identified correctly and duly on time. To understand such capabilities, we add risky situations (activity is completed in a different manner than previous days) into the dataset, and analyze if the Monitor would be able to identify them accurately. This will further be explained in Section 4.3.1.

3.1.3 Notification Generation

To encourage regular usage of the application, frequent notifications are sent to the Monitor. There are two types of notifications generated: emergency and general. General notifications are sent to remind Monitor about using the application and check current activities of the Target. Emergency notifications are sent when the system itself detects abnormalities in the recent activities of the Target. The main role of the Monitors is to respond to these notifications, check activity report of the elderly and report. Our focus was directed more towards general notifications in this research. We aim to determine how often general notifications are responded by the Monitors, if they motivate the monitors to frequently use the application or not, and if constant notifications will be burdensome or disturbing.

The notification scheduling techniques that are commonly used can be divided into 3 types: randomized time points in a day, timed at specific intervals, and event dependent times [56]. In our system, general notifications are generated by using two types of notification strategies: timed at specific intervals and event dependent notifications. This insures that the Monitors are notified regularly to use the application, and can instantly check information about the activity completed such as completion time and duration of the activity, and provide instant reports.

3.1.4 PATROL Smartphone Application

The information collected from the house of the Target is utilised to create graphical representation of activity completed in a time series form which helps to identify a pattern in the time of completion of activity and its duration, so that any deviation from the usual pattern can be identified with ease. The interaction between the Monitor and the application is shown in Figure 4. We have tried to minimize the number of actions required to be carried out by Monitors. In the application, the Monitors receive notifications as a trigger so that they can check the time of completion and duration of the activity for the current day and previous days, after which they can judge whether the Target is in a risky situation or not, and submit a report.

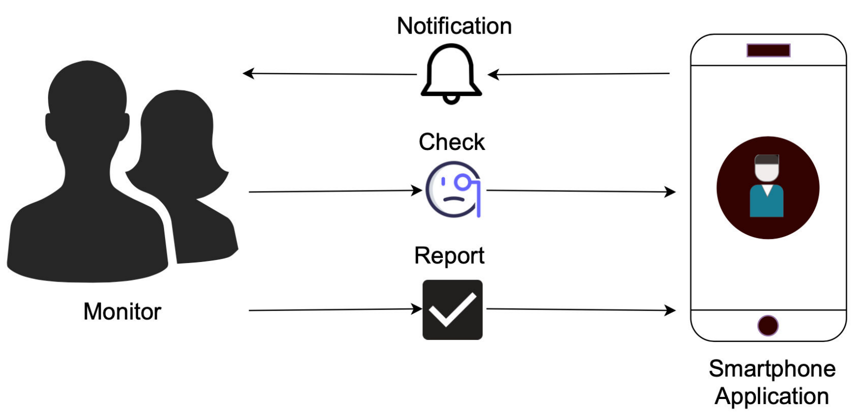


Figure 4: Interaction between Monitor and smartphone application.

The reporting depends on the the perception and ability of the Monitor to distinguish the current situation of the Target based on the graph and other information provided in the application interface. If the Monitor reports that the Target is in a high risk situation, then the application can notify system administrator and emergency contacts of the elderly via text, email, or automated phone calls, who can take necessary actions immediately. The Monitors are not disclosed any details of the Target even in such situations to maintain the anonymity of our system. The system administrators, who are in the vicinity of the Target, will take the responsibility of checking the Target as soon as such reports are received, and determine if the Target needs to be taken to a hospital or not. We will explain more about the types of risks and reporting actions in Section 4.2.1. For our research, we conduct the experiment using smartphones but the application can also be used in any other Android based devices such as tablets.

3.2 Technical Requirements

The objective of our research is to investigate the research questions mentioned in Section 1.4. To fulfill those aforementioned research questions, we determined the following technical requirements that needs to be fulfilled:

3.2.1 Visualization of Activities

Su et al.(2016) [66] developed a user burden scale to assess burden faced by users in computing systems. Among others, it consists of criteria such as demand of mental effort, time taken to get familiar with the system, and amount of information shown. We believe that the way we show the activities, and the amount of information that accompany it can affect the understandability of the activities of the Target. Therefore, we aim to show the activity completion time and duration in clear and intuitive pattern. We hope to answer research questions RQ1 and RQ2 through this requirement.

With our visualization strategies, it is also possible to see time and duration of activities over a sequential period of days. Without proper visualization techniques, though it is possible to observe completion of activities, but it is difficult to induce gradual changes in the routine. Hence, not just high level of risks, it is possible to observe minor level changes and be cautious of the state of the elderly.

3.2.2 Anonymous Monitoring

As mentioned in Section 2.1, privacy and security are major concerns for the elderly. Since a monitoring system can contain valuable information about a person, such as their time table of activities, it is imperative that some form of precautions should be taken to maintain a level of privacy and secrecy. Because of this, we aim to make the monitoring anonymous, where anonymity is maintained by not disclosing any personal or private information of the Target to the Monitor, and similarly by not disclosing any personal or private information of the Monitor to the Target. Engagement of users with the application will prove that regardless of anonymity, the application will be useful. RQ2 can be answered if this requirement is fulfilled.

3.2.3 Regular Update of Activities

It is important that the Monitor is aware of the current situation of the Target. To do so, it is better if they are notified as soon as a Target completes an activity. This makes sure that the Monitor is up to date with the current situation of the Target and their activities. Similarly, to provide a trigger to use the application even when no activity has been completed recently, or to make sure the Monitor do not miss any past events, it will be helpful if they are notified periodically as a trigger to open the application and monitor if any new changes have been observed in the daily life of the Target. To answer RQ3, it is necessary to know if such notifications are considered distraction.

3.2.4 Low Burden on Monitors

The interaction between Monitor and the application can be largely affected by the amount of burden experienced by them while using the application. The Monitor has to analyze different daily activities, and then decide the situation of the Target. Therefore, it is necessary that the application is intuitive and takes less mental effort from the Monitors, which fulfils RQ3. In this research, we consider burden as the time taken by the Monitors between opening the application and submitting the report. If this time period is low, then we can be sure that the application does not require much effort. Therefore, it is necessary that the application provides adequate information so that the Monitors can easily detect the activity pattern and duration at a glance.

3.3 Chapter Summary

PATROL system has been proposed especially for the betterment of the elderly, as a tool which can be used to monitor their day to day activities anonymously in order to determine if they are in any kind of risky situations. The overall system comprises of activity recognition, monitor generation, notification generation and the smartphone application. The main focus of this research are the two components of the system: notification generation and smartphone application. To achieve our objectives, there are some technical requirements that needs to be fulfilled. This will help us answer the research questions we have devised.

4. Implementation and Evaluation

The main idea behind PATROL is that the daily activities of the elderly should be visualized easily, any abnormality in the day-to-day activities should be detected accurately, and if any risky events are identified, then they should be reported, after which necessary actions can be taken. Moreover, we send notifications to maximize the monitoring activities, and encourage Monitors to use the application frequently. Since, notifications play an important role in the application, we first aimed to analyze the perception of users towards recurring notifications and the frequency with which they would be responded to.

In this chapter, we first report the findings of our preliminary experiment based on recurring notifications. Then, we explain the updated design of our smartphone application, how we created the dataset to be used in the evaluation and the notification strategy used in the application design.

4.1 Preliminary Experiment

Notifications are an integral part of our application, since we want to ensure that any recent activities are duly checked by the Monitors. With that in mind, we wanted to determine the perception of users towards recurring notifications and evaluated the response time and type for notifications. Users often tend to ignore notifications, if they are sent from the same source or applications [51]. Since, we want to alert the Monitor every time an activity is completed by the Target, our system needs to send notifications on a regular basis. Hence, it was important to determine the perception of frequent notifications by users.

We developed a background service application, that sent notifications to users at a fixed interval of time. The application did not have any user interface, and the only task for users was to respond to the incoming notification, shown in Figure 5. Receiving notifications every 30 minutes or an hour can be very inconvenient and disturbing for the user. Hence, we decided a 2 hour gap between notifications would be an ideal gap, and sent notifications every 2 hours, barring the period between midnight to 6 in the morning.

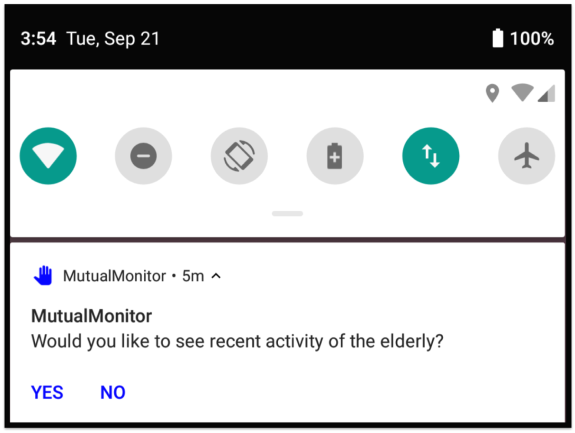


Figure 5: Notification prompt.

4.1.1 Experiment Details

A total of 8 participants were asked to use the application for a period of 1 week, and were assigned only one task, to respond to the notifications through the prompt available in the notification panel, as shown in Fig. 5. The goal of this experiment has more to do with the perception of notifications, than with monitoring, which is why no extra information about the activity was provided.

The notification prompt included only 1 question, *"Would you like to see recent activity of the elderly?"*. The question was designed to provoke a neutral response, and had the option of choosing either Yes or No. This option was provided to determine if the Monitor would be interested in finding out about the recent activities of the elderly.

Whenever participants received the notification, we logged the time, and saved it in the smartphone of the participant using shared preference feature of the Android smartphone platform. Similarly, the time when they responded to the notification was also saved, and all the data were collected from all the participants after the experiment.

4.1.2 Results

A total of 312 notifications were sent to the participants. However, 2 of them reported to receive notifications less frequently than others, mainly because of the notification settings in their smartphone. Hence, an average of 39 notifications were generated per day, for all the participants. We found out that about 87% of the notifications were responded in total, with 62.5% positive response (participant responded Yes to the notification prompt) and 24.4% were negative (participant responded No to the notification prompt), as shown in Table 2.

Table 2: Response to notifications.

Response	**Number**	**Percentage (%)**
Yes	195	62.5
No	76	24.4
Missed or ignored	41	13

Only about 13% of the notifications were either missed or ignored by the participants. This highlights the importance of recurring or frequent notifications, since it is imperial for PATROL application and elderly monitoring systems, that the notifications are responded as much as possible, and as quickly as possible. Sending frequent notifications can ensure that the Monitor will check the application more frequently. None of the participants complained that the recurring nature of notifications was a hindrance to them. 62.5% of them said that they were not at all disturbed by the notifications, while 37.5% were unaffected, and said it was okay.

The results from the experiment mentioned in Section 4.1 were positive in terms of response to notifications, however, participants highlighted the lack of user interface and other information in the application. This was also confirmed by a participant who commented *"Add more details when I click Yes"*. We then moved on to the next step of this research - creating an user friendly smartphone application which incurs a lower burden to the Monitors and helps them to track risks in day to day activities easily.

4.2 Application Design

After the preliminary experiment, we updated the user interface of the smartphone application and designed the interface with minimal tasks to be completed within the application. The application interface is limited, with limited number of view or view options, and simple actions as seen in Figure 4. With the application interface, we aim to provide all required information in one view, and also separate each activities into a separate group, thereby minimizing confusion. All the activities are shown in a single interface to reduce the burden of going back and forth between interfaces to monitor the activities. We will now discuss the features of the application interface in Section 4.2.1.

4.2.1 Interface Design

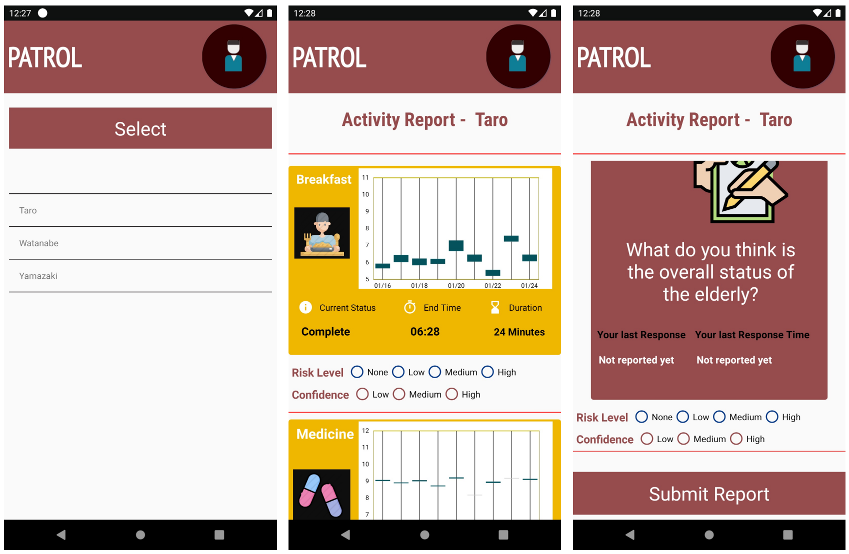
To ensure that the irregularities or abnormalities in the activities are correctly identified, the application should be clear and informative. Moreover, our targeted demographic are volunteers who are already busy with a lot of other tasks, which is why we aim to make the interface intuitive for quick analysis. To ensure that, we decided not to include features such as multitasking & multiple action keys/buttons, and designed an interface with simple actions to be completed within the application.

Similarly, since there is high chance of people forgetting the task very next day in new applications [61], we felt that it was necessary to make the interface design as simple as possible. We also realised that there should also be a consistency in the display of information, and interface in the system [67]. Moreover, it was also necessary to provide a better understanding of the ongoing procedures as such systems are more preferred in general [68].

Activity Report

The user at first need to register in the application and sign in. The first interface presents them with the option to chose who them want to monitor. Since we want our application to conduct monitoring anonymously, we selected three common Japanese family names: Taro, Watanabe and Yamazaki, as shown in Figure 6(a). This ensures that the Monitors feel they are monitoring someone they know. Whenever they select a Target, then the application shows activity report, as seen in Figure 6(b). They report about the activity based on their intuition and available information, then select the risk level they feel the elderly is currently on, and finally select the level of their confidence about the risk level.

They can do this for any number of activities that might have been completed at that particular time, and then scroll down and submit the report through the button, as seen in Figure 6(c).



(a) Selecting targets. (b) Activity reports. (c) Submit reports.

Figure 6: Application snippet.

For the purpose of simplicity, all of the activities are shown in a single interface, but separated by cards. Each card represents a different activity and consists of graphical representation of activities, current status of the particular activity, duration and activity completion time. The icons for each activity are also provided to make it easier to recognize the activity. We selected Candlestick chart to show the activities because it provides an intuitive approach to see the activity duration, start and end time. At a glance, we can see the duration easily and the difference between consecutive days is also understandable.

The Monitor, ideally, should be able to submit only one report per activity per day as well as provide the report for an activity only after the activity has been completed. Hence, in order to prevent multiple and erroneous reporting, we use 2 techniques: color codes in activity cards; and radio button for reporting. In the cases of activities that occur multiple times in a day (such as TV, medication), multiple activity cards of the same activity are shown. To avoid confusion to the users, only one activity card is shown at the start of the day, when no multiple activities have occurred. The activity cards are then subsequently added soon after their occurrence.

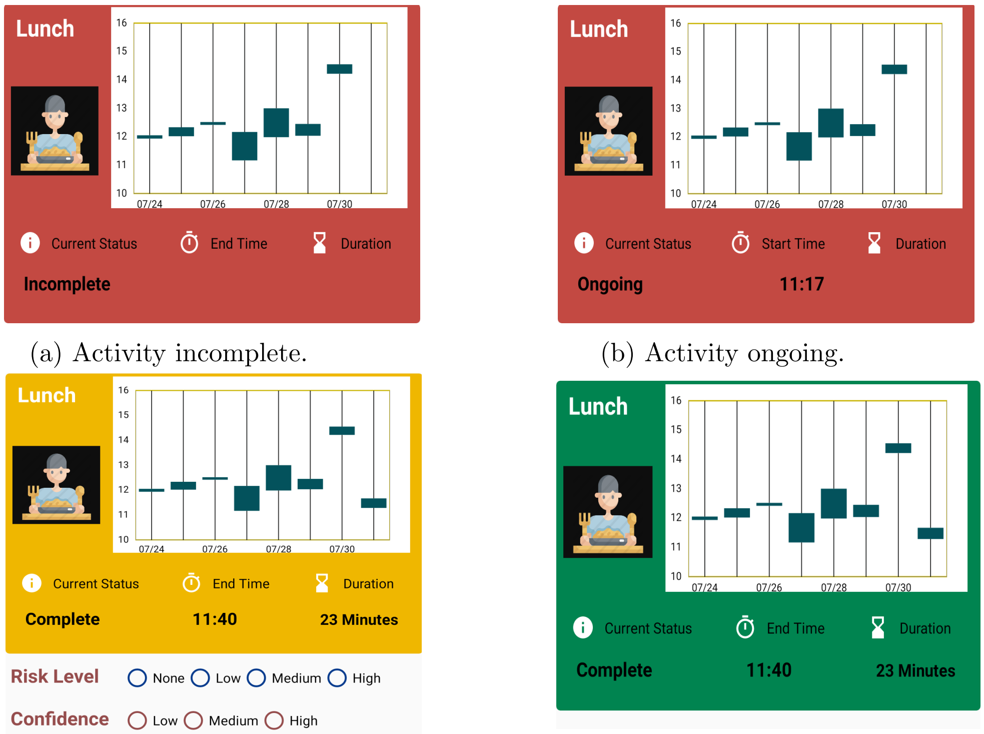
Colors coding in activity cards

Traffic light colors has been used in various researches, from labelling traffic colors on food to indicate their edibility or freshness [69, 70], to using traffic colors as a means of self-monitoring by recording the weight and shortness of breath in a diary [71]. We use traffic color codes for the activity cards in order to make the current status of various activities of the Target clear.

The background color of the activity card is represented by red when the Target has not completed the activity, as shown in Figure 7(a). The current status information, shown as 'Incomplete', also gives update that the activity has been not been finished for the current day. The information about end time and the duration of the activity is also empty at this stage. This state requires a higher attention from the monitor because if the background color does not change from red for a prolonged time, then it should be deduced by the Monitors that the elderly might be in a risky situation and thus the Monitor should report, via Overall report card (explained below). The background color of the activity card is represented by red when the Target starts the activity, as shown in Figure 7(b). The current status information is changed to 'Ongoing' in this case, and the information about the start time of that activity is updated. The information about the duration of the activity is also empty at this stage.

The background color changes to yellow when the activity is finished by the Target. The current status is also updated, to 'Complete', along with information about end time and duration of the activity. Along with the change in color, the radio buttons for reporting the status is also shown below the card, as shown in Figure 7(c). This state requires lower attention from the the Monitor compared to the red background color state.

When the Monitor reports about the activity, then the background color of the card is changed to green and helps to confirm to Monitors that they should not pay any attention to that particular activity anymore. Along with that, the radio buttons for reporting are hidden, as shown in Figure 7(d). Thus, when the Monitor opens the application again after submitting a report, then the option



(a) Activity incomplete.

(b) Activity ongoing.

(c) Activity complete.

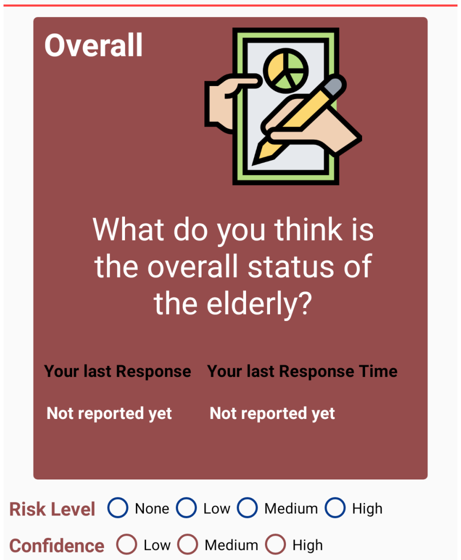
(d) Activity reported.

Figure 7: Use of traffic color coding in interface design.

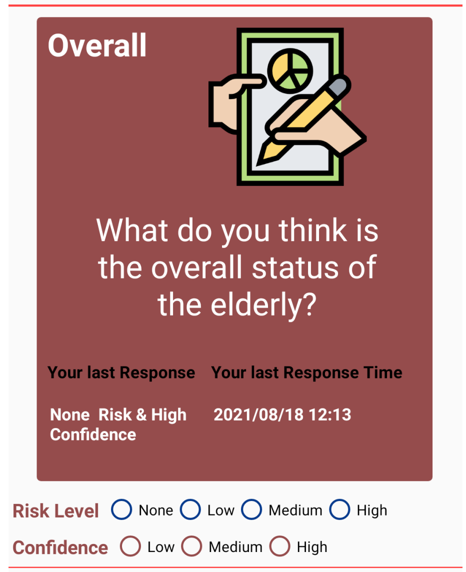
to report again is not available, and the color codes help them to identify the activities they have already reported. We believe that since people are familiar with traffic colors and its working, this feature in the application is intuitive, and helpful in clearly distinguishing the states of activity.

Overall Report

Along with the activity cards for each activity, there is a separate card called 'Overall' card. This, in general, is to report about overall impression about the status of the elderly. This can be reported multiple times by the Monitor throughout the day, and has the same reporting option of risks and confidence as in other activity cards, as shown in Figure 8(a). Thus, when submitting reports for activities, the Monitor has the option to chose what they feel is the overall status of the Target based on their judgement of activities completed or not completed. This feature also makes sure that even if the Monitor opens the



(a) Overall report card before report submission.



(b) Overall report card after report submission.

Figure 8: Overall report card.

application, and there is no activity to report about, the Monitor can still send some report.

In cases of High risk situations such as no activity or long deviation, the Target will not register completion of activities regularly, which means that no notifications are sent and the activity cards are not updated. If no activity has been updated for a significant time, then the Monitor can deduce that there is something wrong with the target. In such situations, they can report the emergency situation using the Overall card. The card also shows the type and time of previous response for the Overall card, to make it easier for the Monitor to recall their previous impression, as shown in Figure 8(b).

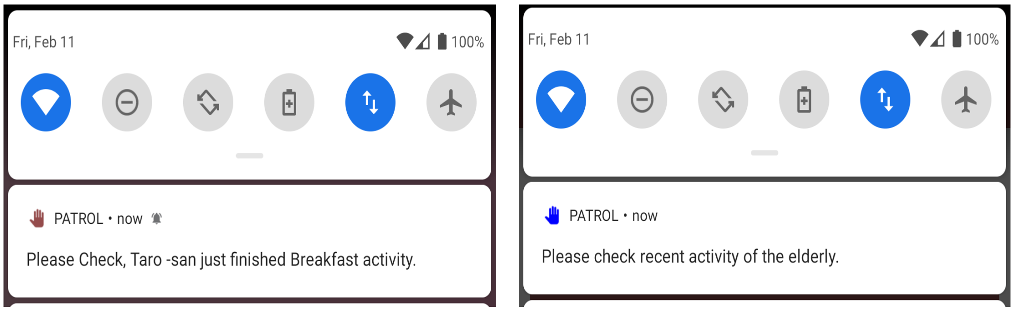
Submit report

When a Target completes an activity, the background of that activity card is changed to yellow, as well as Radio buttons for reporting are visible or functional, as shown in Figure 7(c). The risk levels shown are classified already in Table 3. After viewing each activity, the Monitor has the task of determining the current status of the Target into one of the risk levels mentioned. This reporting depends on the judgement and intuition of the Monitor, and how they perceive the current situation of the Target based on the graph and corresponding information. The Monitor therefore also should report how confident they are with their prediction of the risk level. To make their judgement easier, we provide textual as well as graphical information about the activities of the Target. Thus the option to deduce the confidence of the Monitor about the report was included in the application as 'Low', 'Medium' and 'High'. The confidence levels hence act as reference points of risks for each activity, especially when there are multiple Monitors. The confidence level provides a perception of each of the Monitors and their report, and also helps to analyze their monitoring capabilities.

The report can be submitted for one activity at a time, as well as for multiple activities at the same time. To submit the report for each activity, the Monitor needs to scroll down in the activity report interface and click the submit button at the end of the activity report interface, as shown in Figure 6(c). If the Monitor responds with 'high' risk and 'high' confidence to any activity, then the application can infer that the elderly might be in emergency situation, and can promptly notify the emergency contact of the Target (friends, family or health professionals), who can take necessary actions. Similarly, if more than 2 consequent 'medium' risks are reported with 'high' confidence, then also their emergency contact can be notified immediately.

4.2.2 Notification Strategy

We deploy two kinds of notification pattern in our application : recurring notifications (rN) and activity based notification (abN). The strategy for rN is similar to the one explained in Section 4.1. We send notification every two hours to provide a trigger to the Monitors to use the application. Apart from this, we also send a notification, abN, which is sent as soon as a Target completes an activity. We mentioned in Section 2.2 that it is necessary to provide contextual information in the notification. We provide name of the Target and the activity completed in the notification, to provide context of the notification to the Monitors, as shown in Figure 9(a). To make distinction between the two types of notifications, we indicate abN with red icon of notification (see Figure 9(a)) and rN with blue icon (see Figure 9(b)).



(a) Activity based notification (abN). (b) Recurring notification (rN).

Figure 9: Example of notifications generated.

4.3 Application Evaluation

In this section, we will explain the study conducted to evaluate the effectiveness of our application. We investigate the usefullness of our graphical interface, and check if our notification strategy is helpful to the Monitors.

4.3.1 Dataset Creation

The dataset used in our research is from a real life experiment conducted in the houses of elderly residents over the age of 60 [32]. The activity dataset were obtained through an extensive research conducted over a period of 2 months, where motion and environmental sensors were installed in each of the houses. Along with that, a physical button was installed in each of the houses, and the residents were requested to press the button whenever an activity is started and ended. The original dataset consists of activity recognition data from single as well as two-person households. For the purpose of this research, we selected only single resident households, that were three in total. We use cleaned and collected data from the above mentioned study, and regard that the activity recognition system is 100% accurate (we used ground truth labels of activities in the dataset as the output of the activity recognition method)

The daily activities of the elderly that we want to track and monitor are mentioned in Table 1. The original dataset however does not contain data related to *medicine* activity. Similarly, we also wanted to include activities related to frequent use of *TV* too. To fulfill our desired dataset, we added aforementioned activities into the dataset. Since the period of experiment for the original experiment was longer than our intended experiment period, we included data from the same time period section for all the three single-resident households.

For the accurate analysis of our monitoring application, it is necessary that any deviation from the usual routine of the targets are identified correctly. Therefore, it was required that we included some risky situations into the dataset, and our application, and examine if participants of our experiment will be able to accurately determine those risky situations. We, however, at first need to define what these risks are, and how they can be related to real life situations. We created a total of 4 risk stages, as shown in Table 3.

Table 3: Risks used in the application and their definition.

Risk	**Definition**
None	Everything seems to be okay with the elderly
Low	There is some problem, but can be handled by elderly themselves
Medium	There is a problem and the elderly should be assisted/checked by caretaker, family members or doctor
High	Elderly is in emergency and requires immediate medical care

For the purpose of our research, we included only Low and Medium level risks. As defined, *None* risk indicates that there is no problem with the elderly. Hence we do not need to alter the dataset for such risk, since they concur with the regular routine of the elderly. If the level of risk is *High*, it indicates that the elderly is in a serious condition and in need of immediate medical care. In such cases, no activity will be completed by the elderly, and the application will not be updated. However, our aim to determine if any deviation from regular routine of the activities could be determined using our application. Though high risks can occur suddenly, we also think that if we regularly monitor and determine low and medium level risks, then high level risks can be prevented or predicted. Because of this, we did not include high level risks in our dataset.

We used standard deviation to include low and medium level risks into the dataset. We calculated standard deviation of duration and time of completion of each activity, for each Targets. Then, we defined *Low* and *Medium* level of risks as follows:

- Low risk
  - duration $\pm 1.5 \times$ standard deviation of duration
  - time $\pm 1.5 \times$ standard deviation of activity completion time
- Medium risk
  - duration $\pm$ 3 $\times$ standard deviation of duration
  - time $\pm$ 3 $\times$ standard deviation of activity completion time

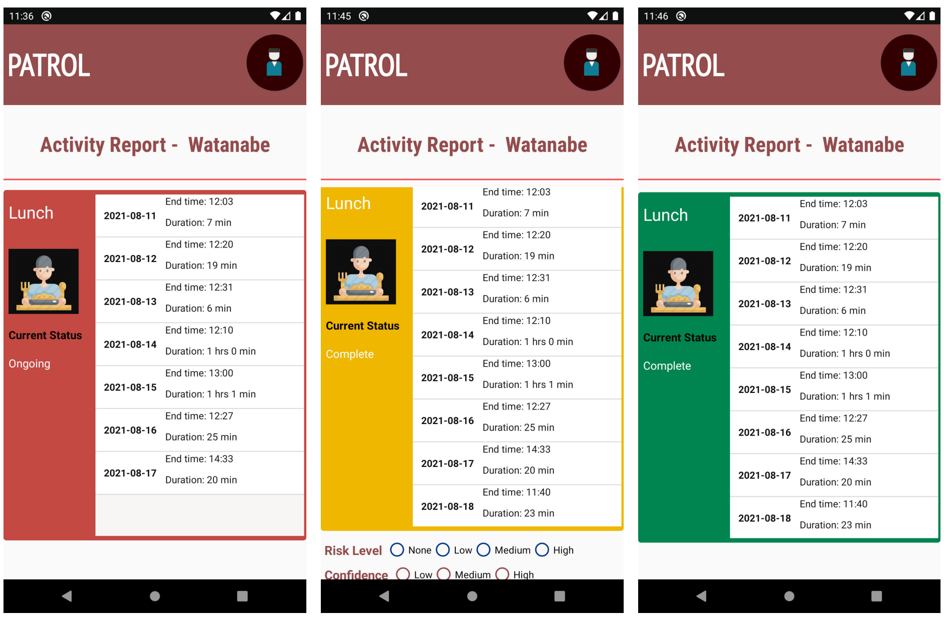
The purpose of using this technique is that it gives us a wide range of duration and activity completion times. Since the deviation from an activity can be in positive as well as negative direction, the above strategy allowed us to include risks strategically into the dataset. However, sometimes, the risks obtained coincided with the start, or duration of subsequent activities. In such cases we did not include any risks. For example, let us say for a particular day, that a Target completes dinner at 19:21 pm. After computing, we receive the following time for low and medium risk respectively.

- Low: 17:22 pm & 21:19 pm
- Medium: 15:23 pm & 23:18 pm

If the same Target was conducting other activities during the time received from computation, such as if the Target finished having a shower at 21:15 pm, then we did not include low risk (21:19 pm) and if the Target started sleeping at 22:54 pm, then we did not include medium risk (23:18 pm) . Similarly, if by adding low and medium risks for duration, if any other activities were affected in similar manner, we did not include such deviation. Finally, the risks were strategically included into the dataset.

4.3.2 Multiple Versions of Application

In order to concretely determine that our proposed method of a graphical interface, as shown in Figure 6, is intuitive and have higher degree of user acceptance, we needed to compare that interface with commonly used activity representations. To make that distinction, we created a separate version of our application where activities were shown in a textual interface, rather than graphs. Figure 10 shows the activity report interface of this kind of version of the application. All the features of the application mentioned in Section 4.2 are included in this version as well, so the working principle is same regardless of the interface. This helps to create less confusion for the participants.



(a) Activity incomplete. (b) Activity complete. (c) Activity reported.

Figure 10: Example of tabular interface.

Similarly, we created a third version of our application, in which we did not send notification to the Monitors when the activity was completed by a Target. We only send them recurring notifications, every two hours. With this version of the application, we aim to determine that our strategy of providing both abN and rN can be effective to encourage and motivate Monitor to use the application, instead of only sending rN. Table 4 summarizes the three versions of the application created, and we will use the same label for versions (GAR, TAR and GR) in future discussions.

Table 4: Types of versions of PATROL application.

Version	**Interface**		**Notification**	
	Graphical	Tabular	Activity-based	Recurring
GAR	✓	–	✓	✓
TAR	–	✓	✓	✓
GR	✓	–	–	✓

GAR refers to the proposed version of PATROL, which consists of a Graphical interface, Activity based notification, and Recurring notification. We investigate the accuracy of risk identification, and the burden of use of our application by comparing the versions GAR and TAR (Tabular interface, Activity based notification, and Recurring notification). Similarly, we compare the effectiveness of using activity based notifications by comparing GAR with GR (Graphical interface and Recurring notification).

4.3.3 Experiment Details

We recruited a total of 9 participants (8 Male, 1 Female) to take part in our evaluation study. The participants were playing the role of Monitors throughout the experiment. The modified dataset of the three single-person households were used for the three Targets in the application. The participants were divided into 3 groups each. So we had three participant each in three study groups. Among the various monitoring patterns, as shown in Figure 3, we have implemented the “multiple Targets, multiple Monitors” strategy in this experiment. This was carried out to implement random distribution of our application in a way that each group, with equal number of participants, will use a different application at a given time compared to other study groups. To implement that, we divided the experiment period into 3 phases in total, 3 for each group to use 3 versions of the application. Table 5 simplifies the study group and application interface division.

Table 5: Study groups and division of version of PATROL application.

Phase	Date (MM/dd)	Number of Days	StudyGroup A	StudyGroup B	StudyGroup C
1	08/25 - 08/27	Three	GAR	GR	TAR
2	08/29 - 09/01	Four	TAR	GAR	GR
3	09/03 - 09/05	Three	GR	TAR	GAR

Application Distribution

The three versions of the application were uploaded in Google Play Store. Before the start of the experiment, we conducted a research and experiment introduction session that all the participants were requested to attend compulsorily. They were explained about the experiment in detail, and about the actions to be completed while using the application. They were provided with a document containing all the information about the working principle of the application, along with QR code for each application. The documents also indicated the version of the application they were supposed to use in each phase of the experiment. As a reward for participation in the experiment, the participants were provided with a gift card worth 2,000 JPY.

To make the transition between interfaces easier for the participants, we included one gap day between each phase. The participants were asked to take a break for a day in between the phases. The phases were designed to be of 3 days each. However, at the start of phase 2, we encountered some complications with the server connected to our application. Hence, we asked the participants to continue phase 2 for one day more. Thus in total, the experiment period consisted of 12 days, with breaks of 2 days in total. After the end of each phase, we asked the participants to fill in a questionnaire developed using Google Forms. Most of the questions had to be rated on a five-point Likert scale (1=strongly disagree, 3=neutral, 5=strongly agree), while some of them were open ended, such as, "*The activity related notifications were helpful in monitoring the elderly as it reminded me to check the application regularly.*", "*I found the change in the interface confusing.*", and "*I feel the new interface needed more mental effort*". At the end of the experiment, the participants were asked to fill a final questionnaire. The purpose of these questionnaires is to gain insight into the impression of the participants for different interfaces and different notification types.

4.3.4 Results

The results of our study are analysed based on the following three conditions:

1. Accurate detection of risky situations
2. Low burden of monitoring on Monitors
3. Timely Detection of risky situations

Accuracy of Detection

In order to verify the effectiveness of our visualization technique, it is necessary to check if the risks included in the application, as mentioned in Section 4.3.1, will be identified correctly. In this section, we report the rate with which the risks included in the dataset were correctly identified in each phase, using different versions of the application. Table 6 and Table 7 show rate of correct identification of risks based on study groups and interfaces respectively.

Table 6: Risk identification based on study groups.

Study Group	Phase	Interface	Risk Identification	Average
StudyGroup A	1	GAR	68.4%	72.6%
	2	TAR	67.7%	
	3	GR	81.9%	
StudyGroup B	1	GR	32.4%	46.1%
	2	GAR	64.7%	
	3	TAR	41.3%	
StudyGroup C	1	TAR	88.4%	90.7%
	2	GR	91.3%	
	3	GAR	92.6%	

From Table 6, we can observe that StudyGroup C were the most consistent group, with highest risk identification rate during all of the three phases of the experiment. The rate of correct identification also increased along with the experiment, which proves that their familiarity with the application helped to analyse the activity reports and submit reports.

There was a slight decrease in risk identification for StudyGroup A when the interface changed from graphical (GAR) to tabular (TAR) in phase 2 of the experiment. All of the participants in StudyGroup A agreed that the new interface needed more time to analyse in their questionnaires after phase 2, with 66.7% agreeing that the tabular interface (TI) needed more mental effort than graphical interface (GI). When the interface changed to graphical layout (GR) in phase 3 of experiment, there was an increase in the correct rate identification. When asked about the change, participants claimed that it was easier to understand the routine with the graph compared to tabular layout (66.7% agree, 33.3% strongly agree).

StudyGroup B showed a considerable increase in correct risk identification, in phase 2, as shown in Table 6 even though they had graphical layout for both phase 1 (GR) and 2 (GAR). We can predict that familiarity with the application was the reason for such change. In their questionnaire after phase 2, 66.7 % strongly agreed that they were familiar with the application and found it easier to use the application during this phase. However, in phase 3, their interface changed to tabular layout (TAR). This led to reduction in risk identification, with 33.3 % strongly agreeing that the change in interface was confusing.

As shown in Table 7, we found out that in total, using GAR, on average about 75.2 % of the time the risks were identified correctly. In comparison, the risks were identified correctly about 65.8 % of the time using TAR. GR, which in this context, is same in visualization as GAR, had a risk identification accuracy of about 68.5 %. The average rate of risk identification is lower for tabular interface (TI), compared to both of the graphical interfaces (GI). This can help to identify that graphical interfaces (GI) provide better understanding or identification of risks.

We also found statistically-significant differences between the average risk identification rates of the three interfaces using one-way ANOVA method ($p=0.037$). A Tukey-HSD post-hoc test revealed a significant pairwise difference between interfaces GAR and TAR ($p=0.032$) whilst no difference was observed between

Table 7: Risk identification based on interface types.

Phase	**GAR**	**TAR**	**GR**
1	68.4%	88.4%	32.4%
2	64.7%	67.7%	91.3%
3	92.6%	41.3%	81.9%
Average	75.2%	65.8%	68.5%

GAR and GR (p=0.2).

To investigate this further, we combined the results of GAR and GR into a single group and compared it with TAR, to clearly determine differences between graphical and tabular interfaces for risk identification. Through the paired t-test analysis, we found that there is a significant difference between the two (p=0.047).

Low Burden Evaluation

We define burden as the time taken by the participants between opening the application to check the activity report of targets, and submitting the report. We logged the time of opening of the application as well as the time of reporting using "Shared preference" functionality available for Android developers. These time periods were saved together in the Firebase database. We analysed the burden time for each participant using this data, and calculated an average burden time for each participant over the whole experiment period, which is shown in Figure 11. The average burden time for each of the versions is also shown.

We can see that the burden time for GAR, on average, is always lesser than TAR. The mean burden time for GAR, TAR, and GR were observed to be 28 seconds, 38 seconds, and 52 seconds respectively. As seen in Figure 11, burden for participant 1 while using GR is very high compared to other participants, and other interfaces used by the same participant. Upon inspection, it was discovered that, while using GR, for one particular report, the participant recorded an unusually high burden time, which was uncharacteristic for the participant based on his other responses. Discarding the unusually high burden time, the average burden time of the participant 1 was reduced from 193 seconds to almost 20 seconds. However, for the final analysis, the skewed data is kept as it is. Similarly,

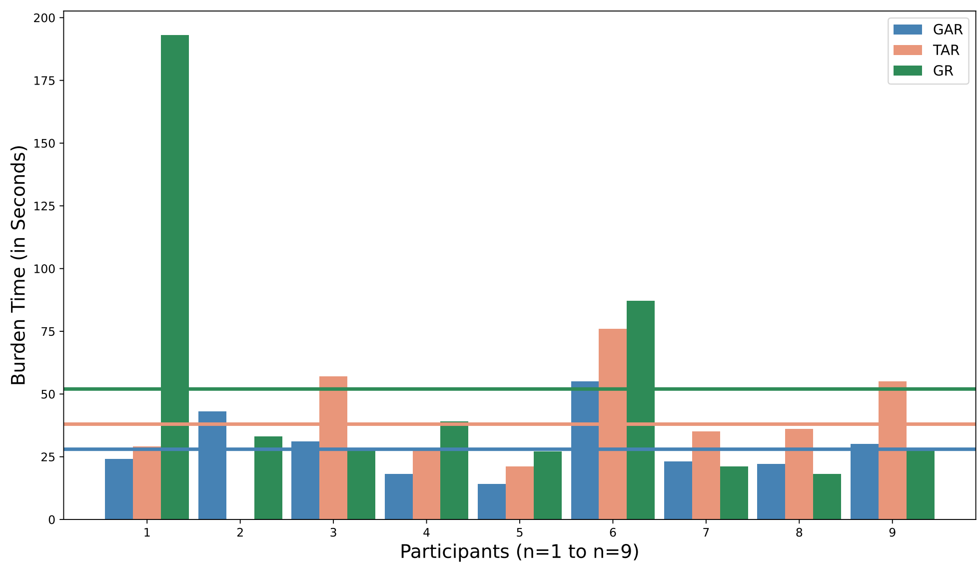


Figure 11: Average burden time of participants.

the burden for participant 2 while using TAR is zero because the participant did not record any response during phase 2 of the experiment.

To analyse the link between burden of using the application, and engagement with the application over time, we calculated the average time it took to report based on the phases of the experiment. The results are shown in Figure 12. When the interface changed from graphical (GAR) to tabular (TAR), in phase 2 for StudyGroup A, we can see that the burden time was higher. In phase 3, when their interface changed back to graphical (GR), the burden time was observed to be extremely high (94 seconds) due to the unusual reporting by participant 1 as explained above. Discarding that particular incident, the burden time was observed to be lower than in phase 2 (28 seconds).

For StudyGroup B, the burden time was highest in phase 1, with 47 seconds, when using GR. However, the burden time decreased in phase 2 (25 seconds) when using GAR. This can be attributed to the participants getting familiar with the interface. In phase 3 however, when the interface changed to tabular (TAR), we can see that the average burden time increased to 37 seconds.

Similarly, when the interface was changed from tabular (TAR) to graphical (GR), for StudyGroup C in phase 2 of experiment, we can see that the average

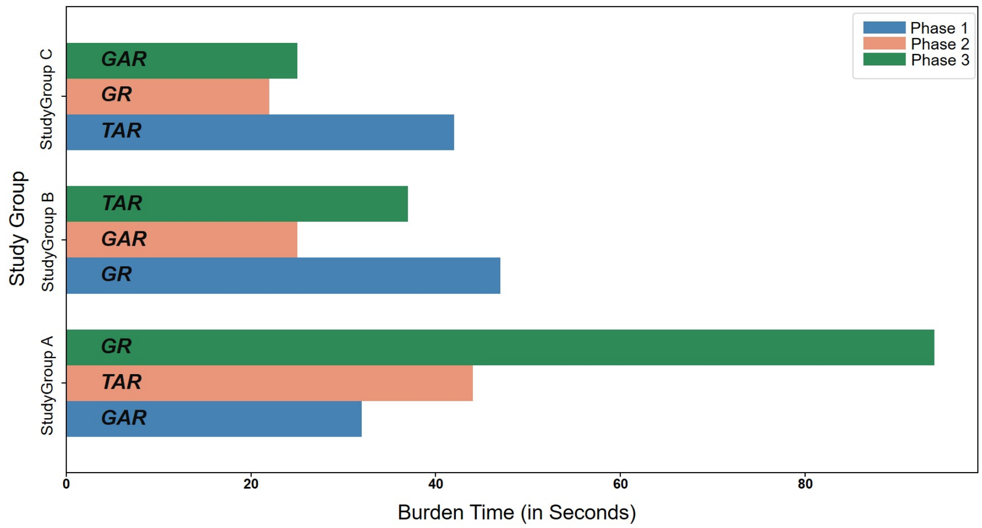


Figure 12: Average burden time of study groups per phase.

burden time was lower (22 seconds). Even though the burden time increased in phase 3 (25 seconds), using GAR, it was still lower than the burden time in phase 1 (42 seconds). Therefore, over the course of the experiment period, we can observe that change in interface had some affect in the engagement with the application and burden time. Familiarity with the application lowered the burden time, especially using graphical interface (GI).

We found a statistically-significant difference in the burden time for the three interfaces using one-way ANOVA method (p=0.012). A Tukey-HSD post-hoc test revealed a significant pairwise difference between interfaces GAR and TAR (p=0.039) whilst no difference was observed between GAR and GR (p=0.13).

For further investigation, we combined the results of GAR and GR into a single group and compared it with TAR and through paired t-test analysis, we found that there is a significant difference between the two (p=0.049). This analysis, along with the results from Figure 11 and Figure 12 help to show that there is a significant difference between tabular and graphical interfaces for the burden faced while using the application, with graphical interface resulting in lesser burden for the participants.

Lesser burden also resulted in higher engagement with the application. Figure 13 shows that the total number of reports received using GAR across different phases were almost consistent across the 3 phases, and on average higher than when using TAR. There was a significant decrease in reports using TAR in phase 2 for StudyGroup A. This can be attributed to change in their interface because in earlier phase they used graphical interface (GI). They also mentioned in the questionnaire after phase 2 that tabular interface (TI) was difficult to understand which resulted in lower number of reports.

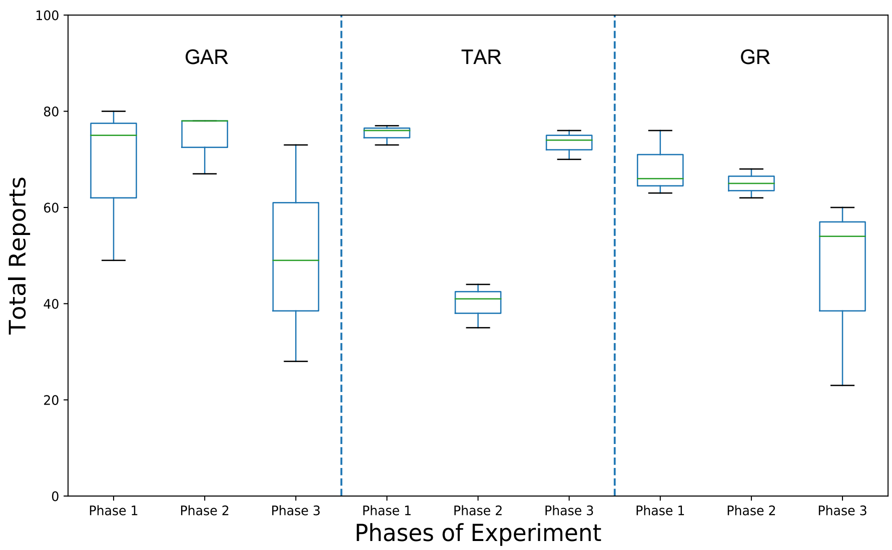


Figure 13: Total number of reports received.

We can thus conclude that GAR provides lesser burden to participants, in comparison with TAR, and on average has higher engagement and reporting. This further strengthens our proposal that graphical interface (GI), with adequate textual information can be helpful for monitors to identify routine of targets and distinguish risky situations whilst spending lesser time and effort analysing the interface.

Timely Detection

Figure 14 shows the time taken to report about a completed activity during each phase, based on types of interface. Over the three phases of experiment, we can observe that using graphical interface (GI), the reports for activities were received quicker compared to tabular interface (TI): GAR (average = 176.46 minutes, median = 115.01 minutes), TAR (average = 201.42 minutes, median = 118.85 minutes), and GR (average = 166.9 minutes, median = 121.12 minutes). Even though such high response times for the report are not favorable, we think that there were many factors that affected the reporting time for activities.

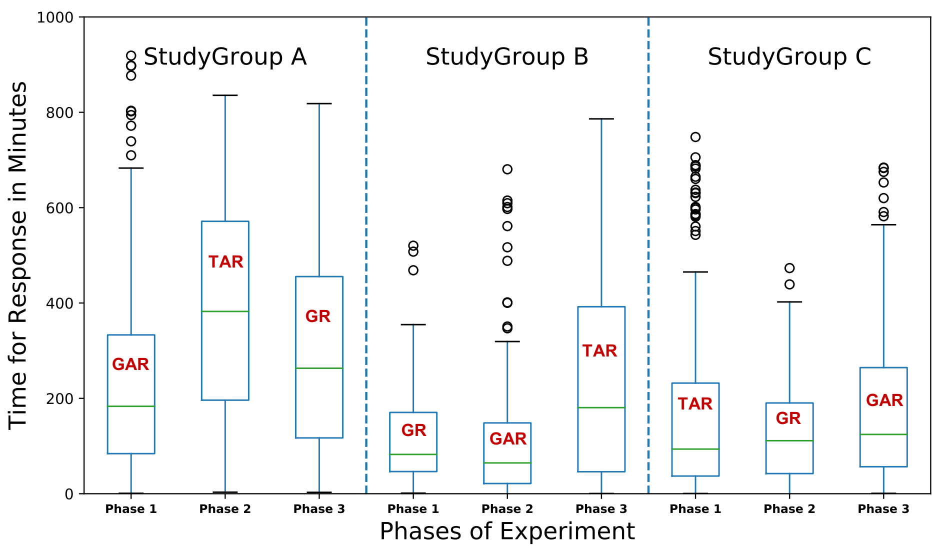


Figure 14: Response time for activities per phase based on study groups.

The time of notification generated, which is also the time when the activities were completed, was saved using "Shared preference" functionality, as mentioned in section 4.3.4. Similarly, we also saved the time when the activity report was submitted. We determine the time taken to report an activity by calculating the time difference between report submission and notification generation. For StudyGroup A, when the interface changed from graphical (GAR) to tabular (TAR) in phase 2, the reporting time was higher compared to phase 1, even if they had received both rN (recurring notifications) and abN (activity based notifications) in both of the phases. This can be attributed to the change in interface because when their interface changed back to graphical (GR) in phase 3, the time of response also was observed to be lower than on phase 2, even though they did not receive abN. This shows that type of visualization can have effect in the response time for notifications received.

StudyGroup B were almost consistent in their performance throughout the first 2 phases of the experiment period. In phase 2, when their interface changed from GR to GAR, there was no significant change in their response time even if they did not receive abN. However, when their visualization changed to tabular (TAR) in phase 3, the time of responses was higher than in the previous two phases.

In contrast, StudyGroup C did not show any significant differences in response time for activities based on changes in interface as well as reception of abN. When their interface changed from TAR to GR in phase 2 and from GR to GAR in phase 3, their response time for notifications did not show any high amount of significant differences. StudyGroup C thus did not show any conclusive effect for the change in visualization or notification strategies for the reception of reports to activities.

Table 8 shows the average response time of each participant while using each of the interfaces, where the lowest response time taken among the three interfaces is highlighted. Even though TAR consisted of both abN and rN notifications, we found that none of the participants responded quickly while using it. Moreover, the mean response time using TAR is highest across all the participants (except participant 2, who did not register any response during phase 2). We found that even though they did not receive abN, some of the participants (4) recorded lowest mean response time using GR. GAR and GR recorded mean response times of about 176.46 minutes and 166.9 minutes respectively, while TAR had a mean response time of 201.42 minutes. Even though GR had lower average response time, we observed that the median response time for notification was lower for GAR (115.01 minutes) compared to GR (121.12 minutes) and TAR (118.85 minutes). This shows that reports were received quicker using GAR than GR or TAR.

Upon further analysis, we found statistically-significant differences between activity response time for the three interfaces using one-way ANOVA method ($p = 0.005$). A Tukey-HSD post-hoc test revealed a significant pairwise difference between interfaces GR and TAR ($p=0.05$) whilst no difference was observed between GAR and GR ($p=0.64$) or between GAR and TAR ($p=0.055$).

Table 8: Mean response time (in minutes) of each participant.

Participant	GAR	TAR	GR	Total average
1	**225**	349	243	272
2	**335**	No response	341	225
3	**182**	418	260	286
4	146	287	**135**	189
5	**33**	146	59	79
6	**154**	301	167	207
7	187	188	**146**	173
8	114	171	**109**	131
9	205	146	**110**	156

We then combined the results of interfaces that received abN i.e. GAR and TAR into a single group and compared it with GR, and found that paired t-test shows a significant difference between the two (p=0.022).

This shows that reception of abN does indeed have an effect in the time for response to the activities. To investigate this further, we determined the time range within which the responses to the activity notifications were received. Table 9 shows the cumulative percentage of reports received within the given time ranges for the three versions of the application. We divide the time into 30 minute intervals, however the table only shows until 210 minutes, since the highest average time of response is within the 180-210 minute range. We can see that the amount of responses received does not vary by a large amount if Graphical interfaces are compared. However, for tabular interfaces the response rate is lower even if abN was received. This shows that abN, when used with graphical interface provides a better result than compared with tabular interface. We then tried to investigate which interface provided the quickest response for activities.

We divided the notifications into those that were for regular activities and those that were for the risky situations. By using the time taken to report to activities, we determined the minimum time taken to submit a report for an

Table 9: Cumulative percentages of responses received per time range (in minutes).

Time Range	**GAR**	**TAR**	**GR**
0 – 30	18.4%	15.45%	13.24%
30 – 60	30.55%	23.21%	29.66%
60 – 90	42.36%	31.22%	41.79%
90 – 120	51.56%	37.09%	49.44%
120 – 150	57.63%	41.42%	58.39%
150 – 180	63.88%	44.04%	65.29%
180 – 210	68.92%	47.29%	70.52%

activity among all the participants, and the version of the application used to submit that report. Thus, we found that using which version of the application we received the quickest response for each of the activities. The results are shown in Figure 15 and Figure 16. We can see that the risky situations were responded quicker when using interfaces that consisted of abN even though there is not much difference between interfaces for the quickest time of response to non-risky notifications.

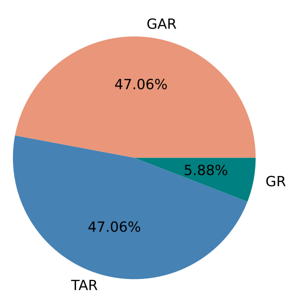


Figure 15: Quickest response for risky situations.

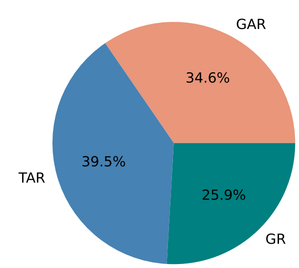


Figure 16: Quickest response for non-risky situations.

In the final questionnaire, the participants responded with the reasons that could also provide the reason for such higher response time. Almost 45% participants (n=4) mentioned that they were busy with their research/private work and could not respond to the notifications on time. We received responses such as: *"I was so busy with my work"; "Busy with my research work or play a game"; "mentally busy with my own work"; "sometimes i was busy"*. Similarly, two of the participants mentioned that they often forgot to check the application. This can be attributed to the different interface types used and notifications received.

Two of the participants responded in the questionnaire that they did not use the application if they did not receive any notifications, while six (66%) of them said they did not wait for the notifications to use the application but were busy with their work and could not respond immediately. We also wanted to know if the notifications received were perceived as distracting or disturbing, to analyze if their perception played any role in the response time. When asked if the notifications received from the application were distracting, 2 (22%) of them strongly claimed they were not disturbed, 5 (55%) said they were not disturbed, while 1 of them was neutral, and 1 agreed that he was distracted. Similarly, 8 (88%) (strongly agree: 4; agree: 4) agreed that they prefer to receive abN so that they can be regularly notified monitor frequently, while 1 of them was neutral.

4.3.5 Discussion

After analysing the results from the experiment, we can conclude that the results are fairly positive towards GAR, as compared to TAR, when considering user engagement, and their ability to identify routine of individuals with the interface. Similarly, we found that the monitoring task did not provide a higher degree of burden to the participants and they were able to analyse and report with a minute (mean burden time of 28, 38, 52 seconds respectively for GAR, TAR and GR.) We further analyse our results and investigate if our research questions are answered. Our main focus for answering research questions will be based on the results of GAR, whilst comparing it to TAR and GR.

RQ1: Is it possible to identify daily routine of individuals using a smartphone application?

We analysed answers from questionnaire filled by participants after each phase of the experiment, from which we can say that in each phase, participants using GAR mentioned that they were able to identify the daily routine of the Targets through the interface. At the end of the experiment, we asked the participants which representation of activities did they prefer: table or graph. All of them agreed that graphical representation was better. Some of the responses we received, such as, *"Got on a quick glance the exact duration of past activities and could check exact time of the day"; "With graph, it's easy for me to compare the length of activity at the glance."*, further strengthens our proposal that graphs can help to identify daily routine in a clear and intuitive manner.

We received a total of 1680 responses from participants over the experiment period. We can claim that such interaction is a result of participants willing to use the application. When interface of participants changed from graph to table, there was a reduction in the number of reports obtained (45.6% for StudyGroup A in phase 2, and 9.8% for StudyGroup B in phase 3). Similarly when interface changed from tabular to graph, we obtained increase in the number of reports by 96.7% for Studygroup A in phase 3 and reduction by 11.5% for StudyGroup C in phase 2. However, it should be mentioned that one participant did not provide any response for StudyGroup A in phase 2, but did on phase 3, which makes the difference considerably higher.

RQ2: Can a monitoring person detect potential risks in day to day activities based on visualization of activities in our application?

We included risks in our dataset to check if the participants will be able to determine them correctly (as either low, medium or high). Using GAR, we found that 75.2% of the responses for risky situations were correctly identified as risks, compared to 65.8% and 68.5% for TAR and GR respectively. Though identification of risk varied between study groups using GAR (68.4% for StudyGroup A; 64.7% for StudyGroup B, and 92.6% for StudyGroup C), the overall identification rate is higher for GAR. This shows that risks can be identified using graphical interface and the style of graph that we used. A response from a participant, *"I can see the difference of the duration directly from the graph. The table one need to scroll up and down to see all the information, which sometimes kind of annoying"* also suggests that our visualization is effective.

All the participants of the experiment using GAR mentioned that they could easily detect differences in the daily routine of the Targets with the help of the (100% strong agreement by StudyGroup A, 66.7% strong agreement, 33.3% agreement by StudyGroup B, and 100% agreement by StudyGroup C). This is reflected in their risk identification analysis explained above as well (see Table 6).

RQ3: Is constant notification and using the application a burden for the monitoring person?

The engagement with the application depends on the burden faced while using the application. Using the graphical representation, and intuitive design, we hoped to create an application that was not a burden to use. Similarly, we used 2 different notification techniques to notify participants and encourage them to use the application frequently. It is necessary for us to determine if such technique causes distraction to participants.

Figure 11 shows the average burden faced by each participants. Burden is defined here as the time taken by participants to submit report after opening the activity report of a Target. We recorded the times, and calculated difference between report submission time and opening time. We then calculate an average value for the burden across all the s for all the participants. Using GAR, participants faced the lowest burden, 28 seconds, compared to 38 seconds in tabular (TAR). Similarly, none of the participants claimed that the application demanded a lot of time and effort from them. All of them also preferred to use the graphical interface that has the lowest burden time on average. This proves that graphical representation was intuitive and easily understandable (RQ1) as well as causes less burden to the participants.

The notification received through the phases of the experiment varied for all the users, depending on the version of the application they were using. However, rN, that is sent every 2 hours, was common for all the versions. When the pattern of notification was changed from only rN to combination of rN and abN (send whenever an activity is completed), the participants said that abN was helpful for monitoring purpose. 66.7% strongly agreed and 33.3% agreed that this change in notification pattern was useful in both the cases: StudyGroup B in phase 2, and StudyGroup C in phase 3. Similarly, when notification pattern was changed from combination of rN and abN to only rN, 66.7% of participants in StudyGroup A (in phase 3) agreed that not receiving abN affected the frequency of their use of the application. Similarly, all of them felt that it was important that abN was sent in the application. For StudyGroup C, 33.3% strongly agreed that they did not use the application because they did not receive abN, while the rest were neutral. They also positively believed (66.7% strongly agree, 33.3% agree) that abN is an important part of monitoring hence proving that notifications were not deemed as annoying or interfering.

We further analyze the results to analyze about reception of anonymity in the application from participants, perception of the application, and the time of reception of reports.

Reception of anonymity

To encourage anonymity in the application, we presented the names of the Targets with common Japanese names such as Taro, Watanabe and Yamazaki, as shown in Figure 6(a). When asked if receiving notification with the name of the Targets and activity (abN) made them eager to use the application, all of the participants were positive. When notification pattern changed from not receiving abN to receiving abN, participants in StudyGroup B reported that they agree with the inclusion of such information. Participants in StudyGroup A were also positive, with 66.7% strongly agreeing and 33.3% agreeing that anonymity didnt affect them as long as information of activity was informed, in the notification as well as activity report.

Time of reception of reports

We experienced variation in the average and median time between participants on submitting a report after completion of an activity by the Target. The average and median time for the response of activity for the whole experiment period, using GAR was 176.46 and 115.01 minutes respectively. Our proposed method performed better compared to the other two methods: TAR (average: 201.42 minutes; median: 118.85 minutes), and GR (average: 166.9 minutes; median: 121.12 minutes). We experienced a considerable amount of decrease in the reporting times during phase 2 of the experiment. We attributed it to the change in interface in Section 4.3.4, but it is also to be noted that phase 2 of the experiment included a weekend gap, and all the participants were students. One participant responded as *"I don't look at my smart phone much on my days off."*. Similarly, one of the participants mentioned that, *"I missed to record at night several times because my sleeping time was earlier compared to the elderly."*. This shows that not only notification strategies used in smartphones, but differences in lifestyle can also be attributed as a reason for not sending reports, or reporting at a later time.

Usability of the application

We also asked the participants about the usability of the application, and if elderly people would be able to understand and use the application properly. 44.4% agreed, while 11.1% strongly disagreed, and 33.3% were neutral (not sure), while 11.1% disagreed. Since we did not receive any negative comments regarding time and effort used in the application, we believe that the application is easy and intuitive. 77.8% strongly agreed and 22.2% agreed that use of traffic color in activity cards was helpful in determining the state of each activity and reporting. Since elderly people are also acquainted with the traffic colors and its working, we feel this result is positive.

4.4 Chapter Summary

In this chapter, we first described the preliminary experiment we conducted using service notification functionality in Android, to test the perception of rN (recurring notifications). The results from the experiment were positive (62.5% positive response to notifications). We then designed the interface of our application to make it easier and intuitive for the users, and included low and medium level risky by ourselves into the dataset. We also developed three versions of our application for evaluation by participants. Each version were distinguishable based on the type of notifications received and type of interface to show the activities. The experiment concluded that with our proposed method of graphical interface and combination of abN & rN, about 75.2% of the time, risks included in the application were correctly identified. Similarly, the time spent on using the application to check the activities and report, was on an average about 28 seconds.

5. Conclusion

5.1 Summary

In this study, we proposed a system, PATROL, that can be used to anonymously track everyday activities of the elderly and identify any potential risks in their daily routine using a smartphone application. Our system is aimed to be deployed in elderly residential areas or communities and does not disclose any private information such as age, location, etc. to the monitoring person to maintain the privacy and security of elderly residents. The monitoring person receives recurring notifications every two hours and activity-based notifications whenever an elderly completes an activity from the service server and assesses elderly condition by a smartphone application visualizing elderly activity history. The smartphone application is designed with novel visualization features and a two notification strategy. By comparing it with baseline methods (the method without the notification strategy or the visualization features), it has been confirmed that the proposed method not only provided better risk identification, but also incurred lesser burden on the monitoring person, who at once may be responsible for monitoring single or multiple elderly people.

Initially, we focused on the perception and receptions of notifications from a monitoring system. The response rate of 87% of the notifications was a favourable result, with 62.5% of them positive responses. Since we aim to send regular notifications to the users, it was also important to know if regular notifications will be received well, whilst not interfering with the ongoing activity of the user. None of the participants claimed to be disturbed by the incoming notifications.

We designed and updated our application, with different features in the interface. We used a single interface in order to show the daily basic activities, and decided that a graphical interface using Candlestick chart style graph will provide a better understanding of activity duration, and start/end time. We divided each activity into separate cards, and used traffic colors to indicate status of the activity (red = incomplete; yellow = complete; green = reported). This coloring pattern is designed so that the monitoring person can identify at a glance, if the activity has been completed for the current day, and if they have already reported to the activity or not. Along with that, each activity cards were accompanied by an activity icon representing the activity, current status of the activity (incomplete, ongoing or complete), start/end time and duration of the activity. Similarly, we decided to include two types of notifications in our application: one that is send periodically every 2 hours; and another that is sent whenever an elderly completes an activity.

We added risky situations in an activity dataset obtained from a real-life experiment with elderly residents and conducted a user study to check the usability and perception of our application. We compared the proposed method (GAR) by creating 2 other versions of the application that differ in visualization technique (TAR) and notification strategies (GR), and we asked the participants to use each of the versions at different phases of the experiment. We divided the experiment period in to 3 phases, and participants into 3 study groups. This made sure that at a particular phase of the experiment, each study groups were using a different version of the application. The versions varied based on the interface and types of notifications received. By comparing the results of all the versions across different phases of the experiment, we concluded that our proposed method provides a better result compared to other versions. The rate of correct identification of risks using our proposed method was 75.2%, compared to 65.8% (TAR) and 68.5% (GR) of other versions. Similarly, the time taken between opening the report of elderly, and submitting report, on average by all the participants was lower in our proposed application (28 seconds) compared to 38 & 54 seconds in other methods (TAR & GR respectively). We also found out that abN and rN both were received positively by the participants, and abN was perceived to be important (88.8%) for reminding the users for checking the application and monitoring the elderly.

The time between completion of activity and submission of report was considerably higher than we would like to be. The average time, using our proposed method GAR is 176.46 minutes. There were varying degrees of reporting times across the participants, with the lowest average time of 33 minutes (using GAR) and highest average time of almost 7 hours (using TAR). The proposed method provided a better result for the timely reception of activities: GAR (median = 115.1 minutes), TAR (median = 118.85 minutes), and GR (median = 121.12 minutes). We attributed this to difference in the lifestyle between participants and the elderly since the application consisted of real life data of activities of elderly. The participants mentioned that they were busy and could not conduct monitoring in time. This reasoning further solidifies our proposal, because the reason we propose participatory monitoring is to overcome such situations. The children of the elderly are far away and busy, while caretakers and health care officials have a lot of people to deal with on a daily basis. Therefore, if we employ volunteers and personnel who work in fields related to elderly care to monitor activities of the elderly, then, we can assume that the activities will be monitored quickly and we can receive timely reports about the current situation of the elderly. We also believe that increasing the number of Monitors will help to reduce the average response time since each Monitor has their own life style and working patterns.

These results are definitely a positive step towards developing a platform that can be used to determine current situations of the elderly, in an anonymous manner, without disturbing them in any way. The positive reception of the smartphone application shows that even with minimal information of the elderly and their living environment, it is possible to regularly monitor an elderly and differentiate a change in their daily routine of activities. Even though we provided remuneration, it was pre-determined and was not based on the reporting frequency or accuracy of participants. We found that all of the participants used the application regularly, and provided reports frequently. We have received many considerate suggestions regarding betterment of the application which also proves that we are heading in the right direction towards developing a system for monitoring activities of the elderly using a smartphone application.

5.2 Limitations

The user study with multiple versions of our application was conducted for a total period of 12 days. The number of reports received varied between participants, and in some cases (participant 2 in phase 2), we did not receive any reports. Thus, we feel that the experiment could have been conducted for a longer period of time to minimise such defects. The study also consists of low number of participants which makes it a bit difficult to generalise the result for a wider population.

Our system evaluation requires that there are certain risky situations in the activity of the elderly. We did not conduct a real-time activity recognition of elderly, but instead, we used a pre-existing activity dataset, because in real time scenarios there is no surety of receiving such risky situations, and we would need to request someone to deliberately change their activity pattern so that others could detect it. Such a situation can invoke unfavorable reactions. Similarly, since activity recognition systems are not perfectly accurate, sometimes the activities may not be correctly identified, or falsely identified, which would hamper our evaluation. Moreover, we recruited students for the experiment, but they are always busy because of their academic work, and/or personal lives which might have affected the number and time of reception of reports.

5.3 Future Work

As future work, we will conduct real-time activity recognition and monitoring using our application. To achieve that, we will also research/work on activity recognition systems using other kinds of sensors that can potentially provide better activity recognition in real-time.

For future, we could consider to include non-activity related information such as temperature, humidity, and status of light bulbs (On or Off). Many casualties and deaths have been reported due to extreme temperature conditions inside the house during both summer and winter seasons. So, addition of temperature might help to prevent such incidents. Similarly, inclusion of lighting information might help to eradicate any falls and mishaps that might occur in dark environments.

Along with that, activities like going out of house, for exercising like walking, or for social interactions, are also an important part of elderly life. Inclusion of such information was out of scope of this particular research, but in the future, adding such information will definitely be an additional trait to the PATROL system.

The ideal response time for activities varies based on the situations and purpose. To monitor non-risky activities, a response time of 30 minutes (corresponding to the lowest average time of 33 minutes observed in the experiment) between activity and report can be accepted. However, in terms of risky situations, such time might not be ideal. This is why, we believe that increasing the number of Monitors can be a solution to achieve quicker reports. Moreover, in the cases of assigning multiple Monitors, it will be beneficial to analyze if they inhabit identical lifestyle patterns. Assigning Monitors with identical life routines might produce similar kind of reports (reporting time and type) which is not favorable. Therefore, it will be useful to have Monitors with varying lifestyle routines to receive a wider range of responses.

We will also try to conduct evaluation studies for longer period if possible. A longer evaluation period can help to identify decline or changes in activity routine more accurately. We also do not consider similarity between elderly people and the volunteers in assigning Monitors. We feel that Monitors with similar habit and lifestyle to the elderly people can be more efficient in recognising risky situations quickly. Such feature can also be an addition in the PATROL system.

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Publication List

Main Publications

1. Research Dawadi, Teruhiro Mizumoto, and Keiichi Yasumoto: "Mutual-Monitor: A Tool for Elderly People to Anonymously Monitor Each Other", *Proceedings of the Eleventh International Conference on Mobile Computing and Ubiquitous Networking (ICMU 2018)*, pp. 16, 2018

2. Research Dawadi, Teruhiro Mizumoto, Yuki Matsuda, and Keiichi Yasumoto: "PATROL: Participatory Activity Tracking and Risk Assessment for Anonymous Elderly Monitoring", *Sensors*, No. 18: 6965, 2022.

Other Publications

1. Research Dawadi, Jose Paolo Talusan, Zhang Zhihua, Teruhiro Mizumoto, and Keiichi Yasumoto: "Promoting Behavior Change in Food-Exercise Routine with Mobile Application Based on Social Support Strategy", *Proceedings of the 2019 Workshop of Social System and Information Technology (WSSIT 2019)*, pp. 1-8.