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Social acceptance by senior citizens and caregivers of a fall detection system using range sensors in a nursing home

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Social acceptance by senior citizens and caregivers of a fall detection system using range sensors in a nursing home

We developed a fall detection system with a status view function using range sensors in nursing homes and investigated how it was evaluated by seniors and caregivers about their intention to use and feelings of security. Our system calculates the positions and heights of seniors using range sensors for falling detection and sends an alert to the terminals of caregivers. Moreover, the system sends silhouette images from the range sensors that display the largest appearance of a person to the terminal to provide detail information of seniors for the caregivers. In user evaluation, seniors and caregivers watched the three videos: simulated out-of-bed sensor, fall detection under constant observation, and fall detection without constant observation. Participants answered questionnaires and were interviewed after watching each video. As a result, the seniors indicated significantly higher intention to use and feelings of security in the second and third videos than in the first video. Most seniors could accept being constantly monitored by the caregivers because they deemed safety to be more important than privacy. A few seniors (often healthy individuals) felt nervous under constant observation. Caregivers commented on the importance of flexibly switching the functions of the fall detection system to reflect individual status.

Keywords: Fall detection system; ubiquitous network robot platform; safety system for seniors

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1 Introduction

From 10 to 40% of nursing home residents in Japan have fallen [1] (Figure 1). Most seniors in nursing homes cannot rise by themselves once they have fallen because of their limited physical capabilities. Under such circumstances, they would suffer pain and fear alone until they are discovered. If they are left alone for a long time, the memory of the pain and fear might reduce their physical activity and cause depression and other health problems [2,3].

To prevent such negative situations, caregivers must discover the falls of seniors as quickly as possible. According to our interviews in four nursing homes in Japan (two public special elderly nursing homes, one private pay nursing home and one hospital), caregivers in nursing homes patrol each room once every hour or two at night in Japan. This means that a person who falls just after a patrol might not be found for an hour, which is too long for a senior who might need help as quickly as possible.

Fall detection systems have been developed to help caregivers discover falls rapidly. Out-of-bed sensors [22] have already been commercialized and introduced in many nursing homes in Japan. Such sensors are useful to detect falls down of seniors from their beds, but they also react to physical contacts even though such contacts are

Figure 1. Elderly person suffering a fall in a nursing home

not falling down, e.g., when seniors go to a toilet (Figure 2). The caregivers need to confirm seniors' situations when an alert was coming from such sensors, but they could not know whether the person has fallen or just moved. In other words, estimating the degree of risk is difficult for the caregivers through existing fall detection systems. This would cause wrong priority assignments; for example, if someone has fallen and almost simultaneously another moved to the toilet, sometimes a caregiver go to the person who just moved, and then the fallen person will be left more.

To solve such problems, fall detection systems have been developed that use sensors that visualize a person's appearance, including cameras [4-6], and range sensors [12-15]. Studies on fall detection systems have basically focused on the development of new fall detection algorithms using these sensors and contributed to the improvement of the detection accuracy and recall. On the other hand, the studies seem to not take care of user evaluations so much. Actually, most such studies have not reported the evaluations of their fall detection systems by seniors and caregivers. Therefore, still it is an open question whether seniors accept fall detection systems that use range sensors from the standpoint of privacy as well as what kind of a system caregivers consider useful.

We must investigate user evaluations about senior and caregiver intentions to

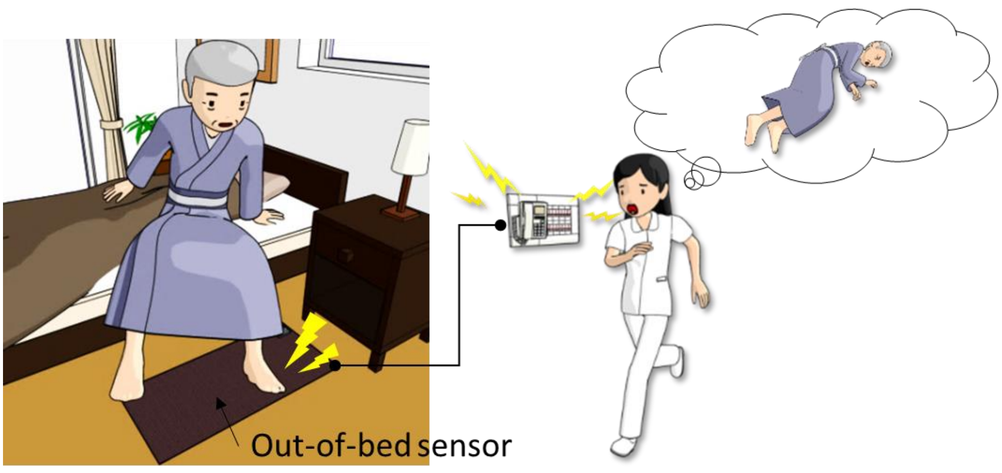

Figure 2. Problem of out-of-bed sensors (carpet type)

use and feelings of security as well as system performance if our aim is to introduce a fall detection system in nursing homes. Thus, this paper conducts an experiment which investigates senior and caregiver feelings towards a fall detection system, which is designed based on our survey results of several nursing homes. To fulfil the needs fall detection systems, we constructed a depth sensor network to cover wide areas by using a Ubiquitous Network Robot Platform (UNR-PF) [23], which enables us to accelerate developments of networked systems. When the system finds a falling down, it automatically selects a sensor which displays the largest appearance of fallen person and sends its sensor data to the caregivers' terminal with alert information. Due to the difficulties of actual falls of seniors, we conducted video-based experiment to investigate the intentions to use and feelings of security of seniors and caregivers.

2 Background

2.1 Related works on fall detection systems

Various fall detection systems for seniors in nursing homes have developed in recent years [16]. Fall detection systems can be divided into the following two types based on how sensors detect falls: wearable sensor approach and ambient sensor approach.

In wearable sensor approaches, seniors hold or wear sensors to detect falls. An accelerometer [17,18] and gyroscope sensor [19] is typically used. The acceleration pattern of body movements changes rapidly during a fall. A fall detection system detects falls by recognizing the changes of acceleration patterns. However, the wearable sensor approach has a weak point: seniors generally dislike wearing sensors [17]. In particular, seniors suffering from dementia tend to remove them.

The ambience sensor approach does not need to carry sensors by seniors; it installs sensors in rooms to detect falls [20-22]. An out-of-bed sensor [22] is common in typical nursing homes because sensors can be easily setup. Out-of-bed sensors, especially the carpet type, are usually installed on the floor next to a bed to detect falls from it. However, we consider there are two fundamental limitations in these out-of-bed sensors. First, the sensors cannot visualize appearances of fallen persons; therefore caregivers could not check details of seniors when the sensors reacted. It has a risk to postpone a response to most critical person when some sensors reacted simultaneously.

Camera-based systems are a kind of the ambience sensor approach, which can visualize a person's appearance. They are increasing because cameras are less expensive. New algorithms have been proposed that detect falls using a normal camera [5-7], an omni-camera [4,8,9], and a time-of-flight 3D camera [10,11]. For example, Töreyin et al. developed a fall detection algorithm based on an HMM that uses video features to differentiate falls from walking [5]. Williams et al. presented that a distributed network of overlapping low-power and low-resolution cameras for detecting and localizing fall. The network used a decentralized procedure for computing inter-image homographies that allows the location of a fall to be reported in 2D world coordinates by calibrating only one camera [7]. Miaou et al. proposed a fall detection system using a MapCam (omni-directional camera), which can capture a 360 viewing angle of a surveillance space in single shot [8,9]. However, camera-based systems have two demerits. One is that cameras cannot be used in the dark, and the other is privacy. Caregivers can see the faces and the bodies of seniors through the cameras.

Recently, as a kind of ambience sensor approach, using range sensors installed in environments have been studied [10-15]. Jansen and Deklerck presented a method for automatic fall detection that uses information extracted from images obtained using 3D image by the camera. The context model they proposed interpret the visual fall detection results depending on the exact location, time, and duration of the detected event [10]. Range sensors can be used in the dark and seem to protect privacy more than other RGB-cameras because they do not obtain vivid colour and texture images. However, since the evaluation of fall detection systems by seniors has never been conducted, it remains unknown whether they accept them.

2.2 Needs of nursing homes

We consider it useful for the design of a fall detection system to hear comments from professional caregivers. Therefore, we interviewed nine caregivers working at public special nursing homes and private pay nursing homes, and two directors of a private pay nursing home. The contents of our interviews were about problems of fall detection systems they have used and the functions that are needed. The details and results of the interviews are described in the following sections.

2.2.1 Problems of fall detection systems they have used

Firstly, to investigate the problems of fall detection systems they have used, we asked the following two things:

- What kind of fall detection systems have you used?
- Could you tell me the pros and cons of the systems?

About the first question, they said they have used wearable sensors (card-type and bracelet-type), a nurse call system and out-of-bed sensors (carpet-type and sheet-type). Card-type sensor is similar in size to a name card and can detect falls of a person who carries the sensor. Bracelet-type sensor can also detect falls of a person who wear the bracelet. In the nurse call system, an elderly person pushes a nurse call button when they fall. About out-of-bed sensor, carpet-type and sheet-type sensor are a kind of pressure sensor and can detect moves from a bed. A carpet-type is installed beside the bed and a sheet-type is on the bed.

Next, we asked the pros and cons of those systems. We show their typically answers about each system;

Wearable sensors

They said that wearable sensors have a problem that some seniors do not try to wear it positively. For example, the caregivers and the directors commented as follows;

> "Seniors who use a card-type sensor often forgot to take it with them."
> "Bracelet-type sensor was also not used so much. It did not have much meaning for a fall detection."
> "A dementia person, in particular, seems to dislike to wear such sensors. I heard that she often removed a sensor even if her family give it."

Nurse call system

According to their comments, nurse call system has a problem those seniors sometimes fall in the places where they cannot push the button. They commented as follows;

> "A nurse call button is attached on the side of a bed. So, they can push the button if falling down from the bed. But, they also falls in the places other than around the bed. If they fall far from the bed, they cannot push the button."
> "The other day, a guest had fallen when trying to sit on a chair. She we crawled on the floor to the button and push it. Since that case was a mild fall, it was success. But it doesn't always work."

Out-of-bed sensors

They commented it as problems of out-of-bed sensors that the sensors often make false-positive alerts and some seniors avoids the sensors. For instance, there were the following comments;

> "We have set up an out-of-bed sensor in the room of a dementia person. But, since he had wandered at night, we must have gone there again and again. We couldn't get anything done without it. So, the switch of it was turned off."
> "When we used a sheet-type sensor, we saw the sensor react depending on a person's posture even though a guest was on the bed. And, there was a machine trouble because of leakage of urine."
> "Surprisingly, some seniors avoid the sensor when getting out of bed. She knows that we will come if she steps on it. She wants to avoid troubling us; so avoid it."

These comments show that the caregivers and the directors are not very satisfied with the systems they have used. Based on the results, we asked the next question about functions of fall detection systems that are needed.

2.2.2 Functions of fall detection systems that are needed

Secondly, to investigate what kind of functions they need in fall detection systems, we asked the following question and are free to discuss it:

- What kind of functions do you need in fall detections?

Based on the interview results, we categorized their requirements of the systems to three categories: Senior's acceptance, appearance view, fall detection area. The details of the categories are described below.

Senior's acceptance

The caregivers and the directors said that the most important thing is that their guest can accept the system, in the sense of comfort, security and privacy. They commented;

> "Even though a system is very useful and convenient, we cannot employ the system unless guests prefer and have intention to use it."

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> "In our nurse home, there are few guests who use wearable sensors because most of guests think that attaching it every day are a bother."
> "Monitoring through cameras maybe is discomfort for guests. It is difficult to use."

Appearance view

They would like to know senior's status as soon as possible if a fall happened because they can early take the appropriate responses depending the status. For example, they said;

> "It will be useful if we can see how a person is when a sensor reacted. Depending on the situation, we are easy to make a suitable response. Even if the sensors give a false-positive, we will take care of issues in a calm manner."
> "We want to know a guest's situation. Depending on how to fall, it will change whether one or a group go there. We can rapidly make a plan how to deal with the guest.

Fall detection area

They requested the system to detect anywhere in a room and outside the room because seniors fall in various place other than near a bed. They commented as follows;

> "The elderly falls in various places other than near a bed. We can see a fall in a toilet many times. An entrance is actually a place where a fall happens. They try to open a door but cannot open it perfectly, and then they hit the closing door and fall down."
> "A dementia person wanders and falls down in a corridor sometimes. So, it is better to be able to find a fall in the corridor as well as in a room."

In our survey of previous researches [4-22]], we have not find such fall detection system has been developed that satisfies the above three requirements.

3 System

3.1 Design policy

Based on the interview results from the nursing home caregivers, we built a fall detection system with a status view function using range sensors. The system's design policy is described in the following section.

3.1.1 Social acceptance

We consider that a use of range sensors in the rooms for fall detection is better than a use of wearable sensors, and other environmental sensors like pressure sensors and optical cameras. This is because the sensors do not need to wear or hold them like wearable sensors and they seem to be more acceptable than optical cameras in the standpoint from privacy problem, due to their silhouette images. In addition, range sensors can even show silhouette images in the dark. This availability will increase senior feelings of safety.

3.1.2 User interface

We made an interface so that caregivers can visually confirm a senior's status when a fall happens. We developed two functions on the caregiver terminal; the first visualizes the places where the fall happened, and another visualizes the person's appearance. Since the system can detect falls in various places, prompt care is required so that caregivers know where the person fell. The visualization of senior appearances will be helpful in the care plans of caregivers. In addition, we made the system show images from the camera that is capturing a fallen person most clearly to show images useful for caregivers to confirm her status.

3.1.3 Scalability

To detect a fall various places, multiple range sensors are needed. We consider the sensors should be flexibly added in the place where the caregivers want to detect falls; therefore, we need to build a scalable system. We use networked range sensors in our system to enhance scalability. Designing a system that can handle multiple sensors simplifies the expansion of fall detection areas. For example, to add a bathroom to the detection area, we just put a range sensor on the wall, connect it to the network, and modify the system configuration.

According to the above design policy, we built a scalable system that contains networked sensors and terminals. To develop it quickly, we employed a Ubiquitous Network Robot Platform (UNR-PF) and explain its details in the following section.

3.2 Ubiquitous Network Robot Platform

The system was based on Ubiquitous Network Robot Platform (UNR-PF). UNR-PF is a common infrastructure that supports development of services using not only robots but also networked sensors and terminals. In this section, we describe UNR-PF and the configuration of our fall detection system.

Robot developers can share functional modules for robotic devices on common platforms and rapidly develop working robotic systems by adopting existing functional modules in combination with their own software. Such a modularized development process has accelerated the development of standalone robots as well as individual functional components; however, gaps exist between the development of robots and service applications. Another abstraction layer for service development is required in addition to component-oriented development. In our previous project, six kinds of robotic services were investigated as case studies for the verification of technologies and service coordination, such as shop guidance, shopping support, touring support, active listening, community building support, and health care services [23]. Requirements for common functions arose from those case studies, and specifications for such functionalities have been proposed as UNR-PF middleware architecture [24].

Figure 3 shows a structure overview of UNR-PF. The following subsections describe its architecture and internal modules and address its relationship with several international standards. UNR-PF is a common infrastructure that supports the development of robotic services as applications of networked robot technologies. The platform requirements are mapped into three categories:

(1) Multi-Area Management: shares the spatial information of such multiple areas as map information including the dynamic location information of moving entities and service-oriented information in addition to the static spatial structures of service environments.
(2) User Attribute Management: supports the daily activities of various users, especially seniors and the disabled. It is important to recognize user abilities and such required supports as moving assistance, preference for visual over aural communication, etc. The platform should allocate robotic devices that are suitable for each user’s preferences when the service fails to do so.
(3) Service Coordination Management: executes a number of services across multiple areas. This platform should provide mechanisms for managing the state of the service execution and for sharing information among services.

The middleware consists of two platform layers for the robotic system: a local platform in a single area and a global one that ranges over multiple areas covered by a number of local ones. These platforms serve as a middle-layer between the layer of service applications and the robotic components, including smartphones, agents, sensor networks, etc.

The platform is equipped with five database functions and three management functions to provide common services to the service applications and robots. The database functions consist of robots, maps, users, operator registries, and service cues. The management functions consist of states, resources, and message managers.

In this study, we directly use or expand the following components we have already developed in previous projects: a data receiver of a range sensor, a 3D human tracker, and map and user databases. Using these components, we can efficiently develop a fall detection system with range sensors and enhance the system scalability.

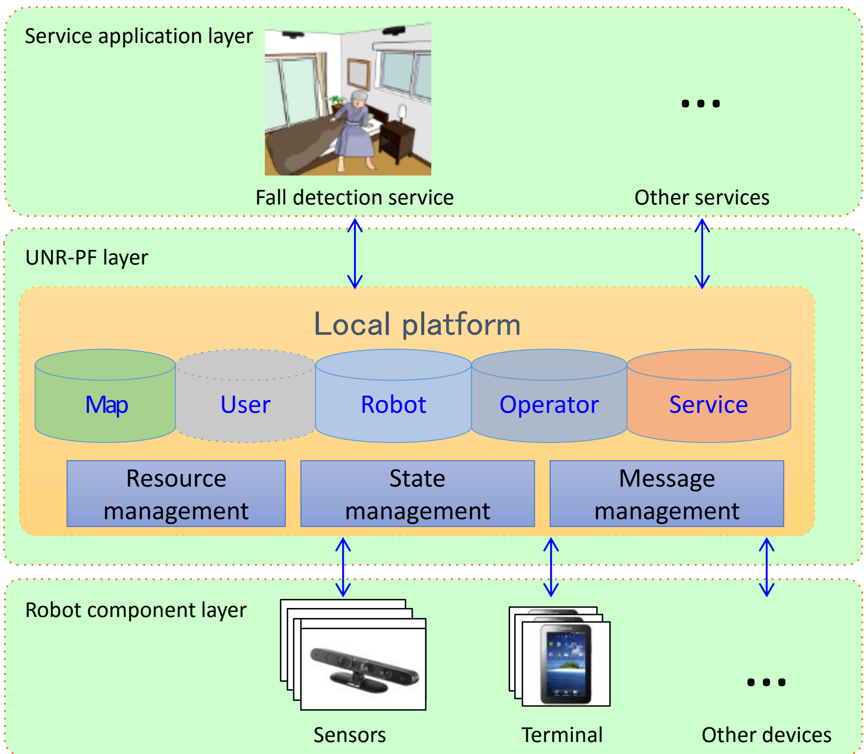

Figure 3 Structure overview of Ubiquitous Network Robot Platform

The following section describes the system details.

3.3 Fall detection system

3.3.1 Hardware configuration

Figure 4 shows an overview of our fall detection system that uses range sensors. It is composed of range sensors, computers, a server, and a tablet. The range sensors are connected to computers, which send received data to the server. When a fall happens, the server alerts the tablet.

We used Xtion PRO LIVE manufactured by ASUS as a 3D sensor, which is easy to install in the environment because it is small (180, 35, and 50 mm) and works only by USB power. The distance ranges between 0.8 and 3.5 m, and the field of view is horizontal 58°, vertical 45°, and diagonal 70°. Several sensors can cover most of a room's area.

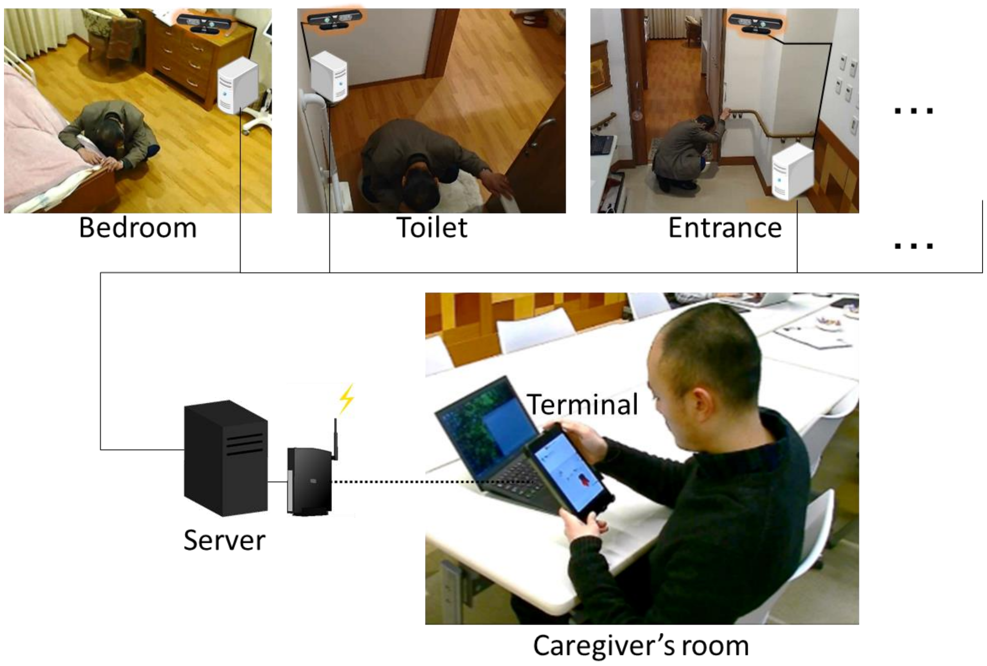

Figure 4. Three components of our fall detection system

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3.3.2 Software configuration

Figure 5 shows the software configuration of a fall detection system that contains a data receiver of the range sensors, a people tracking system, a fall detection module, and viewers/caregivers. The data receiver of the range sensors is a UNR-PF component, which has been already developed. It reads the data from the range sensors and compresses them into a 160 by 120 pixel range image to reduce the transmission capacity. The data receiver sends the compressed data to the people tracking system.

This people tracking system, which is also a UNR-PF component, extracts the seniors through the background subtraction of the received range images [25]. A range sensor outputs an array of values (pixels) corresponding to the distance from the sensor to objects. In the background subtraction, the pixels belonging to moving objects, which are typically persons, are separated from the rest of the background which is scanned when there are no moving objects. To handle changes in the background, the statistic of the background is continuously updated. The extracted pixels are converted to 3D points and clustered to separate points belonging to different persons and filtering other objects. The clustering is done point by point by assigning one to an existing cluster which

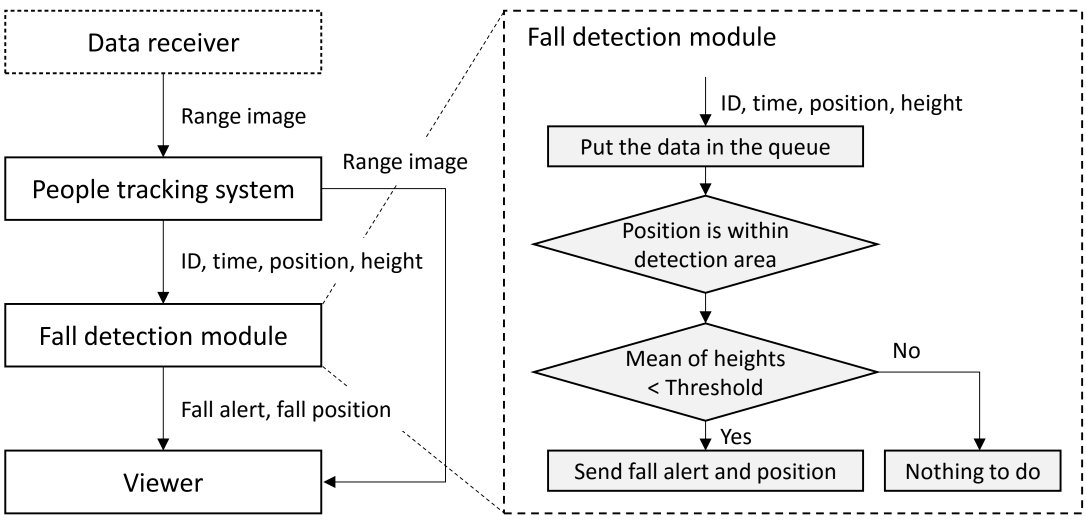

Figure 5. Configuration of fall detection module

contains the closest point, starting from the highest point. After then, clusters that have a very small number of points are removed. Each cluster extracted in the above process is initialized as a tracking target. To obtain continuous tracking, the extracted person results from multiple sensors are combined using a set of Sequential importance resampling particle filters. One particle filter is used for each tracked person, of which the state is given by the position, height and other features of the person. The tracking system calculates people's head location (x, y, z) regardless person's posture such as standing or lying and provided every 33 microseconds. The measured precision is about 10 cm. The technical details were previously reported [25].

The tracking system does not identify the individuals, meaning that it does not recognize whether person is senior A, senior B or a caregiver. According to caregivers' interview in Section 2.2.2, it is important to know the place where a fall happened and the posture of a senior who was fallen, but they did not mention the importance of knowing the senior's personal information such as name, age or care level. We consider that these information would be less significant than the information of the place and situation. When a fall happened and the posture of someone who have been fallen looks serious, caregivers must go there, even if the person was not a senior but another caregiver. If the system can identify the individuals, caregivers may be easy to care a senior who had a fall because they can expect the cause of a fall specific to her; for example, in the case that two seniors fell down in each different place at the same time, caregivers are able to plan the order of treatments for them based on their care level and health condition. In this sense, an individual identification function will be helpful for caregivers, but we consider the fall detection system is sufficient for practical applications even if the individual identification function is not included.

The fall detection module, which was newly developed in this study, determines that the senior fell down if (1) the image's height is lower than a threshold for a certain time and (2) the position is within a place where people do not normally lie down. We use the average height for a certain time to distinguish a fall from other similar movements. Figure 5 shows the process of the fall detection module.

3.3.3 User interface

Fall detection systems using out-of-bed sensors, which are commonly used in nursing homes, just inform the caregivers about which sensors reacted. There are various types of falls, and the ways of dealing with them depend on the type. However, the caregivers cannot determine what kind of a fall happened in out-of-bed type systems.

In contrast, we implemented a function in our system where the position from the people tracking system and the range images from the data receivers are sent to such caregiver terminals as smartphones or tablets. This enables caregivers to quickly grasp the position and status of a senior when he has fallen. Figure 6 shows the interface on an

Figure 6. Interface on Android tablet

Android tablet.

3.3.4 System performance

We evaluated the performance of our fall detection system by collecting the data of "pretend" falls performed by seniors. The system performance was calculated using the data.

Environment

We used a mock-up room of an existing nursing home to obtain the data of falls in a real environment. Five range sensors were installed in it to cover it completely (Figure 7). The heights of each sensor were between 2.0 and 2.2 m.

Procedure

Participants were asked to go to an indicated location where they pretended to fall. For these role-plays, we instructed the participants to feign dizziness and sit down. They

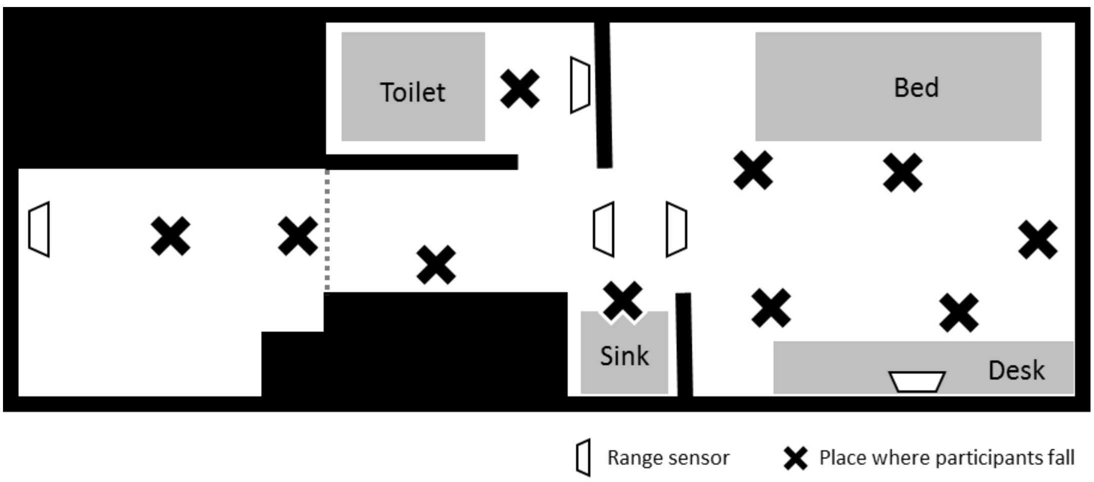

Figure 7. Location of sensors in mock-up room

stopped pretending after about ten seconds. The fall actions were repeated ten times at different locations (Figure 7) and were recorded by the range sensors in the room.

Coding

We manually categorized the data of the falls into fall data and stand data. The fall data are defined from the start of a fall to its end, and the stand data are defined from the start of a move to a location to its end.

Participants

Eighteen healthy elderly people participated in the data collection: eight females and ten males. Their average age was 70.8 (SD=4.66).

Results

We obtained 180 fall data and 180 stand data since 18 participants fell ten times. After inputting these data into the fall detection system, the precision and recall of the fall detection were 94.5% and 86.7%, respectively. False-positive results were caused when the human tracking module mistakenly detected other objects as a person. The false-negative results were caused by three factors: (1) the heights of the participants were not lower than the threshold since they were leaning on a wall in a semi-crouching position, (2) participants by chance fell outside of the sensing area, and (3) the human tracking module failed to track the participants. In total, our fall detection system detected situations where elderly persons fell in the real environment with high accuracy.

4 User evaluation

We conducted an experiment to evaluate senior impressions of our fall detection system. In this section, we describe the experimental details.

4.1 Design

In our experiment, participants watched videos that explained the fall detection systems because the seniors in nursing homes haven't experienced the system: falling from the point of view of their safety.

We are interested in two points. One is that a fall detection system using range sensors is accepted by seniors more than commonly used fall detection systems. The other is the degree of acceptance they feel about being monitored by the range sensors. To investigate these two points, we set the following three conditions: (1) simulated out-of-bed sensor, (2) fall detection with constant observation, and (3) fall detection without constant observation.

4.1.1 Simulated out-of-bed sensor

We showed a fall detection system that simulated an out-of-bed sensor, which is commonly used in nursing homes in Japan. We employed an out-of-bed sensor as a target for comparison with a range sensor. Since we do not have a real out-of-bed sensor, we developed a dummy that provides the same function as out-of-bed sensors using a human tracking module. Our dummy detects a fall if a person enters a certain area beside a bed like out-of-bed sensors.

Figure 8 is a part of video scenes we showed in this condition. The left figure shows a normal situation, and the right figure shows a falling situation. Using this video, we explained as follows. The upper left video is not actually displayed in the system because it is just for explanation. The figure on the display is a map of a room. (We first explained these things in other conditions as well.) The green rectangle represents an out-of-bed sensor on the floor. The system reacts when someone is on the sensor (see the right figure) and send an alert to caregivers.

4.1.2 Fall detection with constant observation

We showed our fall detection system using range sensors. The system viewer always indicated a person's current position and displayed the range images. Caregivers can always monitor the seniors through the viewer.

In this condition, we explained as follows using the video as shown in Figure 9. The green circle indicates a person's position, and the upper right image show her silhouette obtained from a range sensor. The system react when her height keeps to be low for a certain time (see the right figure), and send an alert to caregivers. Caregivers can observe the position and silhouette in any times.

4.1.3 Fall detection without a constant observation condition

We showed the fall detection system using range sensors. Unlike the second condition, the viewer displays the current position and the range images only when a fall is detected. The reason why we prepared for this condition is to investigate whether seniors accept or not a constant observation through range sensors, and to examine seniors and caregivers preferences to monitoring levels. Caregivers can only confirm a senior's state after a fall has happened.

We explained the following things, using the video as shown in Figure 10. The system display nothing on the map during normal situations. The system react when her height keeps to be low for a certain time (see the right figure), and send an alert to caregivers. At that time, the system display a person's position and silhouette obtained from a range sensor. Caregivers can confirm the position and silhouette only when a fall happened.

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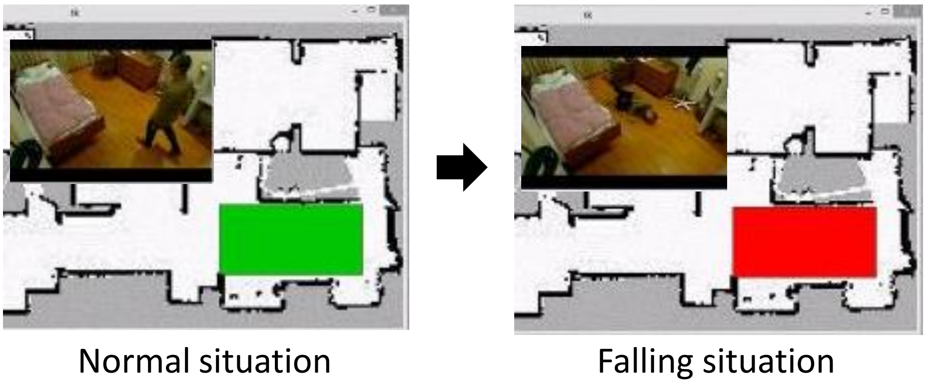

Figure 8. Scenes of the video in simulated out-of-sensor condition.

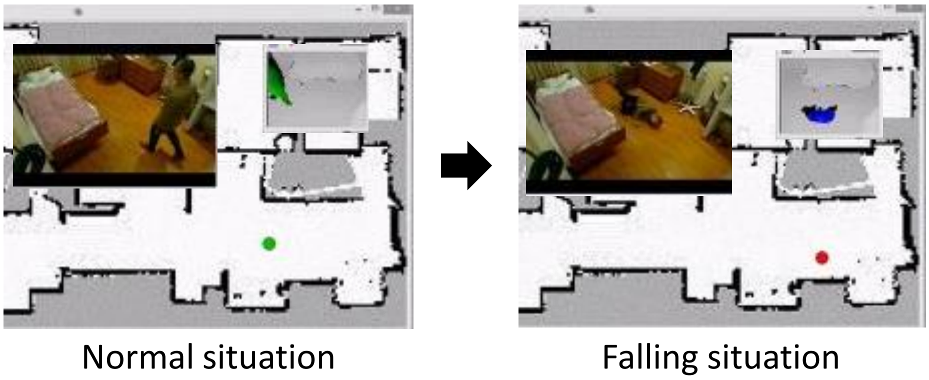

Figure 9. Scenes of the video in fall detection with constant observation condition.

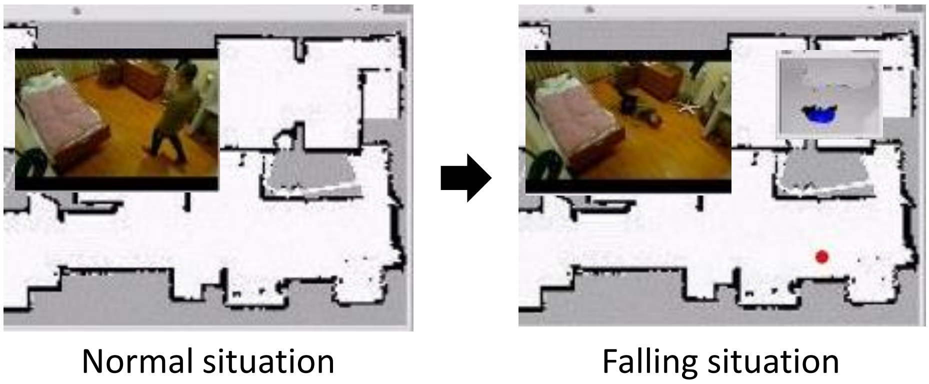

Figure 10. Scenes of the video in fall detection without constant observation condition

4.2 Procedure

After obtaining informed consent, we conducted an experiment. We asked participants to watch a video of an experimental condition and explained the fall detection system demonstrated in it. After watching it, the participants answered questionnaires and were interviewed. We repeated the procedure three times. The order of showing the videos was counter-balanced. An experimental scene is shown in Figure 11.

4.3 Measurements

In this experiment, we measured two items by questionnaires: intention to use [26] and feelings about security. All questionnaire items were evaluated on a 1-to-7 point scale, where 7 was most positive. An index of intention to use is usually composed of multiple questionnaire items [26]. However, since the elderly people had difficulty answering too many questionnaire items because of the mental and physical strain [27], we only posed two questionnaire items:

Figure 11. Experimental scene

Intention to use: I would like to use this fall detection system.

Feeling of security: I feel secure with this fall detection system.

4.4 Participants

Twenty eight elderly people participated in the experiment: 14 females and 14 males. They averaged 74.0 years of age (SD=6.85). Ten seniors from nursing home and eighteen seniors who recruited by a senior resource agency. Caregivers attended on just the ten seniors from nursing home. The caregivers were also interviewed as same as the seniors after the experiments. Nine caregivers participated in the interview.

4.5 Results

4.5.1 Intention to use

The degrees of intention to use were 4.30 (SD=1.92), 5.86 (SD=1.03), and 6.04 (SD=1.05) in the simulated out-of-bed sensor condition, fall detection with constant observation, and fall detection without constant observation, respectively. The ANOVA results indicated a significant difference among these conditions ($F(2,54)=17.22$, $p<.001, \eta 2=0.39$). Multiple comparisons with the Bonferooni method showed that fall detection with a constant observation condition was evaluated significantly higher than the simulated out-of-bed condition ($p<.001$) and fall detection without a constant observation condition was also evaluated significantly higher than the simulated out-of-bed condition ($p<.001$). There was no significant difference between the full and partial monitoring conditions.

Our results show that participants had greater intention to use in the fall detection system with range sensors than the commonly used fall detection system with out-of-bed sensors.

4.5.2 Feelings of security

The degrees of feeling secure were 4.69 (SD=1.54), 6.38 (SD=0.88), and 6.23 (SD=0.89) in the simulated out-of-bed sensor condition, fall detection with constant observation condition, and fall detection without constant observation, respectively. The ANOVA results indicated significant differences among these conditions ($F(2,50)=19.04$, $p<.001$, $\eta 2=0.43$). Multiple comparisons with the Bonferooni method showed that fall detection with the constant condition was evaluated significantly higher than the simulated out-of-bed condition ($p<.001$) and fall detection without a constant observation condition was also evaluated significantly higher than the out-of-bed condition ($p<.001$). There was no significant difference between the last two conditions.

Our results show that participants felt more secure in the fall detection system using range sensors than in the commonly used fall detection system with out-of-bed sensors.

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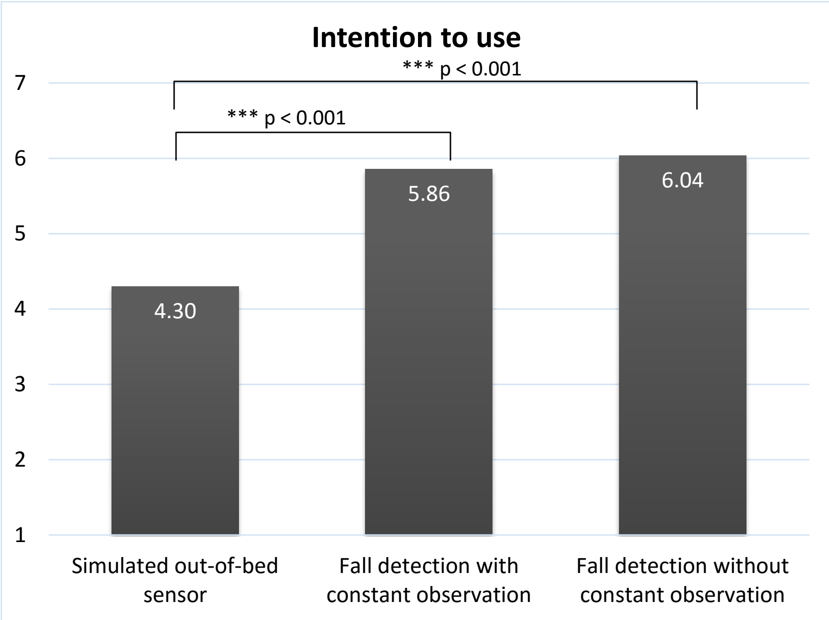

Figure 12. Results of intention to use

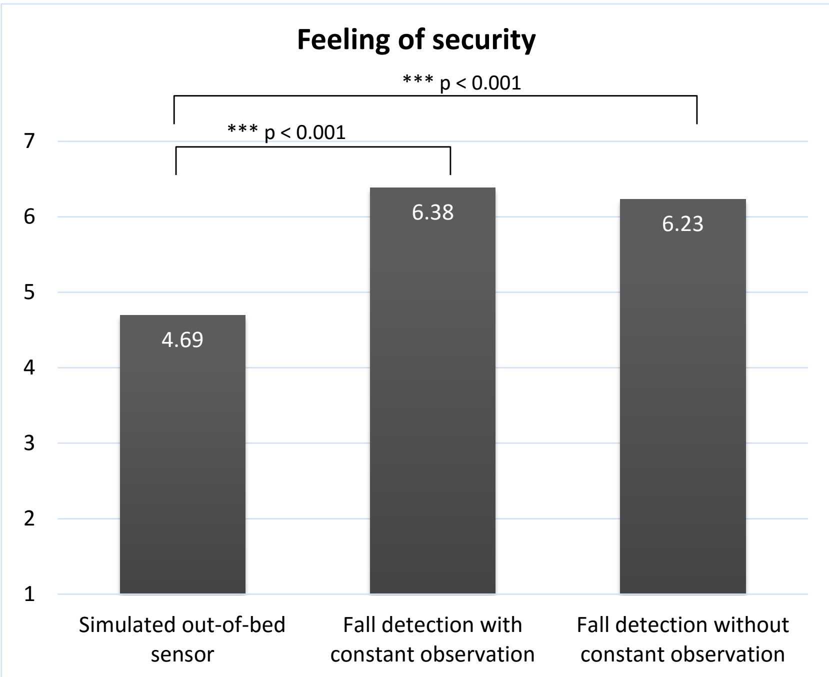

Figure 13. Results of feeling secure

5 Discussion

5.1 Senior impressions

5.1.1 Is the performance sufficient?

The performance of the fall detection system we developed was sufficient for a practical application scenario because it is better in the three aspects, range of fall detection, false detection and miss detection, than out-of-bed sensor systems that have been used in nursing homes. First, since out-of-bed sensors detect falls only from a bed, the detection rate of falls in a toilet, an entrance or a corridor was 0%. On the other hand, the fall detection system detected those falls about 95%. Thus, the performance of the system clearly increased. Second, the false detection happens often in an out-of-bed sensor system because it does not react a fall but getting away from a bed. According to caregivers, particularly in the case of a demented person, the false detection rate becomes higher because she wander around frequently. In contrast to this, the fall detection system will be lower than the out-of-bed sensor system because it does not react getting away from the bed but a fall. Third, miss detection rate in the out-of-bed sensor system is possible to increase by human factors that a senior avoids or remove it. But since the fall detection system uses range sensors, miss detection rate will not increase by such human factors. From those aspects, we thought that the fall detection system proposed in this paper was sufficient for a practical scenario.

From the interview results of caregivers and seniors we obtained in the user evaluation, both of them seem to regard the performance of the fall detection system allowable. They exactly commented as follows;

> "The out-of-bed sensor system may reduce a sense of danger due to a number of false detections. The fall detection system feel safe."

> "The out-of-bed sensor system is not useful because we don't understand whether seniors actually fall down or not."
> "Since (in the fall detection system) I know the location and the posture of a senior, it become easy to deal with a fall."

As well as caregivers, seniors mentioned the performance of the fall detection system as follows;

> "(About the out-of-bed sensor system) It is not acceptable to alert frequently despite no fall. I don't want to put caregivers to any more trouble. (About the fall detection system) It is good that caregivers come in only when a fall happened."
> "I have fallen in a room and in a toilet. I feel anxious if a fall is detected only around a bed."
> "(About the out-of-bed sensor system) I want the system to react only when I fall down. (About the fall detection system) I feel safe since caregivers can monitor me when I had a fall."

Those comments suggest that the fall detection system seemed to be allowable performance for both the caregivers and the seniors.

5.1.2 False detection vs. Miss detection

The false detection and the miss detection in the fall detection system are trade-off. From our standpoint, it is better to control parameters so the miss detection can decrease. The reason that the system should do so is to be able to visualize the condition of a senior who have been fallen for caregivers.

The main problem of the false detection is for seniors to wonder if caregivers have been wearied by the alert repeating over and over again. Caregivers may not show an annoyed look but actually the false detection wastes their time and work. The fall detection system we proposed can solve these problems by visualizing the posture of a senior of whom a fall was detected because caregivers can confirm if the senior is safe

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or not through their terminal, which is a tablet or a smartphone. In other words, caregivers do not need to go to the room for confirming the safety. On the other hand, the miss detection must be avoided because caregivers cannot come to help a senior who has been fallen until a next patrol. That delay will have bad effects on senior's body and mind. Therefore we consider the false detection is more allowable than previous fall detection systems.

5.2 Senior impressions

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In the interviews, we asked the seniors which fall detection system they preferred based on the videos they watched and why. Tow coders analysed and classified the transcribed interview results; as a result, we gathered 110 sentences of their impressions and obtained 9 categories. Their classification matched reasonably well, yielding an average kappa coefficient of 0.667. Table 1 shows the coding result, in which the percentages are from the entire population. The interview results show that most of the participants mentioned one of three things: preference for monitoring by range sensors, comparison

Table 1. Participant opinions of fall detection systems

Category		%
Monitoring level	Constant monitoring is best.	26.4
	Monitoring only for danger situations is best.	18.2
	Switching the monitoring level depending on the situation.	5.5
Comparison of range and out-of-bed sensor	Out-of-bed sensor is not enough, unsafe or unnecessary.	12.7
	Out-of-bed sensor is enough and safe.	12.7
Privacy	Being privacy-minded but acceptable because of safety.	1.8
Requested another function		8.2
Others		14.5

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of range and out-of-bed sensors, and a desire for more functions.

5.2.1 Preference for monitoring level

As shown in Table 1, 26.4% of the participant's comments would prefer that they were constantly monitored by the caregivers. Here are comments from four participants:

> "I feel safe because the caregivers know whether my condition is good or bad."
> "The system is good and safe because caregivers can learn my status with it."
> "The range images do not make me feel as though I'm being watched."
> "For the care of elderly persons, safety is the highest priority."

On the other hand, 18.2% of those would prefer that they were only monitored for dangerous situations:

> "I don't feel comfortable being watched all the time."
> "Just showing images when I fall is enough. I dislike always being watched."
> "I don't feel like being monitored so much."
> "The fall detection system makes me nervous."

Finally, 5.5% requested changing the monitoring level depending on the situation,

> "It'll be necessary if I need more care in the future."
> "The level of the fall detection system should be changed depending on my care situation."
> "Out-of-bed sensors are adequate for those people who shouldn't walk alone, but a monitoring system is better for those who move around a lot."

Overall, most seniors mentioned a preference for monitoring through range sensors. A majority would like to be monitored all the time. This suggests that they basically considered security more important than privacy. On the other hand, half could accept a fall down system using range sensors, even though they feel uncomfortable because they are constantly monitored. (Note that some participants mentioned both a preference for constant monitoring and monitoring only for dangerous situations. Their considerations sometime changed due to conditions.) We believe that the differences in their thinking reflect the differences in their health status or experiences with falls. Seniors who need care or who have fallen might welcome being monitored for security since they tend to feel anxious. In contrast, healthier seniors are annoyed by constant monitoring since they probably have less anxiety.

5.2.2 Comparison of range and out-of-bed sensors

In the interview, some senior participants mentioned the comparison of range and out-of-bed sensors. 12.7% of the participant's comments mentioned that out-of-bed sensors are insufficient:

> "I don't really think that I need out-of-bed sensors. They send an alert whenever I go to the bathroom."
> "The system repeats its alerts even in safe situations, which causes too much trouble for the caregivers."
> "Since the system reacts too often, caregivers are tired."

In contrast, 12.7% of the comments mentioned the availability of out-of-bed sensors:

> "That sensor is better than nothing."
> "I feel a little bit more secure even if it only notices when a person enters its area."

These comments show that seniors want even just a slight feeling of safety. Furthermore, they are not only worried about their own safety but also the mental and physical well-being of caregivers.

5.2.3 Privacy

As shown in Table 1, senior's comments about privacy concern were a few:

> "Actually privacy is important but monitoring care is the best for those who live in a nursing home."
> "Monitoring makes me secure but discomfort as well."

There was no comment that they do not want to use the fall detection system using range sensors due to privacy concern. The results showed seniors considered their security more important rather than their privacy.

5.2.4 Requested another function

8.2% of the participant's comments requested additional functions for the fall detection system:

> "I'd feel more secure if it monitored both silhouettes and real images."
> "I think the data should be recorded and saved. I want caregivers to use the data to tell doctors about falls."

Their requests were almost about improving security rather than privacy.

5.3 Caregiver's impressions

We also interviewed to the nine caregivers who bring senior participants to the experiment as same as the senior participants. The interview results are described in this section.

First, we show the results of questionnaire. The degrees of intention to use were 3.66 (SD=1.41), 5.78 (SD=1.03), and 5.56 (SD=1.70) and the degrees of feelings of security were 4.71 (SD=2.07), 5.85 (SD=0.83), and 6 (SD=0.73), in the simulated out-of-bed sensor condition, fall detection with constant observation, and fall detection without constant observation, respectively. The results seem that they highly evaluate the fall detection system using range sensors.

Second, we interviewed about their impression of the system. The comments of caregivers almost was positive about our fall detection system. In particular, a constant monitoring function was highly valued. We show a part of their comments as follow;

> "It is good to know where they are and how they are all the time because I want to sometimes confirm those who are in bad condition."
> "We can be potentially understand how they do in each period of time. This knowledge might reduce a risk of falls."
> "Constant monitoring is better because we may know why seniors have fallen in this place. Through such understanding, we will give appropriate services."
> "We often know intuitively who are likely to fall at an early date. We want to check them through this system."

On the other hands, some comments pointed out senior's privacy concerns and an excess of services for healthy seniors about constant monitoring. For instances, they commented;

> "For healthy people, it will be easy to accept the system that shows appearance only for danger situations. Depending on health, their impressions to the system will change."
> "Since we know what someone is doing to some extent, it is enough to see her situation just during an emergency. But we agree that constant observation is secure for a dementia person."

In summary, the caregivers requested a flexible switching of monitoring levels depending on senior's health conditions, in the standpoint from the balance of seniors privacy and security. For instance, healthy seniors should be provided a fall detection system that visualize appearance only when a fall is detected, and other seniors who are in a bad condition or with a worse care level need one that show the position and range images of them for caregivers.

5.4 Was there difference in impressions between seniors living in nursing homes and other seniors

In the user evaluation, there were ten seniors from nursing home and eighteen seniors who recruited by a senior resource agency. The ten seniors were attended by caregivers from the nursing homes during the evaluation and had knowledge about an out-of-bed sensor system in their nursing home. Therefore, it may be that the ten seniors had different expressions with other eighteen seniors.

To analyse the effect of those factors on our results, we divided the questionnaire results into two groups, seniors from nursing home and the other seniors, as shown in Figure 1. It shows that the seniors from nursing home rated the intention to use in simulated out-

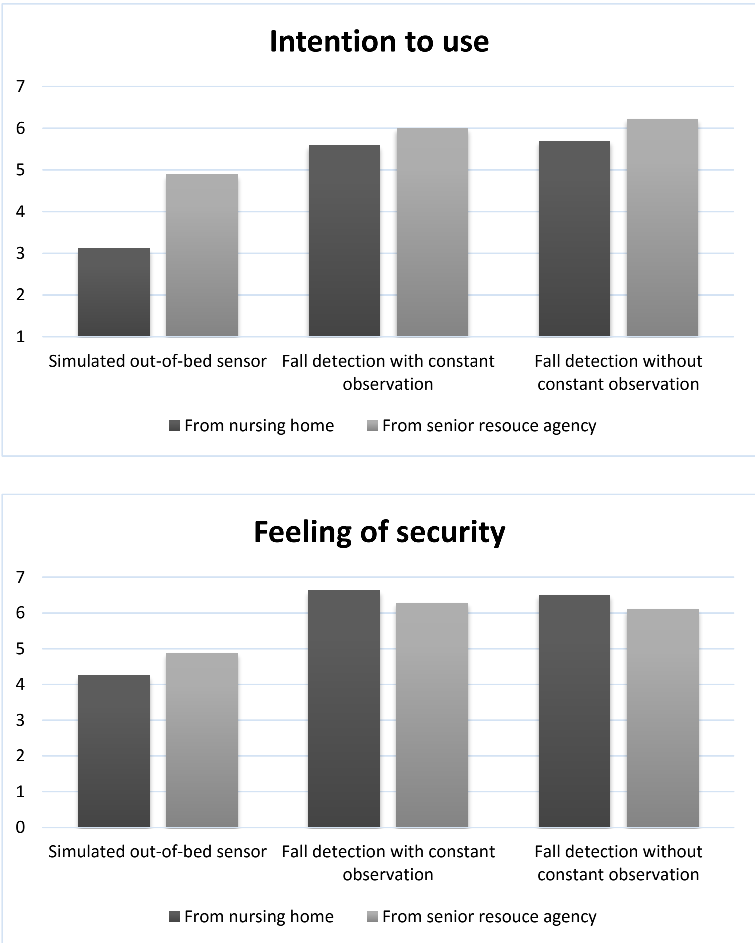

Figure 14. The results grouped by seniors from nursing home and senior resource agency.

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of-bed sensor lower than those from senior resource agency. The reason for their low rating may be because they have seen or heard out-of-bed sensor in their nursing home and understand problems of it. Expect for that item, both groups show similar tendencies in most cases. Therefore, the possibility of an effect of caregivers attending to participants on the results would be slim.

5.5 Design implications

This study shows a promising way to a use of depth sensors for fall detection system in nursing homes. Evaluation results showed that seniors preferred to use our fall detection system based on depth sensors than an out-of-bed sensor, and to provide statuses of fallen people to their caregivers. The caregivers also positively evaluated such depth-based fall detection systems. These results would become an evidence to claim the merits of such fall detection systems.

Further, our interview results showed importance of easiness to change fall detection functions due to health statuses of seniors. For example, for healthy seniors, caregivers can use a function that displays the locations of falls and images when a fall happens (fall detection function). On the other hands, for seniors who require a higher level of care or those to whom caregivers want to pay close attention, they can use a function that constantly displays positions and images (constant monitoring function) in addition to the fall detection function. Moreover, for seniors who should not move without assistance, caregivers can use a function that displays their positions and images when they get out of bed.

5.6 Response to needs

In nursing homes, a care system is required that can switch functions flexibly depending on a particular senior's status. We believe that our fall detection system satisfies such a need with range sensors based on the UNR-PF developed in this study. In it, the information necessary for a care service is described in a map and uses databases. For instance, the map information of a room where monitoring is being conducted is written in the map database. If we need to monitor a new place such as a corridor, adding such information is easy. The information of seniors who are being monitored is registered in the user database. If they request the constant monitoring function in addition to the fall detection function, adding it to the user database is also easy. Furthermore, since a receiver for the range sensors, the 3D human tracker, and a user interface for Android have been developed as reusable components in this study, we can easily develop new monitoring functions. For example, we can develop a move detection function by just implementing a module that sends alerts when a senior gets out of bed using an API for accessing the map database and the 3D human tracker. In fact, we developed a dummy system for an out-of-bed sensor in our experiment. Our system developed in this study satisfies the needs of nursing homes.

6 Conclusion

In this paper, we developed a fall detection system for seniors by considering opinions of caregivers. Based on the interview results with them, we designed the system to be accepted by seniors considering of privacy of them, available in both night and day, scalable to cover large areas, and to display status of seniors, by using networked depth sensors and terminals. We conducted two kinds of evaluations with our system to investigate the performance of the fall detection and impressions by users, i.e., seniors and caregivers.

For testing its performance, we collected and labelled data in which seniors pretended to need help. Using these data, we determined the fall detection precision was 94.5% and recall 86.7%.

We also investigated the user impressions of our fall detection system under three conditions. The first was simulated out-of-bed sensor condition, in which a dummy system were evaluated for comparison with range sensor. The second was fall detection with constant observation condition, in which a fall detection system with range sensors that always displayed a person's current position and the range images was evaluated. The third was fall detection without constant observation condition, in which a fall detection system with range sensors that displayed the current position and the range images only when a fall is detected was evaluated for comparison with constant observation in the second condition. The elderly participants showed greater intention to use and felt more secure with our fall detection system with range sensors than the conventional system that uses out-of-bed sensors. There was no significant difference between with constant observation and without constant observation. Our results show that seniors socially accepted our fall detection system. Furthermore, we got useful suggestions about a switching mechanism to display human positions and range images depending on the level of required care or the senior's condition. More precisely, a fall detection system without constant monitoring should be provided to healthy seniors and the system with constant monitoring should be provided to seniors who has high level of required care.

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