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# The intelligent space for the elderly – Implementation of fall detection algorithm

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**Abstract:** Since many elderly have to live alone, they might suffer from depression, which can lead to physically disabilities. One cause of physical disabilities is falling. Falls are a serious issue for the elderly and can lead to injuries, paralysis or even death. To provide safety and comfort for senior citizens, we adapted the intelligent space concept to design and build a prototype of our intelligent space for them. Our intelligent space provides three services: emergency detection, medical consultation and long-distance social interaction services. We design and proposed an implementation of a fall detection function using 3D acceleration sensor to detect the elderly falls and request emergency service in our intelligent space.

**Keywords:** Intelligent space, elderly, health care

## 1. INTRODUCTION

Nowadays many elderly have to live alone. Without family or caregivers to assist and support them physically and mentally, the health of senior citizens may deteriorate faster than usual and cause depression and injuries that may lead to physical disabilities. Falling is one cause of physical disabilities. Falls are serious for the elderly and can lead to injuries, paralysis or even death. Therefore, senior citizens require assistance.

Many previous researches adopted several technologies to provide comfort and support daily activities to improve the quality of life of the elderly. We adapted the intelligent space concept to design and build a prototype of our intelligent space for the elderly.

Intelligent space [1], which was first conceived in 1995 at the University of Tokyo, is designed to assist people within it and support smart interaction between people and the space that can provide more comfort and security. An intelligent space is depicted in Fig. 1.

Fig. 2 shows the process of a Distributed Intelligent Network Device (DIND), which is an intelligent device that can sense, process and connect with other devices by a network. A DIND is composed of three main components: sensor, processor/computer, and communication hardware. The sensors monitor the environment and feed information to the processor that communicates with other DINDs through the network to share information.

The attributes of an intelligent space includes system perception, cognition, analysis, reasoning, and

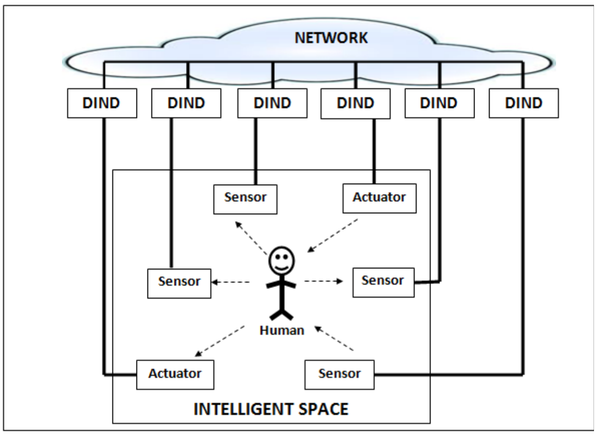



Fig.1 Intelligent space

prediction of user's behavior and their surrounding environments. Situation awareness is the most fundamental form of many capabilities in an intelligent space. Several technologies are integrated into the space, including information processing, speech recognition, and face recognition [2] that make it more intelligent.

Our intelligent space provides three services: emergency detection, medical consultation and long-distance social interaction services. In addition, we improve its efficiency by implementing a fall detection function using 3D acceleration sensor to detect when an elderly person falls that automatically requests emergency service. This paper describes our design and implementation of our fall detection function.

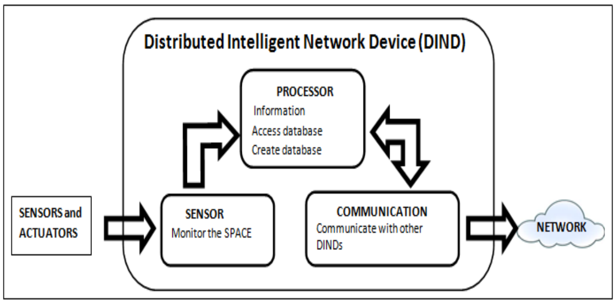



Fig.2 DIND

## 2. RELATED RESEARCHS

Smart House [3] proposed an intelligent space to assist the handicapped and senior citizens. A house is filled with various technologies to maximize the comfort and safety of its occupants. Its features are shown below:

- Smart Mirror displays important information and notices
- Smart Refrigerator is aware of its content as well as expiration dates and can issue a shopping list or recipe recommendation based on its contents.
- Ultrasonic Location Tracking detects the occupants to get information about their current location, movement and orientation to provide security.
- Smart Floor uses many sensors to detect the occupants. If one falls, it reports to emergency services.
- Social-Distant Dining utilizes existing audio/video equipment in the dining room to provide a simultaneous dining experience with others far away.
- Smart mailbox which notify the occupant when mail arrives.
- Cognitive assistance provides reminders about medication and appointment by auditory and visual cues.

Emergency call for help tracks potential emergencies, checks whether the occupants have problems, and requests help when it is required.

Datong Ch. et al. proposed an Intelligent Video Monitoring to Improve Safety of Older Persons [4]. An intelligent monitoring system combined a camera network and an automatic elopement detection algorithm to avoid potential catastrophes. The automatic elopement detection used computer vision and a machine learning algorithm to detect elopements and alert caregivers.

## 3. THE INTELLIGENT SPACE FOR THE ELDERLY

As mentioned above, our intelligent space provides the following three services for senior citizens:

- Emergency service: detects emergency situations and automatically calls an ambulance, warns family and caregivers about emergency situations, requests help and make a video conference call between the elderly and hospital staffs for preliminary diagnosis.
- Medical consultation service: allows senior citizens to consult with their doctors at home whenever they have problems.
- Long-distance social interaction service: allows the elderly to communicate with their family and friends.

Our intelligent space for the elderly is depicted in Fig. 3. It consists of twelve I/O devices: an ECG sensor (heart rate sensor), an acceleration sensor, a thermistor, a humidity sensor, gas sensors, a cdS photoresistor, a microphone, a speaker, a button, a touch screen, a display and a webcam. The input devices monitor the intelligent space and feed the information to our system to provide appropriate services. The output devices will display important information to the elderly. Our provided services can contact to the personal doctor, family, hospital staffs, and friends for communication, consultation, and warning about emergencies. We describe the functions provided by each service in the next section.

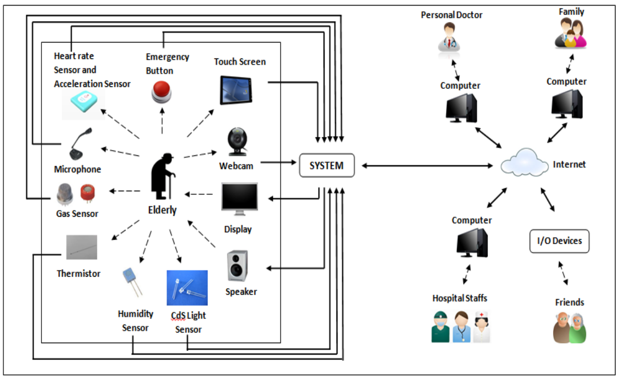



Fig.3 The intelligent space for the elderly

## 4. SERVICES AND FUNCTIONS

### 4.1 Emergency service

The physical ability of senior citizens is usually decreased. During emergencies, they often cannot effectively help themselves. Thus, emergency service provides the following seven functions:

- Heart rate detection: detects such abnormal heart rate situations as heart attacks by analyzing heart rates
- Fall detection: detects falls using 3D acceleration sensor and a tri-axial accelerometer with a threshold based algorithm
- Activity detection: detects other unusual situation using multi-sensor unit
- Emergency button and touchscreen detection: detects signals from emergency buttons and touchscreen for requesting this service
- Automatic ambulance calls: makes phone calls with recorded messages to request help
- Automatically send emails to mobile phones: sends

updates about the situation of the elderly to their family members and caregivers to warn them and request help.
- Video conference calls for preliminary diagnosis: makes a video conference call between the elderly and hospital staffs that get the information about a senior citizen's situation so that they can do a preliminary diagnosis by a video conference call.

### 4.2 Medical consultation service

Seniors may have difficulty going to hospital to meet doctor because of mobility issue. This service provides three functions to support doctor consultations at home.
- Touchscreen detection: detects signals from touch that request this service
- Video conference calls for medical consultation: makes a video conference call between the elderly and their personal doctor. The elderly will feel the convenience of contacting their personal doctor for home consultations
- Appointments and medicine schedules: displays doctor appointments and medicine schedules set by their personal doctor

### 4.3 Long distance social interaction service

Since senior citizens often live alone and away from their families, they may have mental health problems and experience loneliness. To improve their mental health, this service provides three functions so that they can contact with their family and friends.
- Touchscreen detection: detects signals that request this service
- Video conference call for social interaction: makes a video conference call between the elderly and their family members or friends
- Daily and medicine schedule: displays daily memos and medicine schedules set by their family

Our services and functions that are provided by the intelligent space for the elderly are depicted in Fig. 4. In emergencies, our intelligent space provides many functions as we have mentioned above to support the elderly and help them request assistance. One effective and useful function is fall detection, which we describe in the next section.

## 5. FALL DETECTION FUNCTION

For supporting the emergency services in our intelligent space, we designed and implemented a fall detection function that detects when seniors fall using 3D acceleration sensors. We used a common methodology: a tri-axial accelerometer with a threshold-based algorithm [5]. After this function gets the input data from the 3D acceleration sensor, the norm value is calculated from the input data:

$$= \sqrt{(A_x)^2 + (A_y)^2 + (A_z)^2} \qquad (1)$$

Ax, Ay, and Az are accelerations (g) along the x, y, and z axes. This algorithm uses the upper and lower fall

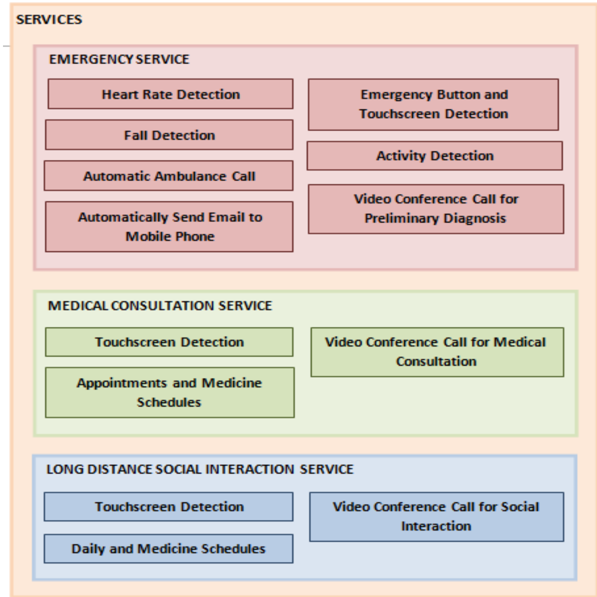



Fig.4 Services and functions

thresholds to detect fall. When human falls, a free fall occurs. Free fall is the state where only gravity is added to the accelerometer. There is no external force in the accelerometer. This means that during a free fall, the acceleration in the three axes become zero. We also found the difference between the norm value at current time (t1) and previous time (t0) to observe the rapid variation in the norm value. The difference equation is shown below:

$$\text{different norm value at t1} = \text{norm value at t1} - \text{norm value at t0} \qquad (2)$$

The norm value rapidly changes when the humans perform such expeditionary behaviors as sitting/standing quickly and falling. However, since normally older people move slowly, we can recognize the difference of norm values to distinguish between normal behaviors and falling situations.

For our study, we set the following four thresholds to separate falls and the activities of daily living (ADL):
- Maximum Acceleration Threshold: upper fall threshold value
- Minimum Acceleration Threshold: lower fall threshold value
- Free Fall Threshold: threshold value that detects free fall
- Difference Threshold: threshold value that detects expeditionary behaviors

We performed falling down experiment to determine the value of the four thresholds. If maximum acceleration, minimum acceleration, free fall, and the difference threshold are reached in 2.5 seconds and the free fall situation occurs before the maximum norm value occurs, the elderly person might have fallen. The workflow of this function is shown in Fig. 5.

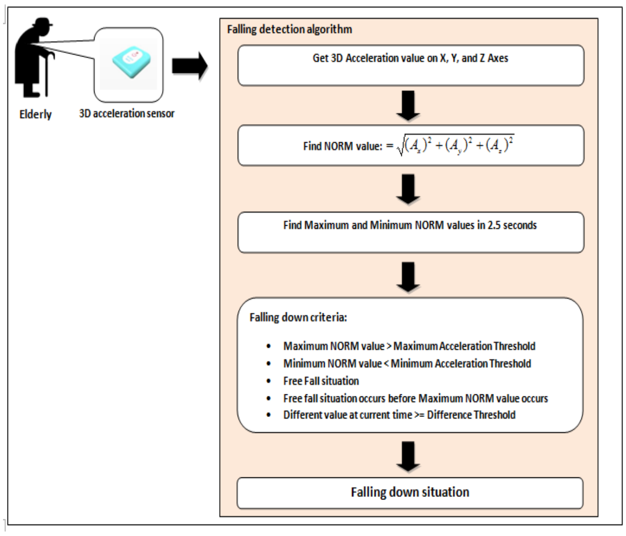



Fig.5 Fall detection function.

## 5. FALLING DOWN EXPERIMENT

Our preliminary falling down experiment determined the appropriate values of the maximum and minimum acceleration thresholds, the free fall threshold and the difference threshold to detect falling down situations.

We only collected the data from young participants for obvious reasons of safety. They wore 3D acceleration sensor on their position of heart on chests (Fig. 6).

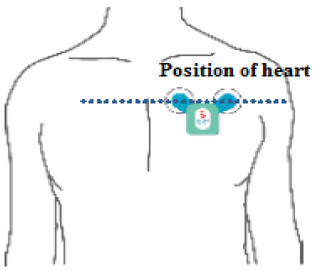



Fig. 6 Position of 3D acceleration sensor

In this experiment, we categorized eight falling motions because the falling directions are forward, backward, to the left and to the right. The possible endings of the falling motions are sitting or lying down, so eight falling motions are shown in Table 1.

Table 1 Falling down motions

| Motions of Fall | End of Fall |
|---|---|
| Forward fall | Lying down |
| Backward fall | Lying down |
| Left side fall | Lying down |
| Right side fall | Lying down |
| Forward fall | Sitting |
| Backward fall | Sitting |
| Left side fall | Sitting |
| Right side fall | Sitting |

Each participant fell four times in each falling motion. After we got the maximum and minimum acceleration data from each participant in each fall motion, the lowest maximum acceleration value was set as the Maximum Acceleration Threshold and the highest minimum acceleration value was set as the Minimum Acceleration Threshold. For the Free Fall Threshold [6] and the Difference Threshold, we experimentally determined the appropriate value for detecting fall. All of the threshold values that we set are shown in Table 2.

Table 2 Threshold values for detecting fall

| Threshold | Value (g) |
|---|---|
| Maximum Acceleration Threshold | 1.173 |
| Minimum Acceleration Threshold | 1.145 |
| Free Fall Threshold | 0.7 |
| Difference Threshold | 0.5 |

After performing this experiment, we set appropriate values for all the thresholds and determined that if a participant falls heavily (Fig. 7), the peak norm value exceeds 2g, the free fall value gets very near to zero or less than zero and the different norm value at the peak is high (more than 1g). If the participant lightly falls, the peak value is small, the free fall value approaches one and the different norm value is less than 1g. Therefore, a free fall value, a different norm value, and a norm value of 3D acceleration from different fall motions do not depend on the fall direction but on its strength.

## 5. EVALUATION

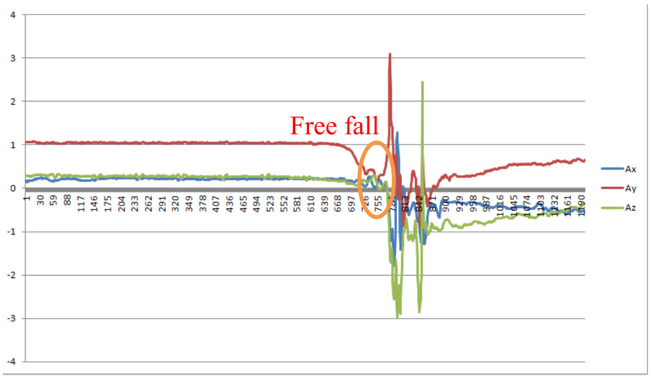
To check the accuracy of out fall detection function and to evaluate it with statistical analysis, we calculated sensitivity and specificity [7]. Sensitivity is the capability to detect a fall. Specificity is the capability to distinguish between a fall or an ADL. We identified the following four possible cases of fall detection as positive or negative:

- True positive (TP): a fall occurred and our function detected it.
- False positive (FP): an ADL was being done but our function detected it a fall.
- True negative (TN): an ADL was being done but our function failed to detect it.
- False negative (FN): a fall occurred but our function failed to detect it.

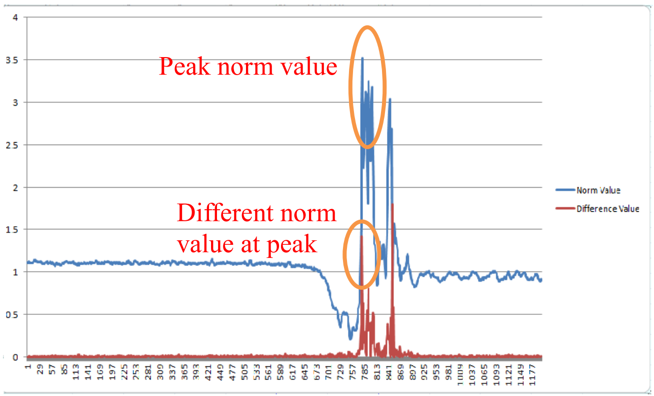
The sensitivity and specificity equations are shown below:

$$Sensitivity = \frac{TP}{TP + FN} \quad (3)$$

$$Specificity = \frac{TN}{TN + FP} \quad (4)$$




(a) Graph of 3D Acceleration




(b) Graph of Norm and Difference Value.

Fig. 7 Graphs when human heavily falls down

To find the sensitivity and specificity, we performed another experiment again with only young participants who wore 3D acceleration sensor on their position of heart on chest (Fig. 6). In this experiment, we categorized falling motions into four by specific only direction and let all the participants fall down. They performed the four falling motions and the basic ADLs three times (Table 3). Fig. 8 shows the 3D acceleration when they fell and performed ADLs.

Table 3 Falling down and ADLs

| Motion of Fall | ADLs |
|---|---|
| Forward fall | Walking for ten seconds |
| Backward fall | Sitting on floor |
| Left side fall | Getting off floor |
| Right side fall | Picking an object off floor |

## 6. RESULT AND DISCUSSION

Our fall detection function detects falls and warns that a senior citizen might fall when the maximum norm value is greater than 1.173 g, the minimum norm value is less than 1.145 g, the different norm value within 2.5 seconds is greater than 0.5 g and there is free fall when the acceleration in the three axes is less than 0.7 g. Free fall situations might also occur before the maximum norm value occurs and all the above criteria should occur within 2.5 seconds. We calculated the sensitivity and specificity (Table 4).

Table 4 Sensitivity and specificity

| | |
|---|---|
| Sensitivity | 86.11% |
| Specificity | 93.06% |

For the experiment, all participants intended to perform a fall and some felt scared when they fell. Due to such fear, humans can control themselves to break their falls. So they fell very softly. Such criteria as free fall couldn't be obtained. In contrast, when people accidentally fall, they cannot effectively control themselves, especially the elderly. This causes acceleration in the three axes to near-zero, and free fall can be obtained. In summary, our fall detection function effectively detects quite heavy falls.

## 7. CONCLUSION

Our intelligent space for the elderly provides three services: emergency detection, medical consultation and long-distance social interaction service. For emergencies, we designed and implemented a fall detection function to request assistance when a senior citizen falls down. The fall detection function detects when senior fall using 3D acceleration sensor. For detecting falls, we implemented a threshold-based algorithm with a tri-axial accelerometer. This algorithm uses four thresholds: maximum acceleration, minimum acceleration, free fall, and difference threshold. We performed two experiments. The first determined appropriate values for all thresholds. The second evaluated a fall detection function. We conclude that our fall detection function effectively detect falls in the intelligent space for the elderly so that emergency service can be requested. Future research will use another acceleration sensor and attach it at different positions to measure norm values, or gyroscope to measure orientation when seniors fall to improve the accuracy and the efficiency of our fall detection function.

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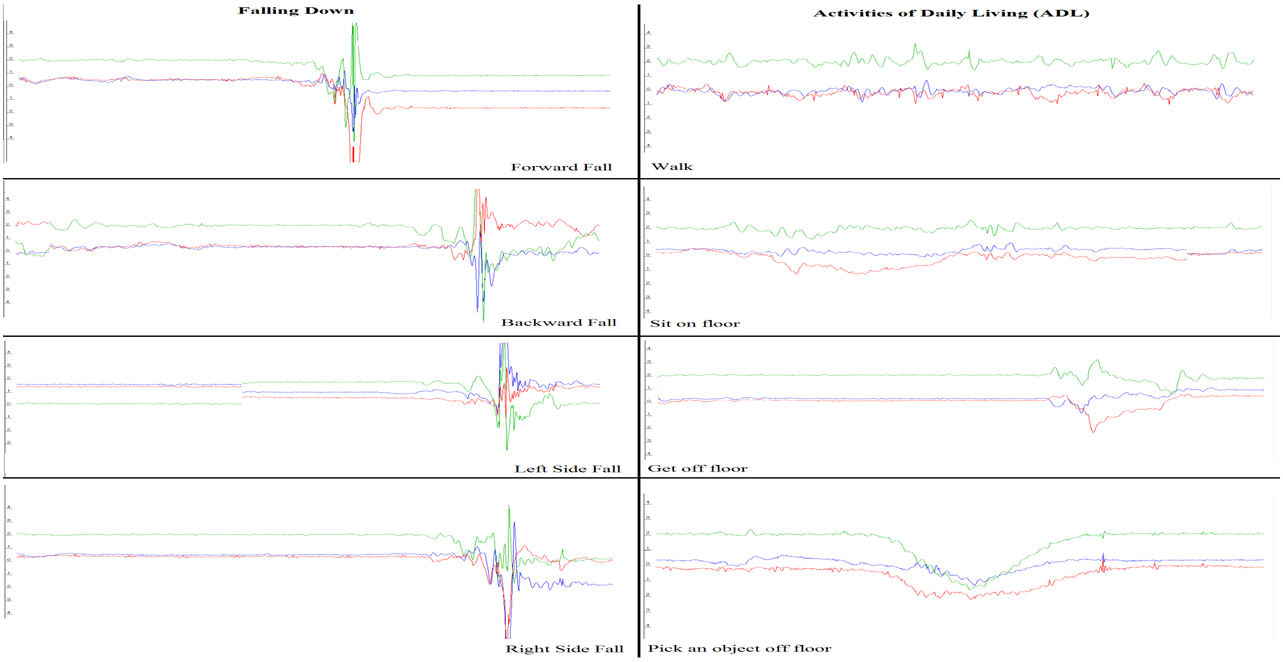


Fig. 8 Graph of 3D acceleration when participants fell down and performed ADLs


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