Activity recognition and anomaly detection for the elderly with dementia by using passive RFID sensor tags

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Abstract: In recent years, the number of demented patients besides the elderly living alone has been increasing in Japan. This study proposes a monitoring system that recognizes the behavior of the elderly with dementia living alone and detects their anomalies. To alleviate a mental and physical burden on the elderly, our monitoring system adopts RFID sensor tags embedded in their living environment. Our experiments have ensured the feasibility of implementation and demonstrated that by detecting anomalies with changes in the sensor data. The results have demonstrated that our system can exactly detect the remaining amount in a trash box and of a meal.

Keywords—**Anomaly Detection, RFID, monitoring**

1. Introduction

The elderly population has greatly increased worldwide these days. Especially in Japan, the percentage of the elderly (persons 65 years old and over) will continue to increase despite the total population decreases[1]. The number of elderly people with cognitive decline besides living alone has also been significantly increasing. Such the elderly are likely to have various problems and dangers in their daily life. Troubles with their neighborhoods and the accidents related to the health are part of such problems. For example, decreased memory of elderlies causes leaving garbage in their home and leads to bad odor because they cannot remember certain garbage collection date or location. Moreover, cognitive impairment of the five senses, one of the dementia symptoms, tends to cause health accidents. The elderly cannot recognize rotten food and then eat it. To detect these anomalies, monitoring the everyday living of isolated elderly people is considered to be an important subject. However, their families or caregivers cannot afford to keep an eye on elderly people the whole time. To improve this situation, monitoring services for elderly people based on the Internet of Things (IoT) have been developed. A variety of prior works that aim to solve the problems have already been proposed, although each with its strengths and weakness. Vision-based monitoring systems are one of them, which can recognize the subject's activity and detect anomaly with high accuracy and immediately. However, the existence of cameras everywhere in their daily lives imposes excessive risk of privacy invasion.

Wearable device-based monitoring systems might eliminate such privacy concerns. However, the major problem of this approach is that wearing sensors is sometimes infeasible. Some users forget or refuse to wear sensor devices. Moreover, such devices typically need regular maintenance involved in battery. Another approach that employs tagged-objects, which sensors are attached to daily use objects such as shoes or clothes, are also developed. The elderly's daily behavior with the object enables to recognize various activities and also detect anomalies. This approach might remain bound by devices, because it forces the elderly to go on using particular tagged objects. In that sense, this approach might be infeasible as with the wearable approaches. Therefore, the device-free and dense-sensing approaches without cameras have been widely proposed in recent years. In this research, we propose an unobtrusive and noninvasive monitoring system for elderly people with cognitive decline who live alone.

2. Related Work

The idea of device-free approaches is to deploy sensors in the environment. The elderly's activities change sensor information and then we can recognize activities and detect anomalies with it. It is more practical than the other approaches because it does not require the user to carry any device while doing activities. Various sensors are utilized for device-free monitoring systems. Table1 shows the comparison of each sensor used for device-free monitoring systems[3].

The binary sensor can get simple information at low costs. However, recognizing and detecting complex activities is difficult by using only binary sensors. Approaches using infrared sensors are popular for an alternative method of the camera monitoring system. Infrared sensors can detect distance and temperature. This method does not use vision information, but some elderly people feel privacy concern by the existence of cameras. Passive RFID tags can measure the distance from objects with the change of radio wave strength. Passive tags are low cost and easy to attach, but are environmentally sensitive. Passive RFID sensor tags have the same feature of passive tags. Additionally, sensor tags detect pressure, temperature, moisture information.

The passive RFID tag-based solution is one of the popular research among them. Passive RFID tags are deployed to the living environment unobtrusively thanks to its characteristics such as smallness, thinness, softness. However, more detail information about daily objects such as contents and temperature of objects cannot be obtained from passive RFID tags. Therefore, if the patterns of the elderly's activities do not change, the anomalies hidden inside the activities cannot be detected.

3. Research Objective

3.1 System requirement

The Purpose of the system is to monitor the living and detect anomalies of the elderly with mild dementia who lives alone. To achieve the objective, 5 requirements are defined.

Table 1. Comparison of sensors used device-free system.

sensors	Information	Feature
Binary sensor [2]	on/off, touch/untouch, etc,.	low cost, simple information
Infrared sensor	distance, temperature	high accuracy, high cost, privacy issue
passive RFID tags	distance	low cost, easy attachment, environment interference
passive RFID sensor tags	distance, pressure, temperature, moisture	low cost, easy attachment, environment interference

At first, considering elderly people's privacy is an important condition. The monitoring system runs all the time, so mental strain should be reduced as much as possible. Second, realizing the system which does not require any cooperation for the elderly is necessary. Elderly people and the people who have dementia are likely to fail meeting the monitoring restriction. Third, installation and maintenance are desirable to be easy. The system installed on each subject's living environment. Therefore, the installation and maintenance are important to be less complicated than them in nursing facilities. Fourth, detecting anomalies especially caused by symptoms of dementia is important. Finally, realizing a robust system, which does not need to train for different subjects and environments is needed. Based on these system requirements, sensor requirements are determined.

3.2 Sensor requirement

Using a monitoring device excluding camera reduce privacy concerns. Also, using devices excluding wearable device can realize the system does not depend on the elderly's activities. To reduce complex installation and maintenance, battery-free and single sensor are desirable for the required sensor. Anomalies caused by symptoms of dementia are difficult to detect because they are complex. Various sensing information is necessary for this system. One of the sensors which fulfill the above sensor requirements is a passive RFID sensor tag.

4. Monitoring System for the Elderly

4.1 Solution by using RFID sensor tags

The passive RFID tags are suitable for installing in the living environment thanks to its unobtrusive shape as explained in section2. They also have the advantage of battery-free. They are activated by the signal from antennas and transmits data, such as ID, the strength of radio frequency back to the antennas. Readers can read many tags in an area all at once. Passive RFID sensor tags have sensing capability which can measure temperature, moisture, and pressure in addition to conventional functions[4].

4.2 Overall structure of proposing system

Figure 1 shows the overall diagram of the proposing system. The system installs sensor tags on everyday-objects such as trash boxes, tableware. Sensor tags receive radio waves from antennas and transmit sensor data with reflected waves. Antennas and readers transfer sensor data to monitoring PC sequentially. By utilizing sensor data (tag ID, RSSI value, temperature, moisture, pressure) from sensor tags, the status of objects is recognized. The monitoring PC sends an alert notification to caregivers or families of the elderly when there are meaningful anomalies in them.

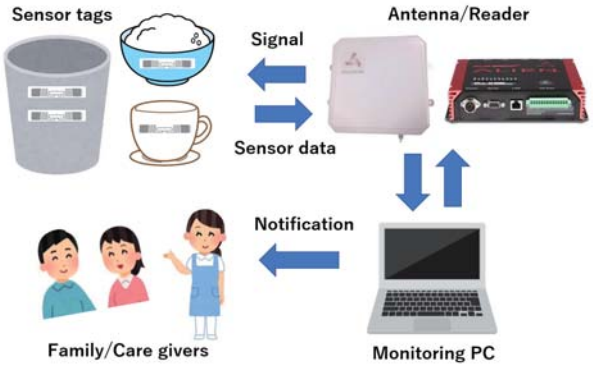

Figure 1. System overview.

5. Experiments of the Trash Box

To detect the anomalies which the elderly neglect to take out trashes, monitoring the amount of the trashes in the trash box is effective. By using RSSI values, we distinguish the activity of taking trashes out and how full the trash box is.

5.1 Determination of constitution

Since RSSI values are susceptible to interference, it is important to find the proper monitoring constitution. In order to obtain an appropriate experimental configuration, the following constitutions were changed and experiments were performed.

- Kinds of garbage.

  RSSI values are influenced by the distance between the antenna and tags, angles of the antenna, obstacles such as the human body, moisture, and metal. Different 3 types of materials, paper, aluminum, wet tissue, are used as an imitation of garbage in everyday life.

  At first, Experiments using each material alone were conducted. When the paper was used as garbage, the RSSI values did not change with changing the amount of garbage in the trash box. In the case of aluminum, the reflection caused by metal occurs, and significant changes in RSSI values were seen. However, different results were obtained even in the same situation, then the correlation between the changing of the amount of garbage and the changing of RSSI values can not be found. The estimation of the amount of garbage is difficult in this case. When the wet tissue is used for garbage, moisture absorbs radio waves. Along with the increase in the

amount of garbage, wet tissue, RSSI values showed a downward trend. From the above experiments, garbage containing water should be used at least. Therefore, experiments were performed in all patterns of plurality types of mixed garbage containing moisture. Experimental results in all types of garbage were almost equal results.

In real-life problems, garbage containing moisture represents kitchen garbage. Kitchen garbage consists of 70 to 80 % of moisture, and more moisture produces more stench. The monitoring using RSSI value is useful for detecting the leaving of garbage that causes odor.

- The number of tags (From 1 to 7).

  Experiments were conducted with 1 to 7 tags. As a premise, giving more tags will help to get more detailed information. However, the increase in the number of tags causes slow reading speed and unstable reading due to mutual interference. From experimental results, 3 or more tags on the trash box cause interference even in different arrangements.
- The number of antennas (From 1 to 2).

  Experiments using different numbers of antennas were also conducted with different arrangements. When 2 antennas were used, mutual interference between antennas occurred, and the reader could not receive enough amount of sensor data. Therefore, using only one antenna for receiving signals from tags on the trash box is appropriate in this experiment.
- Arrangement of tags and antennas.

  Based on above findings, some arrangements that using from 1 to 2 tags and 1 antenna were tried. Figure 2 shows them. In the constitution from (a) to (d), tags are attached on the side of the trash box. Sensor data obtained from (a) taught us which the trash box is full or not. On the other hand, sensor data from (b) to (d) told us more detail information, how full the trash box is. The angle of the antenna is changed in (b) to (d). Almost the same results are obtained, but (b) has the largest correlation between the increase in garbage and the decrease in RSSI value. In the constitution of (e), 2 tags are attached on the opposite side of the trash box. This arrangement was tested to recognize the increase in the garbage by comparing the RSSI values of the tag on the antenna side and the tag on the opposite side. If one of the antenna sides is not affected by garbage, and one of the other sides is affected, the difference between the RSSI values of them indicates changes in the garbage. However, garbage containing moisture affected both tag on the antenna side and tag on the opposite side in experiments. The constitution of (e) is considered to be not proper for this monitoring system. In the cases of(f) and (g), tags are attached on the side and bottom of the box. The tag attached to the bottom of the box was affected by floor material, and when the material is metal, sensor data acquisition from it became unstable.

  As a result of a combination of the respective conditions, the constitution in figure 3 was found to be the most appropriate.

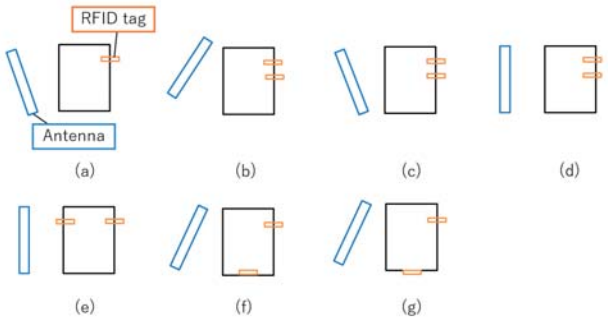

Figure 2. Constitutions using 1 to 2 tag, 1 antenna.

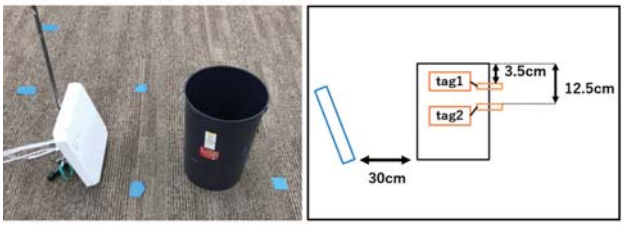

Figure 3. Constitution obtained from experiments.

5.2 Results

Figure 4 shows RSSI value changes of tag1 and tag2 in the above constitution. The experiment lasted for 210 seconds and performed the following 1-6 activities.

1. Placing a plastic bag in the trash box.
2. Putting garbage in the trash box (1/4 of trash box).
3. Putting garbage in the trash box (2/4 of trash box).
4. Putting garbage in the trash box (3/4 of trash box).
5. Putting garbage in the trash box (4/4 of trash box).
6. Taking garbage out from the trash box.

These human activities are surrounded by orange circles, the range where RSSI values change greatly. When there is no human activity, locations in which RSSI values are stable in graphs, the decreasing of RSSI values indicates the increase in the amount of trashes. After the activity of taking out trashes, the RSSI values returned to the initial value, the value recorded when the trash box is empty. In addition, people passing without increases in the garbage did not affect the RSSI value after the action. The conclusions obtained from the experiment are as follows.

- When human activities occur, the RSSI values change greatly.
- When there is no human activity, the RSSI values decrease as the amount of trashes increases.
- After the activity of taking out trashes, the RSSI values return to the initial value, the value recorded when the trash box is empty.
- People passing without increases in the garbage does not affect the RSSI value after passing.

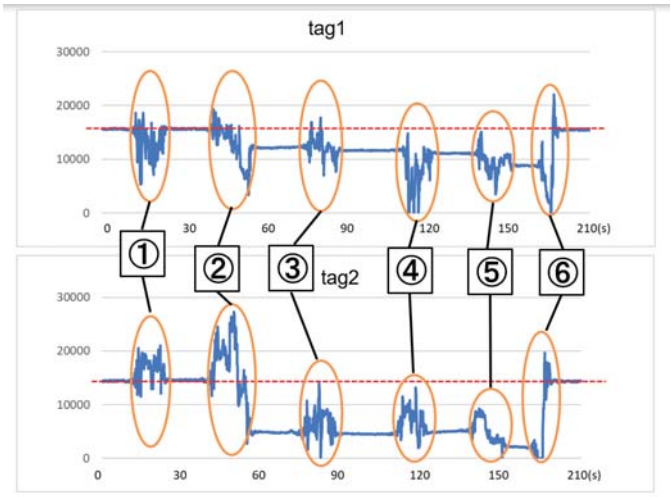

Figure 4. Transition of RSSI value.

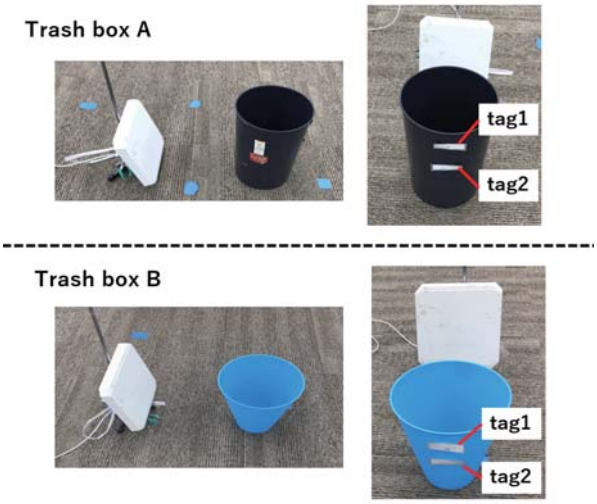

Figure 5. Two types of trash boxes.

If the collection of garbage is not performed for a certain time even though the increase in the garbage is recognized by monitoring the RSSI value, the anomaly can be detected as garbage being left unattended.

5.3 Verification of robustness

The flexibility of the experimental constitution regarding the distance between the antenna and the trash box and the shape of the trash box was verified.

At first, RSSI values were measured under the same activities as in the previous experiment, varying the distance between the trash box and the antenna. The distance varied from 0.3m to 0.8m every 0.1m. Even the distance changed, the tendency of the change of the RSSI value was the same as the previous one. However, the longer the distance, the lowered the empty RSSI value and lowered the rate of the RSSI value changing due to a change in the trash box state. These results demonstrate flexibility in changing distances.

Secondly, the experiment using another trash box, which has a different shape, was conducted. Figure 5 shows its constitution. In experiments in trash box B, the RSSI values change significantly with human activity and gradually decline with increasing amounts of garbage. The change in this value is the same as that in trash box A. Therefore, this system was certified to have scalability for the shape of the trash box.

6. Experiments of Tableware

Impairment of five senses, which comes from the symptoms of dementia, causes health damage to the elderly. They cannot distinguish meals rot and eat it. Measurement of temperature helps to detect neglecting meals. We conducted experiments on the temperature measurement of the mug cup and rice bowl.

6.1 Temperature measurement

Using a ceramic mug, temperature measurement was performed with a sensor tag in the state of different states. Experiments were performed for the case where the ice water is poured into an empty mug and the case where hot water is poured. Figure 6 shows the changing of temperature when the ice water is poured. As time passes, the temperature dropped from the empty temperature gradually. On the other hand, the changing of temperature when the hot water is poured is indicated in figure 7. Contrary to the previous experiment, the temperature gradually rose from the empty state.

Figure 6. Mug cup temperature when ice water was pour.

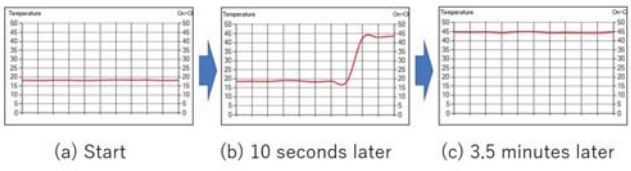

Figure 7. Mug cup temperature when hot water was pour.

Additionally, a sensor tag was installed on the rice bowl as shown in figure 8, and the temperature was measured. Experiments were performed for the case where the rice bowl is empty and where the rice bowl is full. Figure 10 shows its results. When the hot rice was put in a rice bowl, the sensor tag

on the bowl recorded around 40 degrees. On the other hand, when the bowl was empty, the sensor tag recorded around 28 degrees.

6.2 Consideration

We demonstrated temperature measurements of tableware when there is no human activity. Radio waves in RFID systems are obstructed by the human body. For this reason, it is impossible to measure temperature information during eating and drinking activities. When eating and drinking is completed and the tableware is emptied, the temperature should change rapidly and approach the state of room temperature. If there is no such specific change due to eating and drinking activities and the temperature continues to rise or fall gradually, the meal may be left unattended.

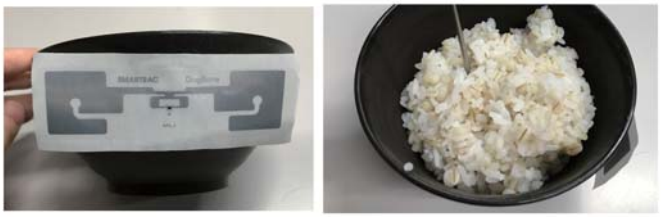

Figure 8. Experimental structure of rice bowl.

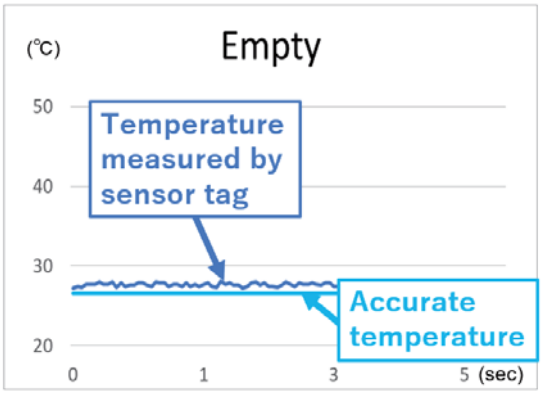

Figure 9. Rice bowl temperature when hot rice-filled.

7. Conclusion and future work

This paper has proposed a monitoring system with passive RFID sensor tags on objects in the living environment for the elderly with dementia who lives alone. The advantage of this system is that elderly people could perform without any restrictions on their activity or fear of damaging the sensors because of battery-freeness. The experiment shows that anomalies in the content of activity such as leaving garbage or meals can be detected by recognizing object status. Moreover, this research proved different types of objects are available. In future work, further analysis of collecting data using

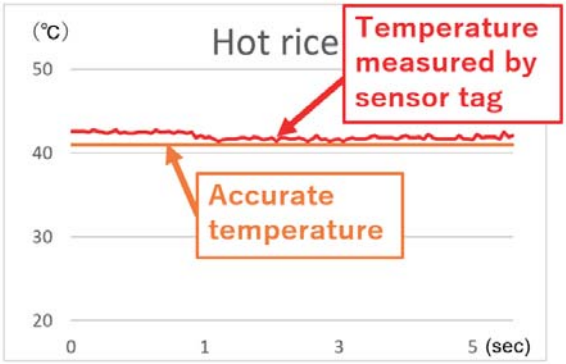

Figure 10. Rice bowl temperature when empty.

sensor tags is required. Monitoring accuracy will be improved by integrating different types of collected information, RSSI, temperature, moisture, pressure.

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