A Bluetooth-based Device-Free Motion Detector for a Remote Elder Care Support System

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Abstract—Remote elder care is important but it is difficult to keep a track of a patient’s medication. We developed a remote elder care support system that enables users to synchronize handwriting, and photos in real-time on ordinal smartphones and tablet devices. However, it remained difficult for caregivers to remotely check the timeliness of the patient’s dose. To solve this problem, we developed a motion detector based on the attenuation of Bluetooth signals, the 2.4 GHz band, by water. The advantage of our method is that it does not require the equipment of any devices to detect care receivers is unnecessary. We experimented the attenuation of Bluetooth signals by human body and concluded that Bluetooth can be used for a motion detector.

I. INTRODUCTION

A support system to remotely care for elderly people is needed, because it is difficult for caregivers to communicate with care-receivers living remote localities. Herein, we developed a remote elder-care-support system that uses smartphones and tablet. Our aim is to create a system that supports the mutual understanding between caregivers and care receivers with a hearing disability. The system shown in Fig. 1 synchronizes freehand drawings, photos, and Web pages in real time on the devices of caregivers and care receivers.

We applied our system to a practical problem. This system supported the mutual understanding between a caregiver and care receiver and showed an improvement in the care receiver’s dementia. However, we discovered that the system increased the workload of the care giver. Caregivers watched the real-time photos of the care receivers like a video in order to check the timeliness of medication.

To better monitor the care receivers, we developed a new motion detection method based on device-free localization (DFL) using Bluetooth. As will be described in detail below, this method utilizes an attenuation of Bluetooth signals. Because the human body is about 60% water, it absorbs signals in the 2.4 GHz band. If the received signal strength indication (RSSI) dips below a certain threshold, the system suggests that a care receiver is near the devices.

The advantage of our method is that it renders specialized equipment such as monitors and radio-frequency identification (RFID) tags useless. This avoids inconvenience and potential problems (e.g., installation or use problems) that occur when care-givers have to install and equip specialized equipment and/or care receivers have to remember to wear tags or other wise use the equipment. Instead, the proposed method relies on Bluetooth technology that is already included in people’s everyday devices such as smartphones and tablets.

II. RELATED WORKS

Recently, techniques for managing position information have been widely studied. Herein, we define position information as information about a user’s position indoors.

A. Remote Elder Care Support System

In traditional remote elder care support systems, caregivers monitors care receivers using a RFID tag [1]. Caregivers can monitor the behavior of care receivers from indoor sensor data. However, in this method requires care receivers to be equipped with positional devices. They may be inconvenient or they may forget to do so. The DFL technique overcomes these disadvantages.

In remote elder care situations, caregivers and care receivers may have different demands. For example, caregivers may wish to improve the life quality of care receivers by monitoring them and communicating with them. However, care receivers may be irritated by changes in their living environments. Thus, elder care support systems need to minimize elements that can irritate care receivers.
Katayama et al. proposed a novel approach—an asymmetric interface—which addresses the problem of the asymmetry [2]. The system does not require care receiver to perform any task; rather, the caregiver has all the controls in order to avoid irritating the care receiver. Katayama et al. evaluated the availability of the system and concluded that the system can be used with a telephone in real time.

B. Positioning Method

Outdoor positioning is very popular because many contemporary smartphones have GPS functions[4]. However, GPS is not suitable for indoor positioning because buildings are obstacles.

Wi-Fi, Bluetooth, infrared light, ultrasonic wave, and similar methods are used for contactless indoor positioning. Fingerprint methods use received radio field strengths of Wi-Fi, Bluetooth, and so on. They are based on a radio field strength map that contains RSSI at points in a room [3]. The RSSI of a target device is compared with the RSSIs of points in a radio field strength map [5], [6].

As an emerging technique with promising applications, the DFL technique has drawn garnered considerable attention. A significant point of interest is that it is able to realize wireless localization without any need for the care receiver to hold or wear a device [7], [8]. The DFL technique detects shadowed links and realizes localization using the RSSIs of these links. This technique can be applied to aged care for people without smartphones or mobile phones if they have other devices with Wi-Fi or Bluetooth.

C. Positioning with Bluetooth Beacons

We focus on a method of using Bluetooth at a frequency band of 2.4 GHz to position people without equipping Bluetooth devices. Bluetooth is installed on many portable devices and is the prevailing technology for radio communication. Increasingly, it is also the prevailing technology for positioning. Its growing prevalence will make it possible to expand the range of applications with positioning by Bluetooth.

The Apple iBeacon is an indoor positioning system that uses Bluetooth1. Positioning with Bluetooth uses RSSI between fixed and and moving devices to estimate the distance between the devices. A Bluetooth device periodically transmits packets of data that contain information to detect devices. The transmitter side is called the peripheral and the receiver side is called central. iBeacon identifies the four categories of distances between devices: Immediate (within 10 cm), Near (within 1 m), Far (beyond 1 m) and Unknown (unclear). The system discerns areas by RSSI, as shown in Fig. 2. Bluetooth beacon devices have two advantages—low cost and long battery life. The price of Bluetooth beacons is ~3-10USD. The battery life of Bluetooth beacons is a few years. Therefore, it is possible to set up a system and install many beacon devices at a low cost.

However, in general, positioning with Bluetooth beacons requires the subject to carry a beacon device. This is a problem in elder care, because people with dementia often forget to carry positioning devices. To resolve this problem, we propose to use the attenuation of RSSI by human bodies to realize localization. This is possible because Bluetooth uses microwaves in the 2.4 GHz band that are absorbed by water, including the water in the human body. As our bodies absorb Bluetooth signals, RSSIs decrease, indicating the possible presence of a person or people between two Bluetooth beacons or devices.

There are issues with positioning using Bluetooth, such as the need for people to carry Bluetooth devices. However, we can solve these issues using the attributes of Bluetooth. In this study, we utilize the attenuation of RSSI when there are obstacles between a Bluetooth transmitter and receiver. Bluetooth signals are at the microwave of 2.4 GHz, which is predisposed to be absorbed into water. Therefore, when a person is located between a Bluetooth transmitter and receiver, RSSI is decreased by the human body, because our bodies are almost 60% water. Decrease of RSSI indicates that obstructions exists.

III. DEVICE-FREE MOTION DETECTION METHOD BASED ON BLUETOOTH BEACONS

A. Remote elder care support based on the medicine calendar

Many people on medication use a special calendar that manages their dose schedule (called a medicine calendar) to help them remember the dosage time or amount. Fig. 3 shows an example of a medicine calendar. However, the medicine calendar only works if a person remembers to check it.

In this study, we support dose to monitor either a care receiver exists near the medicine calendar. In particular, we developed a system to check that a medicated people take medicine on the medicine calendar. The system supports right
Our proposed system addresses three important needs. First, it addresses the difficulty of making care receivers always carry positioning devices. It is difficult for dementia patients to develop new habits such as carry devices. Second, it addresses the need for the system to be easy. For example, the system needs to be installed by a non-specialist. Third, the system does not irritate the care receiver, because it does not encroach on his or her life. As noted above, this is a real problem; when care receivers find that added devices encroach on their lives, they may discard or avoid using the devices.

Our proposed system uses Bluetooth beacons on devices that are already in the care receivers’ home (e.g., smartphones and tablets) as motion detectors. The only required installation and maintenance activities are to update the software. Bluetooth beacons are low-energy, inexpensive, and have long battery lives. Further, Bluetooth beacons can be set where care receivers cannot find them.

B. Utilization of a care receiver’s positional information

In this study, when a care receiver remains near the medicine calendar for a few seconds, we assume that the person may take a dose of medicine. Therefore, a structure that obtains positional information (e.g., the presence of the care receiver near the medicine calendar) is necessary. Fig. 4 shows points in the experiment conducted. Because care receivers often take a dose after eating, we located points near the medicine calendar, refrigerator, and kitchen to determine positional information.

C. Approach to using Bluetooth beacons

As noted above, Bluetooth signals can be absorbed by water; they can also be absorbed by glass, although signals penetrate through plastic and other materials. As such, our proposed system requires the removal of water and glass, as they may prevent wireless connection. Fig. 5 shows a proposal technique using the attenuation of RSSI.

As mentioned above, a human body is about 60% water. Therefore, human bodies are a barrier to Bluetooth signals. When a Bluetooth beacon is separated from a Bluetooth receiver because of a person standing between these devices, RSSI decreases. Consequently, we can utilize Bluetooth beacons to determine the attenuation of RSSI and realize localization without carrying devices.

D. Motion Detection based on Bluetooth RSSI Attenuation

Bluetooth devices are set as shown in Fig. 5. If Bluetooth devices are set within 1 m, a receiving device measures about −60dB RSSI from the Bluetooth signal. When a person stands between these devices, the signal is not shielded completely, because Bluetooth signals are omnidirectional.

However, RSSI decreases and the dispersion of RSSI distribution increases. As a result, the system can discriminate a person between Bluetooth devices.

The dispersion of RSSI increases when a person is present. Therefore, there is a possibility for error due to RSSI variation. This may cause the system to determine that a person is present when that is not the case. Thus, we utilized an average value of some samples taken at the last minute. The system measures RSSI at intervals of a second: it is $RSSI(t)$ at the time $t$. We defined $AVG(t, T)$ to average samples for $T$ seconds from time $t$ using equation.
$$AVG(t,T) = \frac{1}{T} \sum_{\Delta t=0}^{T-1} RSSI(t - \Delta t)$$

We observed a change in RSSI when a person came between the Bluetooth devices. We compared the obtained RSSI when a person was present and when a person did not have a threshold value $\theta$. If $AVG(t,T) < \theta$, we determined that a person was present.

IV. REMOTE ELDER SUPPORT SYSTEM

A. Outline

The system intends to identify when a care receiver has missed a dose and send a notice to a caregiver. We used two iPads for the care receiver and one for the caregiver. We developed the system as an application for iOS, because it enabled us to utilize iBeacon. The system estimates that a care receiver missed a dose if the system could not detect the care receiver. If this occurs, the system notifies the caregiver. Table II shows the implementation environment of the system. Although we used iPads in this study, iPhones or other devices may be used in the future; this system is independent of devices.

B. System Architecture and Operational Method

The iOS application detects if a care receiver is present in front of iPad an iPad using the device’s Bluetooth function. Fig. 6 shows the system architecture. The Bluetooth beacon transmits a signal containing a unique ID, and the Bluetooth receiver measures the RSSI of appropriate signal.

As noted previously, RSSI is constant if there are no obstructions between devices. If someone is present between the devices, RSSI will decrease. Therefore, when the measured RSSI falls below a set threshold value, the iPad transmits the unique ID to the server and the system executes processing as per the received ID. For example, it sends a message to the care receiver and caregiver devices. The care receiver’s device starts to record using its camera and transfers these data to the server. The caregiver can view the video data on his or her device in almost real time. To help prevent the care receiver from forgetting or repeating a dose, the system also sends a message to both devices showing the last dose time.

Fig. 7 shows an example of system installation. A Bluetooth beacon is set on the medicine calendar and an iPad is set facing toward the medicine calendar. In this environment, the distance between the Bluetooth beacon and the iPad is about 1 m. The system does not detect a person when he or she only passes in front of the medicine calendar. It detects a person only if he or she remains there for a few seconds.

C. Implementation

1) Detection structure of care receivers using Bluetooth:

We developed a structure that uses the iPad to executes processing as per the RSSI when the Bluetooth receiver obtains a decreased Bluetooth signal from the Bluetooth beacon. The system can utilize positional information using CoreLocation.framework in iOS.

2) Client for care receiver: A client for the care receiver is set at the care receiver’s house and receives the Bluetooth signal from the Bluetooth beacon. When the system detects a care receiver by the detection structure, the client starts to record from the front camera on the iPad. If the data line at the care receiver’s house is slow, the client converts video data into image data and uploads them every second. Because it is not necessary for the care receivers to operate the device, it has the above function only.

3) Client for caregiver: When the client for the care receiver detects his or her presence at the medicine calendar, the client sends an alert and notice to the client for the caregiver through the server. Caregivers can check the state of the care receiver on the video or images. Or, a caregiver can set the time when a care receiver usually doses. If the client for the care receiver does not detect the care receiver at the medicine calendar at that time, the client sends a notice to the caregiver’s device.

The caregiver can also check the care receiver’s dose history, as shown in Fig. 8. If the caregiver selects an item from the list on the left side of the screen, the video opens on the right side. Items on the list are color-coded to reflect conformance with the care receiver’s standard dose time and quantity (e.g., “right dose”, “excess dose” and “missed dose”). If the system detects the care receiver at the medicine calendar more than once around the time of his or her standard dose (as pre-set by the care receiver), one of the doses is coded as an “excess dose.” If the system does not detect the care receiver, it records a “missed dose.”
V. EXPERIMENT

We performed an experiment to measure the attenuation of RSSI by a human body. In particular, we examined the change in RSSI caused by the presence of a human body. A. Experimental Setup

The experimental environment of experiment is shown in Table.III. The experiment was conducted in a meeting room (6 m × 10 m). We used a Bluetooth beacon as the transmitter and a note PC as the receiver. The Bluetooth beacon is the MyBeacon MB004 manufactured by Aplix, and the note PC the MacBook Pro Retina 13 manufactured by Apple. The distance between the devices is 1 m, and there are no obstructions between them. Each device is set at a height of 1 m from the floor. The subjects are six males in their 20s, who are 170–180 cm in height.

B. Calibration

We decided on the value of θ to identify person’s state either existence or non-existence by calibration of RSSI. First, we measured the value of RSSI when no subject was present between the devices (R_N). Next, we measured the value of RSSI when a subject was present between the devices (R_E). Fig. 9 shows the distribution of R_E and R_N. It is the subject’s distribution smoothed by time window of three. The x-axis of the graph shows RSSI; the y-axis shows the frequency probability by RSSI. We averaged the values of RSSI and set θ of −57.7 dB to divide these cases.

C. Experimental result

The detection rate is the percentage of the system’s success in detecting subjects or lack of subjects (i.e., in the case of R_E, the detection rate is the percentage of correct detection that a subject is present, and in the case of R_N, the detection rate is the percentage of correct detection that a subject is not present).

Fig. 10 shows detection rate with T of 1 to 5 s. The x-axis of the graph shows time window T; the y-axis shows the detection rate. The detection rate is more than 90% when T ≥ 3. We consider that human body composition and worn metals worn by a person influence detection rate. Moreover, T of more than 3 s can decrease errors of in the Bluetooth signal. Therefore, the system is discerning subjects with higher accuracy from smoothed RSSI. In this experiment, the system can discern the subject by measuring for 3 s. When a care receiver takes doses, he or she is likely to remain near the medicine calendar for more than 3 s. Therefore, we consider that the method effective for our system.

VI. DISCUSSION

The method does not require care receivers to be equipped with positioning devices. Hiding the Bluetooth beacon from care receivers is easy, because it is very small. Therefore, care receivers do not have to change their lifestyles. As shown in

\[ \text{TABLE III. EXPERIMENTAL ENVIRONMENT.} \]

<table>
<thead>
<tr>
<th>Size of experimental room</th>
<th>6 m × 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>Aplix, MyBeacon MB004</td>
</tr>
<tr>
<td>Receiver</td>
<td>Apple, MacBook Pro Retina 13</td>
</tr>
<tr>
<td>Programming Language</td>
<td>JavaScript</td>
</tr>
</tbody>
</table>

Fig. 7. Example of system installation.

Fig. 8. Interface of caregiver’s device.

Fig. 9. Frequency of RSSI.

Fig. 10. Detection rate with T of 1 to 5 s.
A study on outdoor sensors can detect the presence of a person as \( P_1 \) and the lack of presence as \( P_0 \). When a care receiver repeats a dose, there can be a risk to them if this scene is not recorded and communicated to the caregiver. Thus, it is more important not to miss dose than an excess detection. In this method, we prevent the risk to the care receiver by setting a time window.

The maximum range of the Bluetooth signal is a radius of 100 m. Bluetooth beacons are easily obtained and low in price. A device equipped with the Bluetooth function can receive Bluetooth signals from some Bluetooth beacons. Therefore, the system can be expanded to encompass more of a care receiver’s house by using a number of Bluetooth beacons. In this case, the system determines the care receiver’s behavior from his or her positional information. The system can also detect if the care receiver is in a concerning condition (e.g., not moving) from this positional information.

As a motion detector, the infrared sensor is popular. It is more accurately to detect people than Bluetooth beacon. The infrared does not pass through material objects, and infrared sensors cannot be hidden. The infrared sensor has directivity; in contrast, the Bluetooth signal is omnidirectional. If a number of motion detectors are set, a flexible arrangement is desirable. We selected Bluetooth beacons to expand the DFL method in the future.

Image recognition is also utilized to detect people. The iPad is equipped with a camera that can be applied for image recognition. However, image processing is thermogenic on the iPad. In remote elder care, the system down by thermal runaway is undesired. Bluetooth beacons transmit small data packets containing unique IDs; then, receiving devices process only those transmitted data. Processing those data is simpler than image processing; therefore, the possibility of the system failure is low. Thus, the system is more reliable.

**VII. CONCLUSION**

The aim of this study is to develop a system that decreases the load of caregivers when they monitor care receivers. We developed a new motion detection method based on DFL using Bluetooth. The method utilizes the attenuation of RSSI by a human body to detect a person. The system enables caregivers to monitor the behaviors of care receivers around the location of the care receivers’ medicine calendar to check the timeliness and amounts of doses taken by care receivers.

This system has an advantage over other systems, as neither the caregiver nor care receiver need to install or equip specialized material, remember to carry receivers, or undertake other special actions. However, the system is based on the assumption that care receivers use their medicine calendars.

In this study, we proposed a positional method without positioning devices; instead, we use Bluetooth beacons. Instead of being carried by the care receiver, the Bluetooth beacons are set them near the medicine calendar to detect attenuation of RSSI because of the presence of the care receiver in that location. Although RSSI varies widely by environment, we verified that variation of RSSI can be decreased by setting a time window.

We used two iPads as devices—one for the caregiver and one for the care receiver. The system records a care receiver taking a dose and notifies the caregiver. In this case, the system decides the threshold value for detecting a person based on RSSI averages. Our experiments showed a detection rate of more than 90%.

We expect that the system will decrease the burden of caregivers and care receivers by using Bluetooth beacons. After this, we plan to verify this suggested method and install it at the earlist.

**REFERENCES**


