Evaluation About the Feasibility of an Unconscious Participatory Sensing System with iOS Devices

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Abstract - This paper develops a prototype implementation of our proposed unconscious participatory sensing system and evaluates its performance about a measurement process on a real smartphone device. The proposed system consists of various beacon devices and smartphone devices. It also requests smartphone owners to install a special application on their smartphones to collect measurement information from beacon devices. Each beacon device has Bluetooth low energy (BLE) module to communicate with a smartphone device. Hence, the proposed system can collect measurement information from beacon devices through smartphones. Additionally, beacon devices can work by a battery for a long time because BLE is appropriate for a low power operation. The feature of the proposed scheme is to activate a special smartphone application in a sleep state to upload measurement information. Therefore, it does not require smartphone owners to launch the smartphone application to collect measurement information. We employ the iBeacon function which is the special beacon mechanism for iOS to active the application. In the experimental evaluation, we have developed a beacon device with a Raspberry Pi and a special application for iOS. Since a background operation period of iOS applications is limited due to the power saving mechanism on iOS, we have evaluated the measurement process of the proposed system. From the results, we can find that the developed application for iOS can collect information from beacon devices in a background operation even if the background operation period is limited.

Keywords: Unconscious participatory sensing, iBeacon, BLE, Smartphone device, Beacon device.

1 INTRODUCTION

Sensor networks have received considerable attention to collect various information [1]. Participation sensing systems, where general participants collect information, have been proposed to realize more flexible sensing systems [2]–[4]. Conventional participatory sensing systems usually request general participants to join their sensing network system as a volunteer to collect information flexibly. In sensing process, the system requests some participants to measure information and to report the measured information to the system [5]. Therefore, participating in the form of volunteering is a key point to realize a practical sensing system. The types of measurement information collected in participatory sensing systems are classified as abstract information, which is evaluated by the participants [6]–[8], and quantitative information, which is measured by sensors [9]–[11]. Since measurements of abstract information are difficult to acquire by sensors, participants should join the sensing process voluntarily to realize effective participatory sensing systems. Hence, various studies have investigated techniques that incentivizes participants to join the sensing process [12], [13]. Additionally, some researchers have attempted to realize a hybrid sensing of participatory sensing and social media [14].

Participatory sensing systems for quantitative information also require participants' interaction behavior, such as checking measurement requests, moving to a measurement location, launching the application, and reporting measurement information. Therefore, participants in conventional systems should operate a measurement application to obtain target information even if the target information may be automatically measured by sensors. For the above reasons, conventional participatory sensing systems currently attract early adopters who are interested in the new service.

Some studies employ smartphones as a communication device and special measurement devices to achieve accurate measurement by the same type of sensors and under the same implementation conditions [15]. The accuracy of measurement information given by acceleration sensors, magnetism sensors, etc. is generally stable, even if the actual specification of sensors is different, because the accuracy depends on a specification of sensors and does not depend on the implementation conditions. Hence, acceleration sensors and magnetism sensors are usually used to realize an indoor pedestrian navigation [16]. However, the accuracy of measurement information given by temperature sensors, illumination sensors, etc. is expected to vary according to the precision of the sensor and implementation environment because different smartphones have different types of sensors, and the implementation condition of the sensors is also different. Therefore, different smartphones obtain a different measurement value even when they try to measure a same environment. As a result, the built-in sensors in smartphones are not sufficient to acquire accurate measurement information in real situations.

We have considered how to carry out a sensing process without participants' interaction [17]. The proposed system consists of beacon devices and a special smartphone application. We assume that beacon devices are installed at a specific place because our target service is an environmental measurement at a fixed place. Since a background processing period of an application on iOS is limited within 10 seconds, the special smartphone application for the measurement is usually suspended by iOS. Therefore, we employ iBeacon [18] function to trigger the special smartphone application in the suspended status to activate a background processing. As a result, the proposed system can realize that the special smartphone application can collect measurement information from beacon devices automatically.

In the experimental evaluation, we have developed a prototype beacon device with a Raspberry Pi which is an ARM-based microcomputer board and a special application for iOS. Since the developed application is usually suspended by iOS, the power consumption of the application is limited. Additionally, iOS permits a background processing of applications within 10 seconds. Therefore, we have evaluated that the proposed information collection process can complete within 10 seconds. The evaluation results show that the information collection process can complete within 5 seconds with a real iOS-based hardware.

2 THE PROPOSED UNCONSCIOUS PARTICIPATORY SENSING SYSTEM

2.1 Overview of Unconscious Participatory Sensing System

Figure 1 shows an overview of the unconscious participatory sensing system. The system consists of the beacon device with sensors, the scanning application on a smartphone, and management servers. We employ Bluetooth Low Energy (BLE) as a communication device because power consumption of BLE is quite low and almost all smartphones implement a BLE module[19]. Since the proposed unconscious participatory sensing system requires an automatic operation mechanism of the scanning application, we use iBeacon on BLE communication to activate the scanning application by the beacon device. The benefits of the proposed system are followings.

- Accurate measurement
  The proposed system uses sensors on a beacon device. Therefore, the measurement is performed by the same sensors even if different smartphones collect sensed data. As a result, the system can collect accurate information that does not depend on specifications of smartphones.

- Continuous measurement
  The proposed system can install a beacon device at a specific location. Therefore, the system can easily measure an environment at the specific location continuously.

- Unconscious participants' interaction
  Beacon devices in the proposed system can activate the scanning application through the iBeacon function. Therefore, the system does not require participants' interaction to collect information.

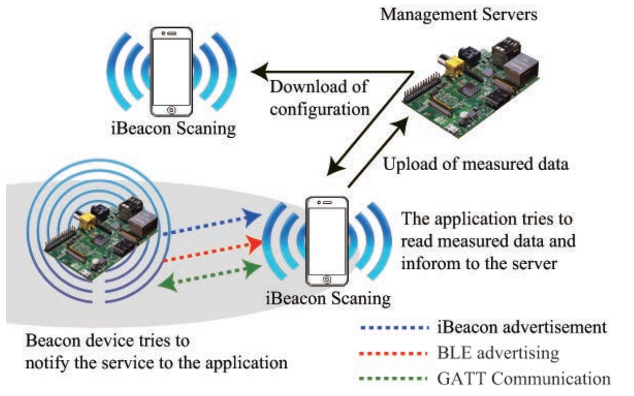

Figure 1: Unconsciousness participation sensing system.

- Usage of participants' cellular network
  Each beacon device uses participants' cellular network to upload sensed information to management servers. Therefore, beacon devices implement only a short-range communication module (BLE).

- Privacy oriented
  The proposed system does not have any privacy information such as participants' positions, status, etc. because the system uses a beacon device to activate the scanning application.

2.2 Structure of Unconscious Participatory Sensing System

The proposed system consists of the management server for the management of beacon devices and measurement information, the scanning application in the smartphone OS to search for beacon devices and to acquire measurement information with built-in sensors, and detectable beacon devices for beacon announcements and measurements with sensors. These components have the following functions.

- Beacon device
  A beacon device has a sensor and a BLE module. The main functions of the beacon devices are to trigger a scanning application installed on neighboring smartphones using the iBeacon function, and to allow the application to detect the beacon devices themselves. The application assesses the legitimacy of the beacon device by evaluating the hash value after it has detected the beacon device, and starts dedicated operations according to the beacon device's configuration. The proposed system uses built-in sensors in the smartphone or sensors in the beacon devices because measurement information may be affected by differences in implementation conditions or sensor specifications. Therefore, the application transfers measurement information from a beacon device using BLE when the system uses sensors on the beacon device. The beacon device performs measurements depending on predefined rules. For example, it starts the iBeacon function to trigger a neigh-

borhood smartphone device after performing continuous measurement operations.

- Scanning application
  The functions of the scanning application can be roughly classified into searching for a beacon device, acquiring measurement information from the beacon device, taking measurements, and sending measurement information to the management server. The scanning application generally should not search a beacon device not to consume a battery energy. Additionally, iOS does not permit the background processing of applications more than 10 seconds. Therefore, the proposed system employs the iBeacon function to trigger the background processing of the suspend scanning application.

- Management server
  The functions of the management server are information management for each beacon device and storing of measurement information. Since iBeacon uses a UUID, major value, and minor value to identify each beacon device, the management server should handle these parameters for beacon devices and should determine suitable measurement rules of each beacon device. Additionally, the server should store measurement information from the scanning application.

2.3 Signaling Process of Unconscious Participatory Sensing System

Figure 2 shows the detail signaling process of the proposed unconscious participatory sensing system. We have classified into each subprocess: the beacon detection period, the scanning period, the recognition period, the initialization period, the data obtaining period, and the acknowledgement period.

A Beacon detection period: iBeacon packets are periodically transmitted from the beacon device. The period starts when the smartphone enters in the detectable area of iBeacon packets and ends when iOS detects an iBeacon packet.

B Scanning period: the scanning application should scan a BLE advertisement packet. The period stats when the scanning application is activated by iOS and ends when the scanning process of BLE services is completed.

C Recognition period: the scanning application should recognize a proposed service by checking parameters. The period starts when the application received the SCA_RES packet and ends when it transmits CONNECT_REQ packet.

D Initialization period: the scanning application should initialize data communication service of BLE before obtaining information. The period starts when the scanning application starts an initialization process of BLE and ends when an authentification is completed.

E Data obtaining period: the scanning application should obtain information by BLE communication. The period

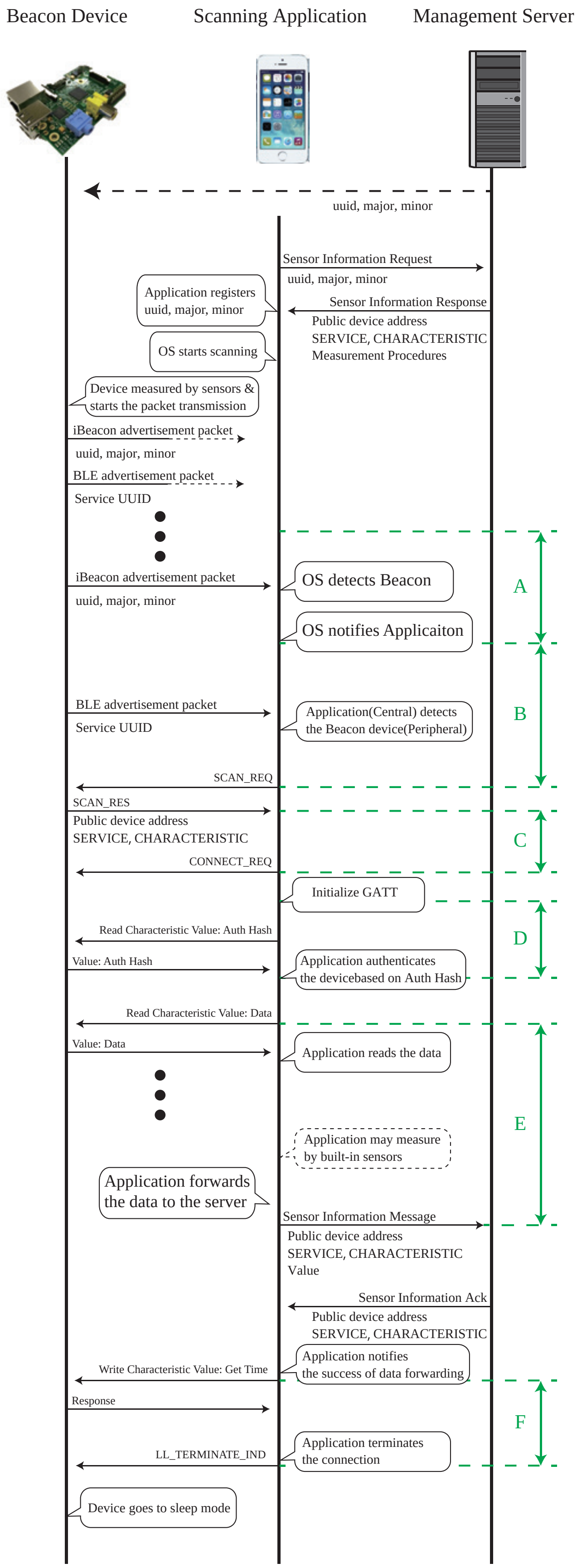

Figure 2: Proposed signaling process.

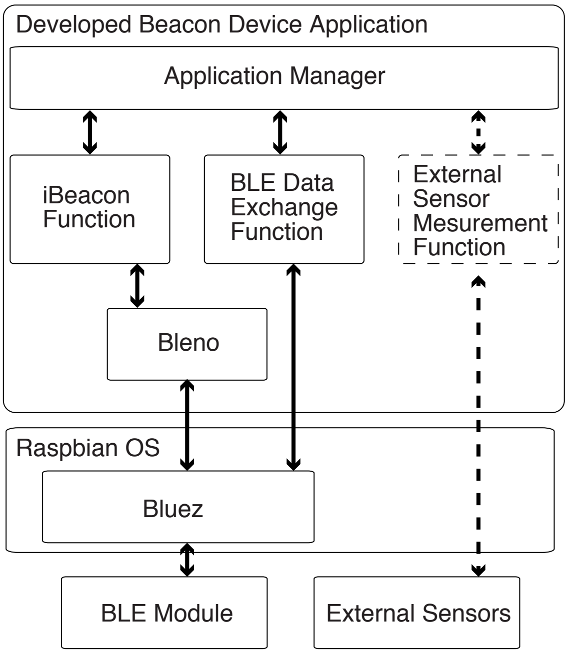

Figure 3: Implementation model of a beacon device.

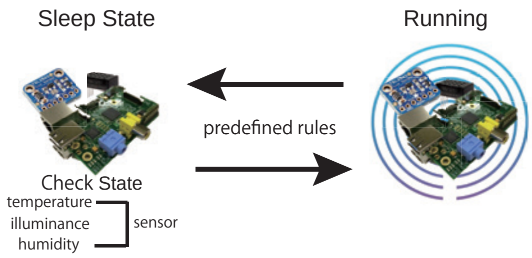

Figure 4: Operation example.

starts when the scanning application starts data communication and ends when the whole information is transferred.

F Acknowledgement period: The beacon device requires an acknowledgement for management of local information. The period starts when the scanning application starts to write an acknowledgement information and ends when it disconnects data communication of BLE.

3 IMPLEMENTATION OF UNCONSCIOUS PARTICIPATORY SENSING SYSTEM

3.1 Beacon Device

We have implemented a beacon device for the proposed method using Raspberry Pi that is an ARM-based microcomputer board. Figure 3 shows the implementation model of the beacon device. The developed application is classified into the application manager, the BLE function and the measurement function with external sensors. The BLE function provides the iBeacon function and the BLE communication function. We have employed Raspbian OS as an operation system, Bluez [20] library for the BLE function, and Bleno [21] library for iBeacon function. As an example sensor, we use a temperature sensor (ADT7410). The prototype beacon device has two operational states: sleep state and running state in Fig. 4 even if Raspberry Pi does not have a power saving mechanism because practical beacon devices should operate by a battery In our future development, we have a schedule to employ special System-on-a-Chip (SoC) modules for BLE to implement a beacon device operating by a battery.

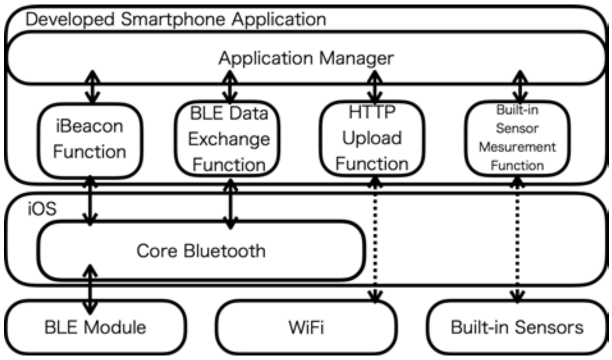

Figure 5: Implementation model of scanning application.

3.2 Scanning Application

Devices for the scanning application should implement BLE module because the proposed system utilizes BLE communication mechanisms. Therefore, we employ iPod touch (fifth generation, version 8.4.1) as a smartphone device. Figure 5 shows the implementation model of the scanning application. The developed application consists of the application manager, the iBeacon function, the BLE data exchange function, the uploading function by hypertext transfer protocol (HTTP) and the measurement function by built-in sensors. Since iOS provides core Bluetooth library, we use it to develop the iBeacon and the BLE data exchange functions. iOS usually suspend applications in background processing. Therefore, the developed application is also suspended by iOS to reduce power consumption. On the contrary, the iBeacon function can activate applications to realize background processing for a limited period around 10 seconds. The developed application also employs the iBeacon function to realize background processing. As a result, we have confirmed that the developed application can work in background processing when iOS detects a designated iBeacon message.

We can develop a similar scanning application for Android OS because Android OS can also receive iBeacon message and permits applications to work in background processing. Additionally, the proposed mechanism can port to Eddystone mechanisms that is the special beacon function proposed by Google [22].

3.3 Management Server

The management server manages identifier information and operational settings for each beacon device. Additionally,

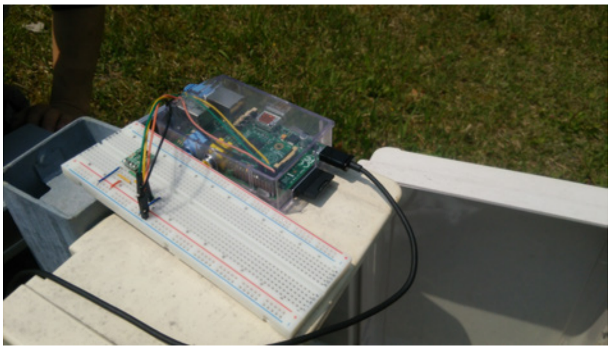

Figure 6: Overview of beacon device.

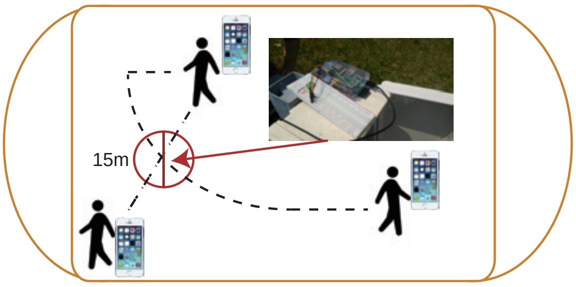

Figure 7: Experiment environment.

it also stores upload measurement information from beacon devices. Since recent smartphone OSs prepare useful APIs for HTTP communication, we employ HTTP to communicate between the management server and the scanning application. As a data format, we use JavaScript Object Notation (JSON). We employ Apache [23] HTTP server and MySQL [24] database server to develop the management server function. We use Raspberry Pi as a prototype hardware due to a portability issue for experimentation.

4 EXPERIMENTS AND EVALUATION

4.1 Objective and Evaluation Points

We have measured the processing period of each task in the proposed unconscious participatory sensing. Due to the limitation of iOS platform, the proposed process should be completed within about 10 seconds. Therefore, we should evaluate that the total process can be completed within the limitation period in iOS platform. We have conducted the experiment in an athletic ground of our university where we can guarantee a Line-of-Sight communication between a beacon device and a smartphone. We have developed a beacon device with a Raspberry Pi and a BLE dongle and a scanning application for an iPod touch device. The scanning information is stored in a database on a laptop PC. Figure 6 shows the overview of the beacon device that was set on the ground. The beacon device implements a temperature sensor and measures an environment at a fixed point. The identification area of iBeacon is about 15 meter according to the advance verification. Therefore, the smartphone moves from 20 meter away

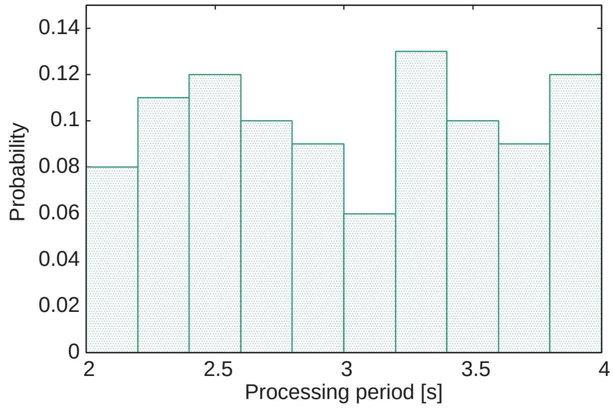

Figure 8: A: Beacon detection period.

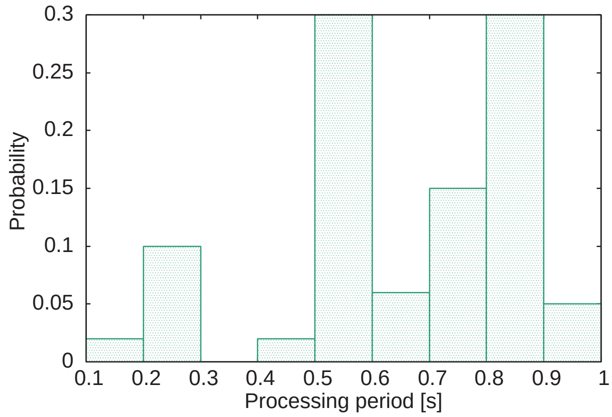

Figure 9: B: Scanning period.

from the beacon device to 15 meter that is the detectable distance of iBeacon. The number of experimental trials is 100 times. Figure 7 shows that experimental environment.

4.2 Experimental Results

A Beacon detection period
Figure 8 shows the probability density of the beacon detection period. The X-axis is the processing period in the second and the Y-axis is the occurence probability of each period. The numerical result shows that iOS requires a few seconds to detect an iBeacon advertisement packet from the device. The main reason of the period is an interval period of an advertisement packet and uncertainness of a transmission range of the packet. Maximum transmission range of typical hardware for BLE is about 100 meter. Therefore, the scanning application has enough period to communicate with the beacon device even if the maximum period is required to detect a packet. Additionally, iOS application can process in a background for around 10 seconds since it detects a packet. Therefore, the beacon detection period is not a critical issue when we assume sufficient transmission ranges.

B Scanning period

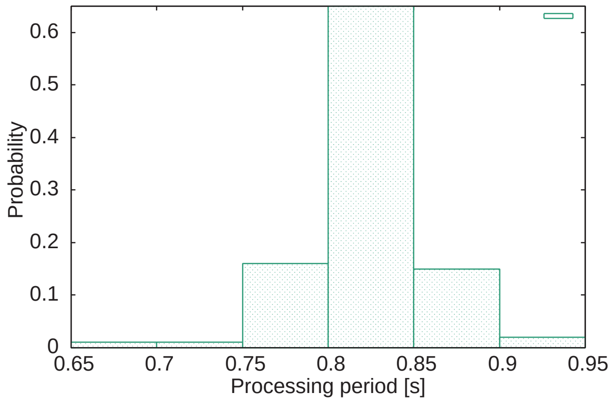

Figure 10: C: Recognition period.

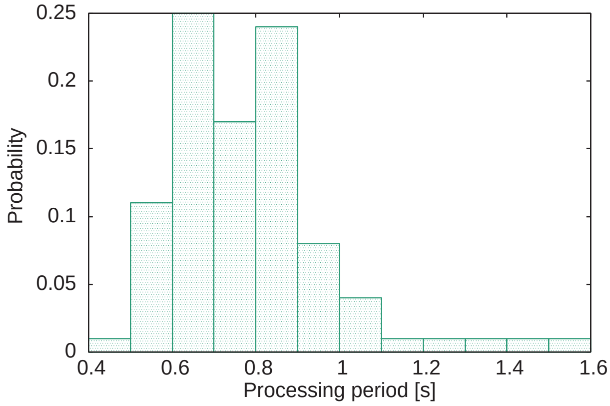

Figure 11: D: Initialization period.

Figure 9 shows the probability density of the scanning period of a BLE advertisement packet. The result shows that the scanning process is completed within 1 second. The scanning period depends on a processing time of an advertisement packet and a transmission timing of a BLE advertisement packet. In the experimental trial, we set 100 milliseconds intervals between iBeacon packet and a BLE advertisement packet.

C Recognition period
Figure 10 shows the probability density of the recognition period of the beacon device. The result shows that the recognition period is completed within 1 second. The recognition period depends on a processing time of a beacon device for a connection setup. From the result, we can find that the developed application can start BLE communication with an adequate background processing period.

D Initialization period
Figure 11 shows the probability density of the initialization period of GATT communication. The result shows that the initialization period is completed within 1.6 seconds. The initialization period depends on a processing time of a beacon device for GATT communication and BLE communication for an authentification.

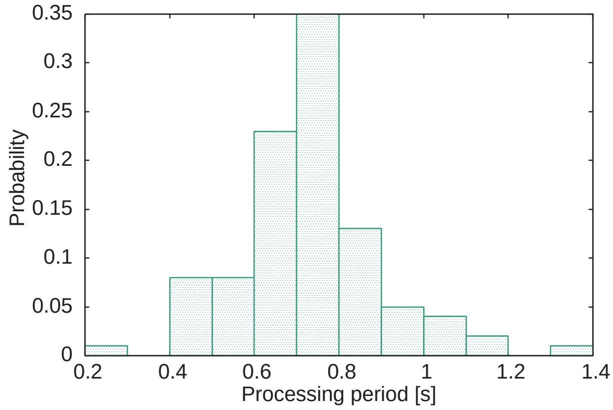

Figure 12: E: Data obtaining period.

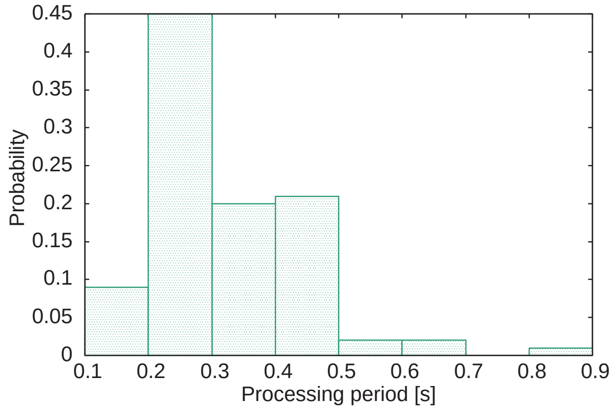

Figure 13: F: Acknowledgement period.

E Data obtaining period
Figure 12 shows the probability density of the data obtaining period. The period includes the data obtaining period from the beacon device and the uploading period to the management server. Therefore, it depends on a processing time of a beacon device for BLE communication and a network delay between a management server and a smartphone. The result shows that the data obtaining period is completed within 1.3 seconds. In practical cases, we should consider longer network delay to the management server. However, we have sufficient period to complete the whole process within 10 seconds. As a consequence, the proposed signaling can work when we consider the number of obtained data carefully.

F Acknowledgement period
Figure 13 shows the probability density of the acknowledgement period. The period depends on a processing time of a beacon device for BLE communication. The result shows that the acknowledgement period is completed within 1 second.

Figure 14 shows the total period of the proposed processing. The result shows that the proposed processing can be completed within about 5 seconds. The maximum processing

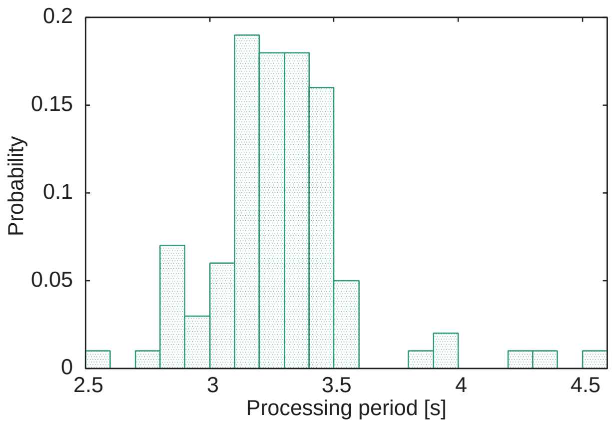

Figure 14: Total processing time.

period of iOS is about 10 seconds. Therefore, the proposed processing can be performed on practical smartphone devices since typical network delay is less than 1 second.

5 ELECTRICITY CONSUMPTION EXPERIMENT IN THE SMARTPHONE APPLICATION

5.1 Objective and Evaluation Points

The benefit of the proposed participatory sensing is that the scanning application can sense an environment and upload sensing data in a background processing. A main reson of power consumption in typical smartphones is a communication module and display. Therefore, we have measured the operation period of a smartphone in both a background processing and a foreground processing. We have developed a special application to perform periodical uploading to a management server. The interval of the uploading is once a second. We have measured the processing period of each task in the proposed unconscious participatory sensing.

5.2 Experimental Results

Figure 15 shows the power consumption of the smartphone device with the foreground processing. The X-axis is the operation period and the Y-axis is the residual battery percentage. The result shows that the smartphone device can work for three hours and 47 minutes.

Figure 16 shows the power consumption of the smartphone device with the background processing. Both X-axis and Y-axis are the same in Fig. 15. The result shows that the smartphone device can work for 15 hours and 27 minutes. The difference between the background processing and the foreground processing is the display use. Therefore, the proposed participatory sensing has a benefit in power consumption comparing to conventional participatory sensing systems.

6 APPLICATION EXAMPLES

The proposed system can apply for various kinds of sensing applications. The following is the example use cases.

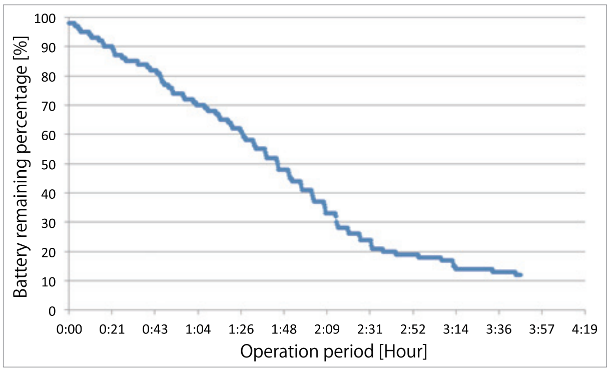

Figure 15: Residual battery (Foreground).

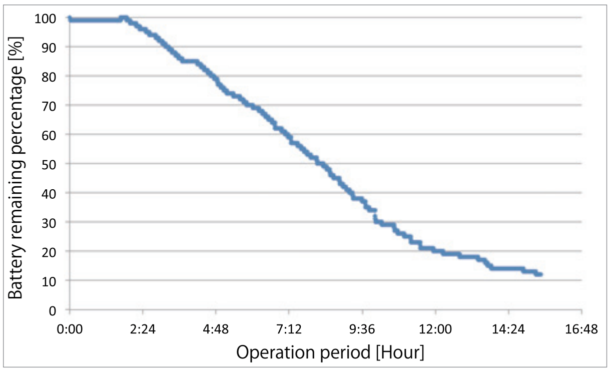

Figure 16: Residual battery (Background).

- Warning system for heatstroke
  The number of people hospitalized suffering heat-related ailments, including heatstroke, is increasing according to global warming. Temperature and humidity are useful information to warn a possibility of heatstroke. The proposed system can realize the warning system for heatstroke by preparing a beacon device with temperature and humidity sensors and an application for smartphones. The beacon device can calculate the waning index by measuring environments periodically, and activate the application on smartphones around the beacon device to inform the risk of heatstroke at the location.

- Personalized environmental control
  Personalized environmental control in facilities is useful technology to improve human productivity. The proposed system can prepare a lot of beacon devices with sensors. Each beacon device can measure accurate environment condition by sensors and inform a facility control application on user's smartphone. Therefore, the application on user's smartphone can recognize the environment condition and control the facility around the users according to predefined rules.

- Crowd sensing
  Human movements in public facilities are useful information to estimate the environmental condition. On the contrary, capturing each human movement is difficult for general sensors. The proposed system can acti-

vate an application on a smartphone to measure human movement by built-in sensors. According to the collected human movement information, the system can estimate crowd condition around a beacon device.

7 CONCLUSION

This paper has developed a prototype implementation of the proposed unconscious participatory sensing system, and has assessed the practicality of the proposed system with the prototype implementation. The prototype implementation uses a Raspberry Pi board and iOS-based hardware. Therefore, we have developed the special beacon application on the Linux OS and the special scanning application on iOS. Due to the limitation of iOS, the scanning application can work in background within 10 seconds. The evaluation results show that the maximum processing period of the total procedures is about 5 seconds. As a result, we have found that the proposed procedures can work well in practical hardwares. Additionally, the proposed mechanism can be port to any beacon mechanism on different OS such as Android OS. Therefore, we believe that it can be a fundamental mechanism to realize unconscious participatory sensing system with the BLE communication.

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