Indoor/outdoor determination method using various sensors for the power saving of terminals in Geo-fencing

Yoshitaka Nakamura†, Mifumi Ono†, Masashi Sekiya†, Kazuaki Honda‡, and Osamu Takahashi†

†School of Systems Information Science, Future University Hakodate, Japan
‡IDY Corporation, Japan

Abstract - Recently, various services using the location information are developed with the wide spread of smartphones. Geo-fencing is one of the services. In Geo-fencing services, terminals automatically carry out the some processing associated with the virtual border when they detect that themselves passes the border. However, it is a problem that power saving of Geo-fencing service covering over indoors and outdoors with high accuracy. In this paper, we propose indoor/outdoor estimation method using various types of sensors with small power consumption. The results of the evaluation experiment show that the proposed method can estimate the movement in indoor and outdoor with 82.14% accuracy, and this method is an effective means for indoor and outdoor Geo-fencing service.

Keywords: Indoor/outdoor estimation, Magnetism sensor, Illumination sensor, Temperature sensor, Geo-fencing, M2M

1 INTRODUCTION

By the wide spread of smart devices with GPS (Global Positioning System), the acquisition of the positional information become easier. Therefore the demand for location-based services which provide appropriate service depending on the position of the user increases. Geo-fencing technology[1] is one of the M2M (Machine-to-Machine) type services and attracts attention recently.

Geo-fencing technology sets the virtual border on a map. This technology detects the positional relations between this border and target terminal, and let the terminal perform predetermined processes automatically according to the relations. Location-based service can be easily provided for terminals by using Geo-fencing technology. There are some type of services using Geo-fencing technology such as “Gotouchi information”[2], “Arrived”[3], O2O (Online to Offline) services that let the information of the neighboring store link the positional information of users, and position monitoring services. The monitoring system in prisons and nursing homes are example of position monitoring services using Geo-fencing. It is necessary to manage the target person surely in such facilities, but it is undesirable to restrict the target indoors from a humanitarian point of view. The use of Geo-fencing is considered as a solution for these problems. The monitoring system sets the movement allowable range of the target person outside of facilities as a virtual border on the map.

To realize the service using Geo-fencing technology, it is necessary to acquire positional information with high accuracy, because it is necessary to determine inside/outside of Geo-fence accurately. Most of services using Geo-fencing technology outdoors acquire the positional information of the user terminal from GPS and determine inside and outside of Geo-fence using this information. In addition, there is another the positional information acquisition method using HexRinger[4] using the radio field strength (Received Signal Strength Indicator, RSSI) from base stations. As for the indoor position estimation method, there are techniques to estimate using wireless communication technologies[5], [6], a technique using positional information and RSSI of the wireless LAN base station[7], and techniques using the Fingerprint method[8], [9] . About the use of Geo-fencing service only outdoors or only indoors, acquisition technology of positional information mentioned above can be used depending on use position. However, if a Geo-fence passing over indoor and outdoor exists, it is necessary to use acquisition technologies of positional information indoor and outdoor together.

At the time of using Geo-fencing technology, the point where it is necessary for user terminals to keep acquiring own positional information becomes the big problem. Generally, Geofencing technology which turns on GPS function always has large power consumption of the terminal. The state that always activated GPS function consumes power of approximately 120 times in comparison with a standby state[10]. Because the battery capacity of the user terminal is not so large at this time, the problem of this power consumption shortens the available time of Geo-fencing service. Reference[11] tries to reduce power consumption of terminals at the time of the acquisition of the positional information by combining movement detection function, switching function of positioning means, and positioning function with variable interval together. However, an effect of the power reduction becomes small by Geo-fencing service including indoor situation because this method assumes only the outdoor positioning. On the other hand, Ref.[12] reduces power consumption by detecting the situation that GPS positioning is impossible including the indoor from temperature information, and turning off GPS function. For reduction of useless power, it is necessary to switch GPS function and indoor position estimation method when indoor Geo-fencing is assumed. However, there is the situation that effective power reduction is difficult, because the temperature information depends on seasons and weathers and indoor/outdoor estimation with high accuracy is difficult. In this paper, we examine method to improve the power consumption of Geo-fencing service by realizing indoor/outdoor estimation with high accuracy using the intensity of illumination and the quantity of magnetism in addition to temperature information.

2 RELATED WORK

2.1 Power saving method using restraint of GPS positioning

Many existing restraint methods of the large power consumption of GPS positioning use three following functions such as movement detection function, switching function of positioning means, and positioning function with variable interval. The movement detection function is used to control sensing and positioning frequency when a user terminal stands still. When a terminal can determine that the user of the terminal is in a stationary state from positional information acquired from GPS, the terminal stops GPS, starts an acceleration sensor and watch the state of the terminal. When a terminal starts to move and acceleration data are measured, the terminal stops the acceleration sensor and start GPS. Because the user repeats a stationary state and a movement state, this method can control the positioning in a stationary state, and enable effective power saving. However, the movement detection function by the acceleration cannot control power consumption in the state that a terminal continues moving. Therefore Ref. [13] expands the movement detection function by adding a function to change the movement detection timing with the acceleration sensor according to the distance to the virtual border. By this function, GPS is kept in a sleep state for a long time.

The switching function of positioning means is used to switch to the positioning means with smaller power consumption depending on environment. Reference [1], [14] consider a positioning error standard of each positioning means and the distance from the terminal to the virtual border using GPS positioning and radio base station positioning. When the distance to the virtual border is longer enough than the positioning error standard, power saving realizes by stopping GPS positioning with large power consumption, and switching the positioning means to the base station positioning with smaller power consumption. By the space variableness positioning function calculating a virtual border and the distance of the terminal to reduce the positioning number of times, and calculating the distance and the arrival time from expected approach speed to the imagination border, and adjusting a positioning interval.

The positioning function with variable interval reduces the positioning number of times, by calculating the distance between the virtual border and the terminal, and calculating the arrival time from the distance and the expected approach speed to the virtual border., and adjusting the positioning interval[15], [16]. When this function is used, a prediction of the approach speed becomes the problem.

Reference [11] proposes the reduction method of power consumption of terminals in Geo-fencing services by combining these movement detection function, switching function of positioning means, and positioning function with variable interval.

2.2 Power saving method using movement timing of indoors/outdoors

GPS greatly consumes electric power at the time of the detection of the GPS satellite. Therefore, it will use too much useless electricity to keep GPS on in the place where GPS positioning is difficult such as indoor place. Reference[17] aims at the reduction of the consumption electricity by stopping GPS positioning on the place where GPS positioning is difficult, and restarting GPS positioning on movement to the place where GPS positioning is possible (i.e., outdoors). When a terminal moves from indoors to outdoors or from outdoors to indoors, the temperature around the terminal is more likely to greatly change. Reference [17] proposes the estimation method of movement timing between outdoor and indoor using temperature information. This method periodically records the ambient temperature of the terminal using a temperature sensor. And this method estimates the timing that it is moving from indoors to outdoors or from outdoors to indoors when the temperature greatly changed.

Reference [18] investigates the average indoor temperature of each season in Tokyo of 2010. Table 1 shows the comparison result between the average indoor temperature of Ref.[18] and the average outdoor temperature observed by Japan Meteorological Agency in 2010. According to this result, there is difference of temperature above a certain level between outdoor and indoor in the season except the summer, and the movement estimation to indoor or outdoor by the temperature seems to be possible. However, the accurate movement estimation to indoor or outdoor is difficult only by temperature, because there is little difference of temperature between indoor and outdoor in the summer and it is thought that the difference becomes smaller by the structure of the building. In addition, when the terminal is assumed to be carried by a user, the influence that the heating element except the atmosphere such as the user's body or terminal itself gives to the temperature sensor grows large. Therefore, it is necessary to improve the precision of the estimation of movement timing between outdoor and indoor by using the information except the temperature for the effective reduction of power consumption.

Table 1: The indoor and outdoor temperature difference in Tokyo of 2010

Seasons	Avg. Indoor temp.(°C)	Avg. Outdoor temp.(°C)	Temp. diff.(°C)
Spring	20.2	13.5	6.7
Summer	28.0	27.1	0.9
Fall	24.7	19.2	5.5
Winter	17.6	7.8	9.8

3 PROPOSED METHOD

The existing methods cannot estimate indoor/outdoor with high accuracy. We aim at the improvement of the precision of the indoor/outdoor estimation by using physical quantities except the temperature to the determination.

3.1 Approach

At first, we examine the indoor/outdoor estimation method using the general sensor device except the temperature sensor to achieve our research purpose.

Intensity of illumination The intensity of illumination has the large difference of values between indoor and outdoor in the daytime and also at night. In the daytime, the outdoor illumination is about 10000 - 80000 lux. In contrast, the indoor illumination is about 300 - 800 lux, and there is a difference of about 100 times. In the nighttime, the outdoor streetlight is about 1 - 5 lux, and the brightness of the full moon is about 0.01 - 0.1 lux. The illumination of the general indoor fluorescent lamp is about 300 - 800 lux. From this, it is thought that the illumination is effective for the indoor/outdoor estimation both in the daytime and the nighttime.

Quantity of magnetism The quantity of magnetism is easy to use for the estimation, because there is a large change in the quantity of magnetism indoors. Though the previous setting including the measurement in the building is necessary to use magnetism for indoor positioning estimation, only the observation of the change in the quantity of magnetism is necessary for the indoor/outdoor estimation.

GPS signal We can guess that there is more likely to be the terminal indoors, if the terminal is in a condition not to be able to acquire correct positional information using GPS. In this case, the noise of the GPS is calculated from the signal to noise ratio (S/N ratio, SNR). We can find the quantity of noise from the SNR of the GPS satellite which communicated. The indoor/outdoor estimation is possible using this quantity of noise.

The standard power consumption of sensors measuring these physical quantities is Table 2. According to the table, the power consumption of each sensor of physical quantity is much smaller than the GPS module.

Table 2: Power consumption of each sensor

	Consumption current
GPS module	50 mA
Magnetism sensor	100 μA
Illumination sensor	80 μA
Temperature sensor	6 μA

3.2 Indoor/outdoor estimation method

We propose the indoor/outdoor estimation method using intensity of illumination, quantity of magnetism, GPS Signal, and temperature conventionally used.

3.2.1 State transition

This method has 3 states, estimating state, indoor state, and outdoor state. Figure 1 is the illustration of the state transition diagram of the proposed method. In the outdoor state, Geofencing service uses GPS like existing method. If SNR of all GPS signals are more than 20dB and GPS module of the terminal can communicate with more than 3 satellites, it is judged that positioning is possible and the state remains in the outdoors state. Otherwise, it is judged that positioning is impossible and the state transits to the estimating state.

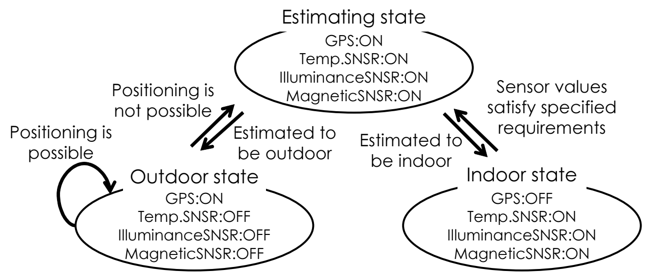

Figure 1: State transition diagram

In the indoor state, GPS positioning is stopped because GPS is not available. Afterwards, if there is some available indoor positioning techniques, GPS positioning is switched to the technique. If some change is seen in one value among the acquired values by sensors (temperature, illumination, and magnetism) in the indoor state, this method causes a transition from the indoor state to the estimating state. It is a condition to estimate to be movement out of the indoor as follows. If each sensor satisfies the following conditions, it is considered that the terminal moved from indoor to outdoor.

1. Intensity of illumination
   The illumination sensor of the terminal measures the intensity of illumination every 1 second and calculate the standard deviation of the illumination every 10 seconds in the daytime. If the illumination sensor sense a change in the variance values more than 35, the state transits to the estimating state. In the night, if there is a change more than 50 lux of the acquired illumination value, the state transits from indoor state to the estimating state.

2. Temperature
   The temperature sensor of the terminal measures temperature every one second. If the temperature sensor sense a change in 1 °C within 30 seconds

3. Quantity of magnetism
   The magnetism sensor of the terminal measures the quantity of magnetism every 1 second and calculate the variance of the magnetism every 10 seconds. If the magnetism sensor sense a change in the variance values more than 18, the state transits to the estimating state.

The condition to transit from outdoor state or indoor state to an estimated state has described. The transition from an estimated state to outdoor state or indoor state is carried out using the following estimation method.

3.2.2 Estimation of indoor or outdoor

It is necessary to estimate whether the terminal is outdoor or indoor in the estimating state. The indoor/outdoor estimations by 3 physical quantities mentioned above are carried out in parallel. In addition, the estimation reliability is calculated in each estimation. If each estimated result is different, the estimated result with highest reliability is adopted.

Estimation by illumination Figure 2 shows the flowchart of the indoor/outdoor estimation using intensity of illumination. Outdoor illumination becomes higher than indoor in the day time and indoor illumination becomes higher than outdoor in the night. In the night outdoors, illumination is almost 0 lux. Therefore, it is necessary to switch the estimation techniques according to the time (night or daytime). The local sunrise time and sunset time are calculated from latitude, longitude, the date, and time. Based on sunrise time and sunset time, it is decided whether it is the daytime or night. The outdoor illumination greatly changes from 10000 lux to 80000 lux (measurement limit) under the influence of the shadow of the buildings, the direction of the terminal, and clouds. In most cases, there is a large difference between the outdoor illumination and the indoor illumination. However, the estimation using the absolute values of the illumination is difficult because the illumination value of about 10000 lux may be acquired depending on time, place, and conditions even if it is indoor. On the other hand, the indoor illumination only changes from 0 lux to 10000 lux, so the variances of the illumination have a large difference between outdoor and indoor. The standard deviation of the illumination is calculated every 10 seconds in the daytime. Therefore if the standard deviation of the illumination is more than or equal to 35, it is estimated that it is outdoor and if the variance is less than 35, it is estimated that it is indoor.

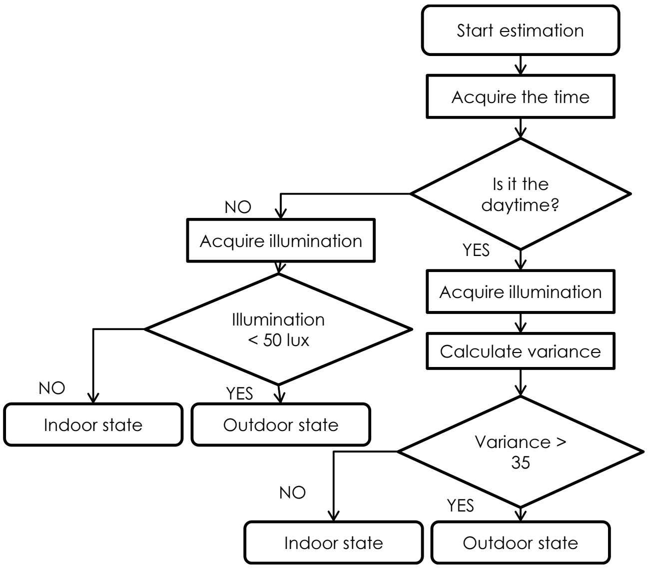

Figure 2: Flowchart of estimation by illumination

We assume 50 lux as the threshold and estimate it by night. It is estimated that it is indoor if the illumination value is more than the threshold, and estimated that it is outdoor if the illumination value is less than the threshold.

The estimation by illumination has high reliability around noon, and low reliability around sunrise and sunset. Therefore we assume the number that the difference between the measurement time and the sunset (or sunrise) time divided by 24 as the illumination reliability. For example, if the measurement date and time are January 24th, 20:00, the illumination reliability becomes $(20 - 16)/24 = 0.1666\cdots$.

Estimation by magnetism Figure 3 shows the flowchart of the indoor/outdoor estimation using a quantity of magnetism. The variance of magnetism greatly changes indoors. In this method, the variance of magnetism is calculated every 10 seconds. If the variance of magnetism is less than the threshold, it is estimated to be outdoor. And if more than or equal to the threshold, it is estimated to be indoor. The threshold of the variance is set to 18 based on Ref. [19].

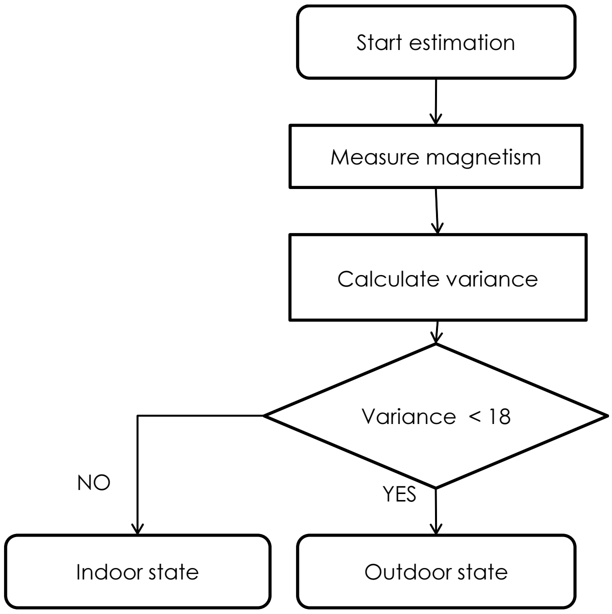

Figure 3: Flowchart of estimation by magnetism

The estimation by magnetism cannot provide accurate result if the terminal is covered in a bag or a pocket. Therefore the covered situation of the terminal is estimated by a proximity sensor, and the value of the proximity sensor at that time is set as the magnetic reliability. Because the proximity sensor acquires 0 if the terminal is covered, the magnetic reliability becomes 0. If the proximity sensor acquires the value except 0 , the magnetic reliability becomes 1.

Estimation by temperature Figure 4 shows the flowchart of the indoor/outdoor estimation using temperature. The relation between outdoor temperature and indoor temperature changes by seasons. Therefore we divided one year into summer from April to September when the indoor is cooler than outdoor, and winter from October to March when outdoor is colder than indoor. Afterwards, this method detects whether the inclination of the temperature change is rise or drop.

The reliability of the estimation by the temperature is high if the season approach to midsummer and the depth of winter. Therefore we assume the number that the difference between the measurement month and the April (or September) divided

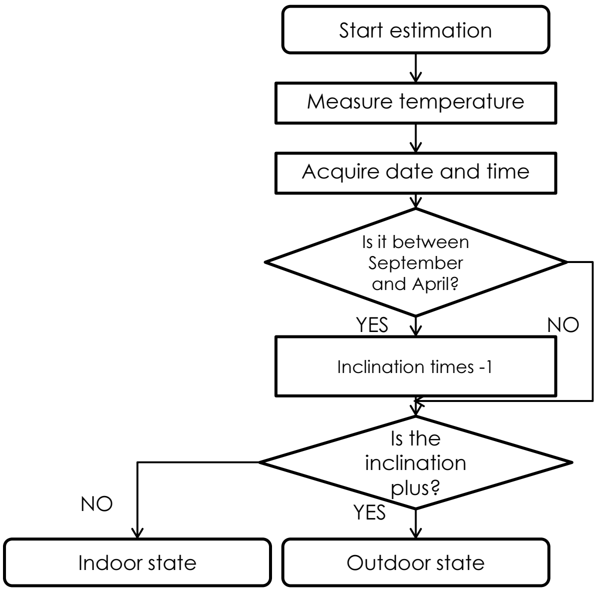

Figure 4: Flowchart of estimation by temperature

by 12 as the temperature reliability. For example, if the measurement date is January 24th, the temperature reliability becomes $(4-1)/12 = 0.25$.

Overall estimation This proposed uses the estimation by illumination, the estimation by magnetism, and the estimation by temperature concurrently and acquires each estimation result and reliability. If 3 estimation results are different, the proposed method considers the result with the highest reliability to be as the estimation result. For example, if this method estimate in the state that the terminal is not covered at 20:00 of January 24th, the illumination reliability is $0.166\cdots$, the magnetic reliability is 0, and the temperature reliability is 0.25. Therefore, the estimation by the temperature is used as the estimated result.

4 EXPERIMENTS

4.1 Overview of the evaluation experiments

We implemented the proposed method to a smartphone (Sony Xperia Z3) as Android application, and evaluated the method by some experiments. For the evaluation of the estimation accuracy, it is necessary to record the correct location of the terminal (correct answer data). At every movement between outdoor and indoor, I assume it correct answer data by pushing the record button, and recording it. Therefore we made the process to record indoor or outdoor, and at every movement between indoor and outdoor, the user pushes the record button and record whether it is indoor or outdoor. This record becomes correct answer data. We compare the estimated result with this correct answer data and calculate the precision ratio.

Figure 5 and 6 are the evaluation results of example scenario. The subject with the smartphone terminal moves indoor $\rightarrow$ outdoors $\rightarrow$ indoor in 10 minutes. Figure 5 shows the estimation result of the proposed method. Similarly, Fig. 6 is the estimated result using only temperature. In this example, the precision ratio of the proposed method is 92%, and the precision ratio of the estimation by temperature is 63%.

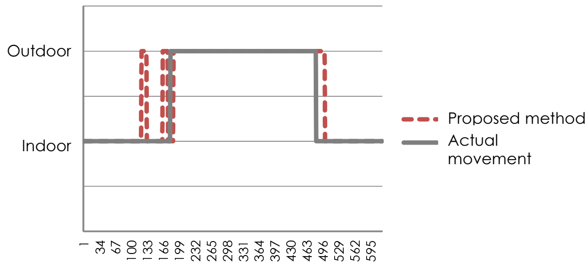

Figure 5: Estimation result using the proposed method

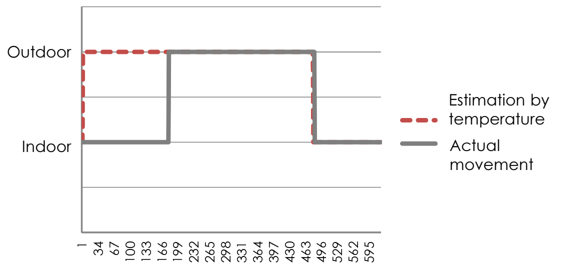

Figure 6: Estimation result using only the estimation by temperature

We evaluate such a precision ratio by comparing the proposed method with 3 kinds of independent indoor/outdoor estimations.

The evaluation experiment is based on 7 scenarios of Table 3. In Ex.1-Ex.4 and Ex.6 scenarios, the subject walks holding the terminal in his hand. And in Ex.5 and Ex.7 scenarios, the subject walks carrying the terminal in a pocket of his jacket.

4.2 Results of the experiments

Table 4 shows the results of experiments. The precision ratio of the proposed method was 82.14% that were higher than other independent estimations. Because the proposed method can use the other estimate technique in the situation which one estimated technique is weak in, the method can keep estimation with high precision. For example, it is the situation such as at the time of the outdoor movement with the large temperature difference in the estimation by the temperature or the situation in the evening in the estimation by the illumination. In Ex.5 and Ex.7, because the terminal is in the subject's pocket and the estimation by magnetism is difficult, the precision ratio of the estimation drops down.

The estimation only by the illumination was able to attain just under 70% of the precision ratio on the average. However, it was not able to be estimated with accuracy at the time without a clear illumination difference between indoor and outdoor such as evening in Ex.4. This is because a false estimate of the indoor occurs by very small difference of the illumination when the subject stopped in the shade for a long

Table 3: Scenario of the evaluation experiments

	Date	Time	Meas.time	Place	Route	Weather
Ex.1	1/28	11:55-12:00	5min.	Within the campus	Indoor → Outdoor → Indoor	Cloudy/Sunny
Ex.2	1/28	12:44-13:16	32min.	Around the campus	Outdoor	Cloudy
Ex.3	1/28	13:26-13:32	7min.	Commercial facility	Outdoor → Indoor	Cloudy
Ex.4	1/28	15:23-16:09	46min.	Commercial facility, around and within the campus	Outdoor → Indoor → Outdoor → Indoor	Snow
Ex.5	1/28	21:44-21:50	6min.	Commercial facility	Outdoor → Indoor	Cloudy
Ex.6	1/28	22:21-22:31	10min.	Home	Outdoor → Indoor	Cloudy
Ex.7	1/28	22:35-22:40	5min.	Home	Indoor	Cloudy

Table 4: Result of the evaluation experiments

	Proposed method	Illumination only	Temperature only	Magnetism only
Ex.1	92%	97%	63%	50%
Ex.2	99%	97%	98%	98%
Ex.3	93%	95%	40%	15%
Ex.4	96%	18%	93%	81%
Ex.5	51%	63%	36%	61%
Ex.6	97%	96%	90%	99%
Ex.7	47%	21%	0%	31%
Avg.	82.14%	69.57%	60%	62.14%

time occurred. By experiment 5 and experiment 7 that a terminal was covered, the estimation by the illumination was not able to achieve the high precision ratio because the illumination became the constant value with approximately 0.

The estimation only by the temperature was able to attain 60% of the precision ratio on the average. The estimation was not able to achieve high precision ratio in the situation that moved indoor from the cold outdoor like Ex.3 and Ex.5. This is caused by the characteristic of the temperature sensor. The temperature sensor is sensitive to cold, and the reaction of the sensor oneself worsens when the sensor observes very low temperature. And it is one reason that there is a time lag for the temperature acquisitions.

The estimation only by the magnetism was able to attain around 60% of the precision ratio on the average. Because it was estimated to be the outdoor by mistake indoor with the magnetic variation, the precision ratio did not rise.

5 CONCLUSION

In this paper, we proposed the indoor/outdoor estimation method to reduce power consumption of Geo-fencing service while maintaining the detection precision of the terminal position in the situation that GPS positioning is impossible such as indoor. In future work, we need a comparative evaluation of the precision and power consumption with conventional Geo-fencing.

REFERENCES

[1] U. Bareth, “Privacy-aware and Energy-efficient Geofencing through Reverse Cellular Positioning,” Proc. of IWCMC2012, pp.153–158 (2012).

[2] NTT TownPage Corporation, “Gotouchi information,” `https://play.google.com/store/apps/details?id=jp.co.ntttp.information`.

[3] underscore.Inc.,“Arrived!,” `http://us.classmethod.jp/apps/arrived`.

[4] amay077, “HexRinger,” `https://play.google.com/store/apps/details?id=com.amay077.android.hexringer`.

[5] T. Fujita, et. al., “Low Complexity TOA Localization Algorithm for NLOS Environments,”IPSJ SIG Technical Reports, Vol.2007, No.74, pp.69–74 (2007).*(in Japanese)*

[6] T. Mogi, et. al., “TOA Localization using RSS Weight with Local Attenuation Constant Estimation in NLOS,” IEICE technical report, Vol.107, No.53, pp.43–48 (2007).*(in Japanese)*

[7] T. Kitasuka, et. al., “An Implementation of Wireless LAN based Indoor Positioning System WiPS,” Proc. of DICOMO2004, pp.349–352 (2004).*(in Japanese)*

[8] H. Konishi, et. al., “A Study on Accuracy of lndoor Fingerprint Localization using WiFi,” Proc. of DICOMO2013, pp.1111–1115 (2013).*(in Japanese)*

[9] Y. Wada, et. al., “A Pedestrian Position Estimation Method using Laser Range Scanner and Wi-Fi Fingerprint,” IPSJ SIG Technical Reports, Vol.2013, No.26, pp.1–7 (2013).*(in Japanese)*

[10] R. Kiyohara, et. al., “Location Detection with Low Power Consumption for Obtaining Context Data for Mobile Devices,” IPSJ SIG technical reports, Vol. 2008, No. 44, pp.33–38 (2008).*(in Japanese)*

[11] T. Nakagawa, et. al., “Evaluation of Variable Interval Positioning Method for Power-saving Geofencing,” Proc. of DICOMO2013, pp.1116–1122 (2013).*(in*

Japanese)
[12] S. Seko, et. al., “An Algorithm to Estimate the Movement Timing to Indoor or Outdoor using Temperature Sensor,” IEICE technical report, Vol. 110, No. 450, pp.131–136 (2011).*(in Japanese)*
[13] C. Lee, et. al, “Energy-efficient Location Logging for Mobile Device,” Proc. of SAINT2010, pp.84–90 (2010).
[14] C. Fritsche, et. al., “Hybrid GPS/GSM Localization of Mobile Terminals using the Extended Kalman Filter,” Proc. of WPNC2009, pp.189–194 (2009).
[15] T. Farrell, et. al., “Energy-efficient tracking of mobile objects with early distance-based reporting,” Proc. of MobiQuitous2007, pp.1–8 (2007).
[16] I. Constandache, et. al., “EnLoc: Energy-Efficient Localization for Mobile Phones,” Proc. of INFOCOM2009, pp.19–25 (2009).
[17] Y. Chon, et. al., “LifeMap: a smartphone- Based context Provider for Location-Based services,” IEEE Pervasive Computing, Vol. 10, No. 2, pp.58–67 (2011).
[18] S. Yoshimura, et al., “Investigation of the comfort temperature and adaptive model in the houses,” Proc. of Architectural Research Meetings, Kanto Chap., AIJ, Vol. 82, No. II, pp.113–116 (2012).*(in Japanese)*
[19] P. Zhou, et al., “IODetector: A Generic Service for Indoor Outdoor Detection,” Proc. of SenSys’12, pp.113–126 (2012).