Indoor Location Estimation 
by Bluetooth Low Energy for Pedestrian Navigation

Hiromune Namie**a)  Member, Osamu Suzuki** Non-Member

(Manuscript received Jan. 00, 20XX, revised May 00, 20XX)

The global navigation satellite system (GNSS) is a satellite positioning system. However, when the signal is shielded by reinforced concrete or metal, it is difficult to be received indoors. This study introduces an indoor location estimation scheme based on bluetooth low energy (BLE) for pedestrian navigation that can save power and reduce the installation density. We investigated indoor positioning methods with the use of the received signal strength indicator (RSSI) in association with two BLE transmitters as the main axis. The error of the single RSSI ranging is more than several tens of meters, and is insufficient for use for pedestrian navigation. However, this error is reduced to a few meters when the proposed simple proportional correction calculation is performed for the estimated distance. The target accuracy required for pedestrian navigation for healthy people is approximately 10 m. This is equivalent to the accuracy of outdoor satellite positioning. For example, given that the size of the Shibuya underground shopping street is approximately 4,676 m², twenty BLE beacons can cover the entire area. If this technology is established, indoor positioning can become possible within a wider range with a lower cost and lower labor effort compared with the current state-of-the-art.

Keywords: indoor positioning, BLE, pedestrian navigation

1. Introduction

The global navigation satellite system (GNSS) is a satellite positioning system. It is represented by the global positioning system (GPS) that is extensively used outdoors for car navigation, smartphone positioning, and for other localization applications. However, when the signal is shielded by reinforced concrete or metal, it is difficult to be received indoors. For this purpose, indoor navigation systems, such as pedestrian navigation in indoor and underground shopping centers, and positioning for guidance of industrial robots, are being studied around the world. Research and development is ongoing with a focus on many relevant applications, including bluetooth low energy (BLE) communications, indoor messaging systems (IMESs), Wi-Fi, sound waves, optical communication, and pedestrian autonomous navigation.

The Japanese government has been implementing the “High-Precision Positioning Society Project” since 2015 supported by the Ministry of Land, Infrastructure, Transport, and Tourism. Correspondingly, various indoor positioning technologies have been studied, and demonstration experiments have been conducted for the purpose of seamless indoor and outdoor positioning. In addition, humans spend more than 80% of their time indoors. Therefore, if indoor positioning is realized, various applications, such as the understanding and analysis of human behavior will be possible in addition to seamless positioning (1).

BLE refers to communications with various electrical appliances, such as smartphones, tablets, personal computers (PCs), or televisions (TVs). In recent years, BLE has attracted particular attention from the viewpoint of low-power consumption (low output) and low cost. The radio waves that can be transmitted by BLE require the use of various devices for indoor positioning owing to the influences of the reflected waves. To this present day, the reception status of the BLE signal and hybridization have been studied with the hybrid indoor positioning method (1) using the BLE signal and pedestrian dead reckoning (PDR). Applications pertaining to management system automation (2) and device-free indoor users based on multiple bluetooth beacons can thus be identified (3). Furthermore, a method has been described (4) to detect the presence of bluetooth devices.

Many methods have been studied to measure distances using radio signal strength indicator (RSSI) positioning applications based on BLE. These have used RSSI ranging (5) in conjunction with the logarithmic normal distribution of RSSI to improve the positioning accuracy, triangulation using weighting filters to suppress signal fluctuation in real time (6), linear approximation models for distance measurement from RSSI (7), indoor positioning using distance and direction from iBeacon (8), and the estimation of weighted averages of distance by RSSI (9). Various methods have been evaluated in the effort to improve the positioning and ranging accuracy.

However, given that these methods had not been originally used for distance measurement/positioning, there are some examples that use a large number of BLE beacons installed every 5 m in a relatively limited space in laboratory or factory settings. However, given that the distance measurement/positioning accuracies of these methods are limited because of their insufficient installation densities, present location and walking direction estimation has not been used in practical applications. Furthermore, no published papers exist on this topic.

Because BLE beacons method has not been originally used for distance measurement/positioning, it is relatively limited in laboratories and factories. There are some examples in which

---

a) Correspondence to: Namie Hiromune. E-mail: nami@nda.ac.jp

* The National Defense Academy, Japan.
1-10-20, Hashirimizu, Yokosuka, Kanagawa 239-8686, Japan

** National Institute of Technology, Toba College
1-1, Ikekami-cho, Toba, Mie, Japan 517-8501, Japan

© 200 The Institute of Electrical Engineers of Japan.
numerous BLE beacons are installed at intervals that are less than 5 m in a limited space, but these paradigms have been insufficient from the viewpoint of the ranging/positioning accuracy and high-density installation. There are no published papers on indoor walking location estimation by BLE.

Based on the above, the method proposed in this study can save power and reduce the density of installation. Additionally, the operation, maintenance, and cost may be better and less expensive than those for conventional radio equipment. In addition, we have used BLE given that it has been incorporated in portable devices, such as smartphones and tablets, and given its expected use and anticipated development in the future owing to its practical applicability and popularization of indoor positioning. We investigated indoor positioning methods with RSSI ranging with two BLE transmitters as the main axis.

The error of the accuracy of ranging by BLE RSSI is more than several tens of meters, and is insufficient for use for pedestrian navigation. However, when the proposed, simple, internal division proportional correction calculation of the estimated distance is conducted, this error is within approximately 10 m. We report significant improvements in indoor positioning accuracy. In this research, the purpose is not to target the indoor, unmanned mobile robots, or visually impaired people, but to grasp the current position and walking direction for navigation for healthy people (defined within approximately 10 m) that is equivalent to the accuracy of outdoor satellite positioning.

### 2. BLE communications

#### 2.1 Overview of BLE communication

BLE is a communication standard that has been recently introduced in Bluetooth 4.0. It uses high frequencies within the 2.4 GHz, industrial, scientific, medical band (ISM). In addition, frequency hopping technology is used for communication, while the frequency is continually changed within the 80 MHz bandwidth. Given that the communication speed is approximately several Mbps, it is used for low-speed, short-range communications. In addition, this frequency band is used by many devices, such as Wi-Fi, microwave oven, and wireless telephone/video transmitters. It is considered that interference is unlikely to occur owing to frequency hopping.

To give an example of the original usages, when an app is placed on standby in the background on a smartphone or tablet device equipped with BLE functionality, it automatically triggers the app when it approaches an installed BLE beacon. In turn, the app initiates the distribution of product information and coupons. The BLE beacon itself transmits only a simple signal, including the identity (ID) information of the beacon at regular intervals, and the receiving terminal side performs some processing upon receiving it. The transmission power ranges from 10 μW to 10 mW and the signal is considered to be much weaker than that of Wi-Fi. As a result, the power consumption of the beacon is very small, and some models have operated for several years with a single-button battery. Additionally, the beacon itself is very small so it can be easily installed in places where it is difficult to prepare a power source, or where large-scale equipment cannot be installed.

#### 2.2 BLE positioning issues

The problem with the use of BLE is that it is not a technology that has been developed for positioning. In addition, the radio wave emitted from the BLE beacon carries only the ID numbers and does not carry any position information. Therefore, to perform positioning and ranging, some arithmetic processing must be performed by the RSSI on the receiver side. In addition, indoor fading is caused owing to the influences of the reflected waves. Moreover, because the BLE radio wave is weak, it is difficult to obtain accurately the distance from the beacon to the receiver that can be used for positioning.

In BLE positioning, distance measurements are performed with RSSI using the property of radio wave attenuation. Examples of radio wave obstacles include concrete, brick, marble, metal, water, and others. Humans may also become obstacles because more than half of the human body is comprised of water.

### 3. Maximum distance measurement

#### 3.1 Outline of experiment

First, a basic experiment was conducted for indoor positioning using BLE to measure the maximum distance from the BLE transmitter. In this experiment, a compact Sony Android smartphone Xperia Z3 was used as a receiver, and one Braveridge corporation BLE BVMCN1001CRH-B (iBeacon, Table 1) was used as the transmitter. In addition, the free Android smartphone application “BLE & Eddy Stone Scanner iBeacon” was used for the measurements. RSSI, measurement distance, group ID, and other information are displayed on the screen.

Two outdoor and indoor situations were set up as experimental environments, and a BLE transmitter was installed on the roof of the Science Engineering Building No. 3 at the National Defense Academy (Yokosuka City, Kanagawa Prefecture) at the end of the corridor. Measurements were acquired 10 times. Building No. 3 is a three-story reinforced concrete structure, and the corridor is several meters away from the outdoors. It consists of various rooms, such as laboratories on both sides of the second-floor corridor used for the experiments. The corridor is approximately 2.0 m wide and the ceiling height is approximately 2.7 m. A BLE transmitter was installed 0.94 m above the waterproof floor on the roof and 2.07 m above the corridor on the second floor.

The distance between the BLE transmitter and receiver was gradually increased to the point at which the reception of the BLE radio waves was interrupted and distance measurements were no longer possible. This distance was defined as the maximum measurable distance.

#### 3.2 Experimental results

Table 2 lists the results of the 10 distance measurements and their average values. Measurements show that the indoor distance is larger than the outdoor distance. According to the specifications, the receivable distance was approximately 50 m when the line of sight was clear. In addition, it was found that it was possible to conduct ranging experiments without problems at the Science Engineering Building (maximum

**Table 1 Specifications of BLE beacons**

| Company       | Braveridge | Estimate          |
|---------------|------------|-------------------|
| Model no.     | BVMCN1001CRH-B | Location beacon  |
| Frequency     | 2.4 GHz    | 2.4 GHz           |
| Power         | 4 dBm      | 4 dBm             |
| Radiofrequency (RF) range | 50 m | 200 m           |
| Size          | φ 30×47 mm | 41×63×24 mm       |
| Weight        | 9 g        | 67 g              |

**Table 2 Available ranging area with BLE transmitter**

| Number of times | Outdoor (m) | Indoor (m) |
|-----------------|-------------|------------|
| 1               | 49          | 70         |
| 2               | 51          | 71         |
| 3               | 48          | 71         |
| 4               | 50          | 71         |
| 5               | 55          | 69         |
| 6               | 51          | 71         |
| 7               | 49          | 71         |
| 8               | 50          | 70         |
| 9               | 48          | 71         |
| 10              | 44          | 71         |
| Average         | 49.5        | 70.6       |
corridor length = 71 m) because stable reception distances up to 70 m could be achieved indoors.

4. Positioning in the corridor with two BLE beacons

4.1 Outline of experiment We used the corridor on the 2nd floor of the Science Engineering Building No. 3 at the National Defense Academy. In this experiment, we used one BLE radio reception smartphone and two BVMCN1001CRH-B BLE beacons (BLE-1 and BLE-2) manufactured by Braveridge Co. The nominal range of BLE radio waves was 70 m. To improve the accuracy of the BLE radio wave distance measurements by RSSI, the distance from each beacon to the receiver was estimated and combined with the measurements of the two beacons. We devised a correction scheme and conducted a verification experiment.

In this experiment, distance measurements were performed in the two corridors separately, and the distances between the beacons were 47 m and 71 m in the two cases. The distances denote the lengths of the corridors in which the experiments were performed. Based on the preliminary experiment, it was found that a beacon was installed at the end of the corridor and two BLE radio waves were received at the same time in the corridor and could be measured simultaneously. Therefore, it was determined that two beacons could be placed anywhere in the hallway.

The distance was measured every 5 m with respect to the center of the corridor, and was measured at the set points for 10 s at 1 Hz. Accordingly, the average value was estimated and used. In addition, it is known from the preliminary experiment that the distance measurements based on the use of the RSSI of the BLE radio waves were several tens of meters smaller than the actual distance. The estimated distance was corrected by a simple internal proportional calculation.

The distance after the internal division proportional calculation correction from the BLE-1 beacon is denoted by \( D \) (known), the pre-correction calculation distance by the BLE-1 is \( \lambda_1 \), and the pre-correction calculation distance by the BLE-2 is \( \lambda_2 \) (Fig. 1),

\[
D = L \times \frac{\lambda_2}{\lambda_1 + \lambda_2} \quad \cdots \quad (1)
\]

As indicated by Equation (1), we examined how much accuracy would be improved based on the performance of correction with simple internal proportional calculation.

4.2 Experimental results Figs. 2 and 3 show the positioning results. The horizontal axis in the figure is the true distance from one beacon to the positioning (ranging) point, the vertical axis is the estimated RSSI distance from the BLE-1 beacon to the positioning point, and the distance unit is in meters (m). The green triangles (▲) in the figure show the results before the internal correction, the red squares (●) show the results after the correction, and the blue diamonds (■) show the ideal values. Before correction (▲), minor changes occur in the calculated distance (distances ≤ 7 m) owing to the wave guiding effect that causes radio wave reflection and propagation over a long distance with minor attenuation. The maximum error was 65 m. Accordingly, BLE could not be used at all for indoor positioning without correction. However, as the true distance between the actual transmitters and receivers changed, it was found that the RSSI calculation distance (▲) before the internal correction was also changed by several meters.

As shown in Fig. 2, the maximum error is 7.0 m, the average error is 3.4 m, and the standard deviation of the error is 2.3 m. In addition, as shown in Fig. 3, the result of the distance measurement with a beacon distance of 71 m yielded a maximum error of 12.7 m, an average error of 6.2 m, and a standard deviation of 3.5 m.
In both figures, the magnitude of the distance measurement and the true distance are reversed in the middle. A phenomenon occurs in the vicinity of 20 m in Fig. 2 and 15 m in Fig. 3. There is a stairway opening to the upper and lower floors along the way. Due to this, it is considered that the estimated position was reversed at approximately 25 m in Fig. 2 and at approximately 20 m in Fig. 3.

Based on the experimental results, the implemented correction based on simple proportional calculation yielded a maximum error of ~13 m, and an average error of ~6 m. Correspondingly, this scheme can be used for indoor pedestrian navigation. As it can be observed from the results in Figs. 2 and 3 before the internal correction (▲), the estimated RSSI calculation distance is much smaller than the actual distance owing to the waveguiding effect, and both values are ≤ 7. This is probably because these distances change in proportion to the true distance from the actual BLE beacon.

Table 3 summarizes the results. The maximum, average, and standard deviations of the errors were found to be proportional to the distances between the beacons. Conversely, the calculation of the estimated distance of this time has a drawback in that it takes 10 s to calculate the result at each positioning point because it uses the average value of 10 measurements for 10 s at each fixed point. Therefore, it is necessary to find a fast method to calculate the distance, while maintaining the accuracy equal to or higher than that of this experiment. The results of distance measurement experiments in Section 3 at short distances and Section 4 at longer distances have been obtained, thus indicating that they are less dependent on the equipment.

5. Indoor mobile positioning experiment

5.1 Outline of experiment The BLE beacon used for the indoor positioning experiment was a Polish estimation BLE beacon with a range that was 200 m larger than the range of the beacon used in the previous section according to specifications. In addition, the smartphone app “Locate Beacon” (compatible with Android and iOS) was used for reception. Radio waves were received from multiple BLE beacons, and the distance between each beacon and the receiver can be estimated simultaneously from the RSSI. The receiver used a smartphone (iPhone7).

The indoor positioning experiment was conducted in the underground training room of the National Defense Academy (Fig. 4). The basement training room has dimensions of ~11.5 m in the x-axis direction, ~20.0 m in the y-axis direction, and a ceiling height of ~3.5 m. There were four BLE beacons installed in the center of the front, rear, left and right walls, and at 2.3 m above the floor. The distance was measured while walking was conducted in straight directions at a perpendicular distance of ~3.5 m parallel to the y-axis. At the time of positioning, the measurement interval distance was ~4 m, and the experimenter walked linearly. The average value was measured 10 times at each point, and was corrected by the proportional calculation described in the previous section to obtain the corrected distance value. When positioning (ranging) was performed, an experiment was performed based on the simultaneous reception of radio waves with four BLE beacons.

Fig. 5 shows a photograph of the first floor of the Library Information Center at the National Defense Academy that...
emulates an indoor space such as that of an underground mall. In Fig. 6, the area surrounded by the red line on the first basement floor was used for the experiment. The x-axis dimension was approximately 24 m, the y-axis dimensions were approximately 29 m or 37 m, and the floor-to-ceiling distance was 3.2 m. The y-axis range was different because the experimental range was changed in two types of experiments that involved linear and square walking. In the linear walking experiment, a beacon was installed at the center of the front, rear, left, and right walls in a similar manner to the indoor positioning experiment in the training room. The location of the beacon was approximately 2.7 m above the floor, and the number of measurements and the correction methodologies were the same as those used in the training room. Positioning was conducted by walking along straight lines parallel to the y-axis and approximately 8 m from the y-axis at 6 m intervals.

In the square walking experiment, we walked so that the square walking trajectory was approximately 25 m along the y-axis direction and approximately 18 m along the x-axis direction. Positioning was performed at 5 m intervals during walking along the y-axis direction, and at 3 m intervals during walking along the x-axis direction.

5.2 Experimental results The experimental results in the training room are shown in Fig. 7. The orange line is the actual walking trajectory, and the purple line is the estimated position calculated from the distance measurement data. Positioning was performed at each marker point. Each number corresponds to a positioning point. In the figure, the installation positions of the beacon pairs are “ ● ” and symbols “◆” are shown to denote the instances at which the internal proportional correction calculation were performed. All the subsequent experimental results are the same.

Analysis of the results of the experiment in the training room based on Fig. 7 shows that the errors at points near the wall, that is, the 0 m (Point 1) and the 20 m (Point 6), increase to values spanning several meters. The same phenomenon occurred in every subsequent experiment. However, in the pedestrian navigation targeted in this study, we concluded that it is rare for pedestrians to move along the walls in underground malls and subway premises so it was not necessary to consider them problematic.

The second aspect is the position error in the x-axis (horizontal axis) direction. According to Fig. 7, there are bias errors because the trajectory of the actual walking locus is not intersected. However, given that the positioning accuracy for pedestrian navigation is ~10 m (that is equivalent to the accuracy of outdoor satellite positioning, such as GPS), the maximum error in the x-axis direction is ~4 m. It can be noted that the accuracy is within the practical range. Analysis of the accuracy in the y-axis (vertical axis) direction shows that the maximum error is ~1.5 m at point 8 m (Point 3), and the other is the positioning accuracy within ~1.0 m. In addition, the root-mean-square (RMS) error is 5.9 m, and the RMS error is improved to 3.3 m (with the exception of the near wall data). This is within a target positioning accuracy of ~10 m.

From the above, it was found that the indoor positioning accuracy that can be achieved with four BLE beacons with linear walking within the space of the training room.

Finally, Fig. 9 shows the results of a walking experiment along a square-shaped trajectory on the first basement of the library. The walking trajectory is shown in the figure. The RMS error was 6.0 m, and was found to be within ~10 m for pedestrian navigation. Fig. 9 shows that the positioning accuracy in the vicinity of the symbols “◆” (i.e., the installation locations of the beacons) is

![Fig. 7 Results generated from linear walking positioning experiments in the underground training room](image1)

![Fig. 8 Results generated from linear walking positioning experiments in the library](image2)
relatively higher than those for other points. Conversely, it was found that there was a large positioning error at locations far from the beacon “◆”, that is, around the four corners of the square shape, with a maximum positioning error of ~11.8 m. This is probably because the internal proportional correction method uses the internal ratio of the linear distance (vector) between the two beacons. In other words, it can be observed in Fig. 9 that the error increases as the distance from the line connecting the two beacons increases. However, positioning accuracy deteriorates near the walls of the underground space, but this is a significant improvement from the situation where the current location is unknown. In addition, healthy people who are lost in the underground mall will not move along the side of the wall for a prolonged time period. Correspondingly, in the vicinity of points 1 and 22, it is expected that the accuracy can be improved by using a separate beacon. The RMS error value is within the range of the positioning accuracies that are considered practical for pedestrian navigation.

A summary of the experimental results is listed in Table 4. The listed values indicate that the RMS error is within ~10 m of the positioning accuracy. This distance is required for pedestrian navigation in the cases of healthy targets.

Accuracy depends on the installation density of beacons. Herein, the installation interval of the pair of beacons used. If the beacons are installed at even intervals, the same error will also be on the x- and y-axes. It is considered that they will be the same in the axes. In this case, we performed a positioning experiment with a minimum of four beacons and effectively used the entire experimental site for practical use. Thus, we did not install them at equal intervals.

The cause of the deterioration of accuracy on the wall is due to the reflection of BLE radio waves from the wall. Additionally, the error depends on the installation density of beacons. Positioning has been achieved with the number of beacons installed as small as possible, and if the distance from the wall is approximately 5 m, the accuracy is within 4 m, and the target accuracy is within approximately 10 m.

6. Measurements along the height direction

6.1 Outline of experiment

Many users require three-dimensional positioning information for three-dimensional structures, such as the stairs, in addition to planar position information. In this experiment, positioning was performed in the height direction, and the positioning methods and accuracy

| Place (underground) | Type       | Error (m)                          |
|---------------------|------------|------------------------------------|
|                     | RMS (other than the wall) | Maximum (other than the wall)     |
| Training room       | Straight line | 5.9 (3.3)                        | 10.0 (4.0)                        |
| Library             | Straight line | 3.8 (3.7)                        | 4.5 (4.2)                         |
|                     | Square-shaped | 6.0 (-)                         | 11.8 (-)                          |
|                     | Height      | 0.56                             | 1.1                               |

Fig.9 Walking positioning measurements of characters with square shapes in the library

Fig.10 Spiral staircase in library

Fig.11 Schematic of the library’s spiral staircase

Table 4 Results of mobile positioning experiments
improvements were examined.

The experiment was conducted on the spiral staircase in the library, as shown in Fig. 10. The used beacons were installed on the top and bottom parts of the stairs, the distance between the beacons was 12.1 m, and the height was 5.7 m. The measurer climbed the stairs along the red arrow shown in Fig. 11, and conducted measurements every two steps. In addition, given that each step of the staircase is 0.15 m, there are 18 points in total (with height differences of 0.30 m between successive steps). In addition, the distance was measured 10 times (2 Hz) at the same point to improve the environment. The correction formula was the same as the internal division proportional correction formula.

6.2 Experimental results The experimental results are shown in Fig. 12. The maximum error of the measurement outcome was 1.1 m, and the RMS error was 0.56 m. Correspondingly, it can be concluded that the accuracy that enabled indoor pedestrian navigation was achieved. Because the distance between the beacons was 12.1 m (was closer in the height direction), the distance between the upper beacon and the ceiling was 3.6 m. As shown, it is thought that the influence of the reflection of beacon radio waves was small due to the fact that the floor at the site of the lower beacon was covered with a carpet, as indicated by rate value listed in Table 3. It was also found that the instantaneous distance measurement results varied considerably, and that the accurate values could not be obtained by single distance measurements. Therefore, it is necessary to identify a faster method to calculate the distance, while maintaining the accuracy to values equal to or higher than those of this experiment.

7. Conclusions

Experiments were performed at three locations, namely at the corridor, basement training room, and the first basement level of the library, using internal division proportional correction with the minimum number of BLE beacons. In this study, linear and square-shaped walking trajectories were executed, and positioning experiments were performed along the height direction of a spiral staircase. In the linear walking experiment, we were able to obtain a positioning accuracy with errors less than ~10 m. We believe that the practical positioning accuracy will be obtained in a square-shaped walking positioning experiment on the first basement of the library that emulates an indoor space similar to that in an underground mall.

Positioning accuracy deteriorates near the walls of the underground space, but this is a significant improvement from the situation where the current location is unknown at all. In addition, healthy people who are lost in the underground mall will not move along the side of the wall for a prolonged time period.

In this study, positioning was possible with four BLE beacons regardless of the size of the place. For this reason, the size of the experimental space of the library was ~888 m². This allowed the emulation of real spaces, such as Shibuya (Tokyo) underground shopping street with a size of ~4,676 m². Twenty BLE beacons covered the studied area. If this technology is established, indoor positioning in wider ranges will be possible with a lower cost and lower labor than the current state-of-the-art. Therefore, indoor positioning with BLE beacons using the internal correction method implemented in this study is considered useful.

Additionally, given that an BLE beacon with a radio wave that reached 200 m by specification was used, for example, Table 2 shows that to maintain the average, RMS, and maximum error within 10 m (1,000 cm), the beacon pair distance must be approximately 1,000 cm/8.7 cm/m = 115 m, 1,000 cm/4.9 cm = 204 m, and 1,000 cm/17.9 cm = 55.9 m. The positioning accuracy was degraded at the corner of the space, but this can be overcome by arranging four or more beacons in succession.
Indoor Location Estimation by BLE (Namie Hiromune et al.)

(6) Jianyong, Zhu, Haiyong, Luo, Zili, Chen, and Zhaohui, Li: “RSSI based Bluetooth low energy indoor positioning,” 2014 International Conference on Indoor Positioning and Indoor Navigation, pp. 526–533 (2015)

(7) Chowdhury, T. I., Md Mahbubur Rahman, Sadre-Ala Parvez, Alam, A. K. M. M., Abul Bashar, Absuayeed Alam, and Shahriar Riazan: “A multi-step approach for RSSI-based distance estimation using smartphones,” Proceedings of the 2015 International Conference on Networking Systems and Security (NSysS), pp.1–5, (2015)

(8) Yan, G. Z., Che, N., Liu, H., and Tang, Y. Y.: “How to confirm iBeacon direction?,” Electronic Engineering and Information Science - Proceedings of the 2015 International Conference on Electronic Engineering and Information Science, ICEEIS 2015, pp. 139–142 (2015)

(9) Anagnostopoulos, Grigorios G., and Deriaz, Michel: “Accuracy enhancements in indoor localization with the weighted average technique,” 8th International Conference on Sensor Technologies and Applications, pp. 112–116 (2014)

(10) https://tech.nikkeibp.co.jp/kn/article/knp/news/20140731/672522/ Nikkei XTECH

(11) Ministry of Land, Infrastructure, Transport, and Tourism Geospatial Information Authority: “Guidelines for installing BLE beacons for indoor positioning,” 2017 Version 10 (in Japanese)

Hiromune Namie (Member) graduated from Tokyo University of Mercantile Marine, Logistics, and Information Engineering (now Tokyo University of Marine Science and Technology) in 1995, where he completed his Doctorate degree in Engineering in 2000. He has been employed as an Assistant Professor by the National Defense Academy (Department of Electrical and Electronic Engineering). Dr. Namie's research interests include Quasi-Zenith Satellite Systems (QZSS), Global Positioning Systems/Global Navigation Satellite Systems (GPS/GNSS) and indoor/outdoor seamless positioning. He is a member of the QZSS Project Promotion Committee, Executive Office of Strategic Headquarters for Space Policy, and the Cabinet Secretariat. He is a member of the Institute of Electrical Engineers of Japan (IEEJ). He is an Advisor of the QZSS Business Innovation Council (QBIC), he serves as the Secretary-General of the GPS/GNSS Society of the Japanese Institute of Navigation (JIN), and serves as a Board Member of JIN and the Institute of Positioning, Navigation, and Timing of Japan (IPNTJ) (URL http://www.nda.ac.jp/~nami/).

Osamu Suzuki (Non-Member) graduated from Tokyo University of Mercantile Marine, Navigation Engineering in 1991, and completed his Master’s degree at Tokyo University of Mercantile Marine, and was employed as a research associate by the National Institute of Technology, Toba College. Subsequently, he was employed as a Lecturer, Assistant Professor, and as an Adjunct Professor. At present, he is working as a Professor. His research interests include marine information systems. He is a member of the Managing Committee of the GPS/GNSS Society. He is also member of IEICE, ITE, and a member of the Japanese Institute of Navigation.