Indoor Pedestrian Navigation System Combining Spatially Continuous and Discrete Location Information

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Abstract: In this paper, a new positioning method which can suppress the increase in location estimation error margin is proposed. In the proposal method, the output of a spatially continuous location information and a spatially discrete location information are combined to achieve an accurate and robustness positioning system. By combining of these different kind of positioning methods, it is thought that the system can provide an accurate position information seamlessly. The particle filter is deployed to combine the several kind of positioning method. For the weighting process at the particle filter, suitable weighting algorithm for each positioning method are given. To show the effect of the proposal method, the results of two experimental studies in an office and an exhibition hall are shown.

1. Introduction

Recently, various kind of indoor positioning technologies for pedestrian are widely studied. For example, the method that detects a visual marker using cameras[1], the method based on a wireless beaconing devices such as the IMES(Indoor MEssaging System)[2], [3], the method used Wi-Fi radio waves[4], [5], [6] and so on. However, the practical system for most indoor applications has not been established yet. Because there are no seamless positioning system which can cover a wide area like the GNSS(Global Navigation Satellite Systems)[7] for an indoor environment. Since GNSS needs the satellites which are in the line of sight, it is too hard to apply it in an indoor environments.

Therefore, it is thought that combining several positioning methods is effective to achieve the practical system for an indoor environment. Because it is thought that the blank area of the positioning by each positioning method can be interpolated by combining of the several positioning methods. For instance, there is a conventional work which combines the spot positioning method and the inertial navigation technique. This work is a sample to achieve the seamless positioning method.

However, the technique of combining several positioning methods has the risk of increasing the location estimation error margin. Because the characteristics of the location estimation error margin by each positioning method are different, and it depends on the positioning method. The positioning methods that uses spatially discrete information, such as IMES, are accurate when detecting anchors. However, after some time, the reliability of the estimated position gradually declined. Therefore, it is difficult to use the position information for the service at places far from the anchors. On the other hand, the positioning methods that use spatially continuous information such as Wi-Fi cover a wide range[4], [5], [6]. But it cannot achieve good accuracy as IMES. Moreover, its estimation accuracy varies depending on the surrounding environment. Therefore, it is necessary to improve the robustness of the estimation in order to realize better quality service.

In this paper, a new positioning method which can suppress the increase in location estimation error margin is proposed. The proposal method combines the output of a spatially continuous location information and a spatially discrete location information. The weight coefficients decides corresponding to the reliability of each estimated position information. This method can suppress the increase in location estimation error margin by the combining. To show the effect of the proposal method, the demonstration experiment in the exhibition hall are executed. The result of the demonstration experiment is shown in this paper.

Contents of this paper are following. In section 2, the related work is explained. In section 3, the theory and the implementation of the proposal method are described. In section 4, the results of the experiment in the exhibition hall and the office to show the effect of the proposal method are shown. In section 5, the experimental result in Chapter 4 is considered. Finally, in section 6, the summary of this paper is shown.

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2. Conventional Method

Up to the present, a variety of wireless indoor positioning techniques and systems have been proposed[5]. However, their use in real environments has been difficult because the radio waves are susceptible to interference, depending on the reflection conditions of the environment. It is known that the Wi-Fi fingerprint method is not likely to be influenced by reflected radio waves[8], [9]. This method measures in advance the distribution of the RSSI (Received Signal Strength Indicator) at multiple points in the environment. When executing positioning, the UE(User Equipment) position is estimated by comparing it with the RSSI measured at that time and one measured in advance. There is a problem whereby estimation accuracy varies because the RSSI may significantly change depending on the motion of the person and slight differences of the positions at which the RSSI is measured.

Another positioning method, PDR has also been studied[10]. The PDR estimates the relative change of position by determining a pedestrian's movement using an accelerometer and gyro sensor. Although most PDR can estimate the position with high accuracy in a short time, it is difficult to continue positioning independently for a long time period. Because the gap between the actual movement and the estimated one by the PDR increases constantly.

On the other hand, a method that independently applies PDR to continue positioning has been proposed[11].

It narrows the possible trajectories and positions using a hypothesis where a certain person in a building repeatedly passes over the same passage. This method cannot be applied in cases where a given person passes over each passage only once. In addition, the positioning result is expected to become unstable with irregular movements.

In recent years, positioning methods that supplement weak points of the above-mentioned approach using wireless signals and the PDR, and that enable accurate estimation have been proposed[12], [13]. Moreover, there have also been studies[14] into positioning systems using smartphones, which are becoming increasingly popular. Smartphones are useful as sensor devices for positioning because they have Wi-Fi modules, accelerometers and gyro sensors.

However, in these conventional method, the spatially discrete information have not combined. This means continuity of the positioning is ruined when the blank zone when position information cannot be acquired exists. Therefore, if using their positioning system in a large space, they sometimes may lose its position.

3. Proposed Method

To decrease the problem of the conventional method, the method which combines the spatially continuous location information and the spatially discrete location information was proposed[15]. That is, the proposal method consists of the conventional method and the method which uses the spatially discrete location information. It is thought that this proposal method can decrease the demerits of the conventional method so far. This suggests that the blank zone of the positioning can be interpolated, and it can make amends for the accumulated error margin of the PDR. Here, "blank zone" means the zone which the positioning is not available. In this section, information about the concrete system architecture, theory and implementation of the proposal method are described.

3.1 System Architecture

The system architecture of the proposal method is shown in Fig. 1. In Fig. 1, the user's relative change of position is estimated by PDR using information obtained from the accelerometer and the gyro sensor in the UE. The position is estimated by combining the information acquired from the PDR method, the information from the following four positioning methods and the information of the layout map. The particle filter is deployed to combine these information. Details of each methods and the layout map are showing below.

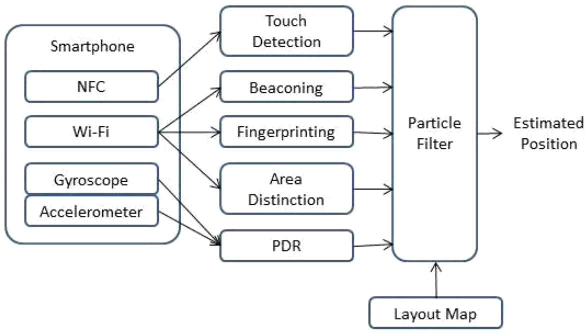

Fig. 1 System Architecture

- *Wi-Fi Fingerprinting:*
  The Wi-Fi fingerprint method[8], [9] as shown in Fig. 2 is deployed to find the center of the position. In Fig. 2, first, Wi-Fi beacons signals that include SSID transmitted by each access points(AP1∼AP3) are received by the UE. Then, the position of the UE is estimated by MLE(Maximum Likelihood Estimation) algorithm. In this process, the MLE module refers the RSSI information of each AP on the RSSI maps. The RSSI map is prepared by the measuring work. This method can cover the wide area such as hall, office and so on. However, there is a problem in that estimation accuracy fluctuates. Because the RSSI may significantly change depending on the motion of the people in the environment, and slight differences in the positions at which the RSSI is measured. In addition, time and personnel expenses increase depending on the number of points being measured in advance.
- *Wi-Fi Location Beaconing:*
  Although positioning techniques that combine the PDR and Wi-Fi fingerprint methods are usually accurate, the

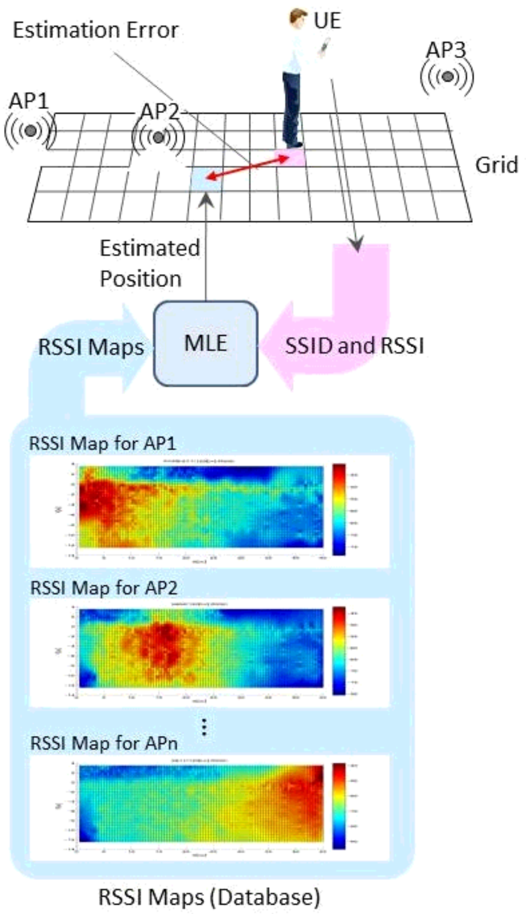

Fig. 2 Wi-Fi Fingerprinting

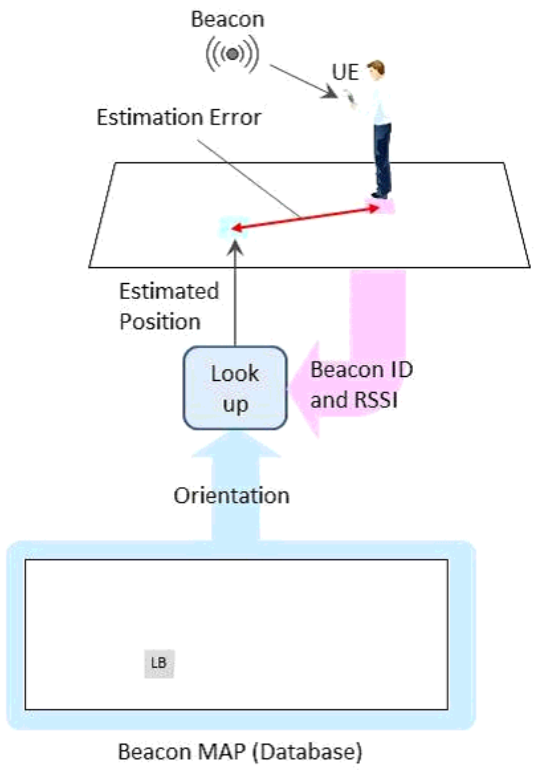

Fig. 3 Wi-Fi Location Beaconing

positioning errors sometimes increase once it loses position of the UE. In this case, the estimated probability distribution of the position is corrected using Wi-Fi Location Beacons, which are Wi-Fi access points that are modified such that they do not transmit their beacon signal over great distances. As shown in Fig. 3, the Wi-Fi location beacon simply looks up the UE's position using a look-up table called a "beacon map." When a given UE detects the beacon signal, the range of the possible area in which the UE exists can be narrowed down to within several meters. It is difficult to arrange the beacons so that they cover the entire area of the hall because the number of beacons that can be installed is limited in order to minimize the costs of hardware, installation and maintenance.

- *Wi-Fi Area Distinction:*
  Therefore, even if the beacon cannot be detected, the authors used a method that uses Wi-Fi RSSI in a way different from the Wi-Fi fingerprint method to prevent the system from outputting an entirely different position. This method is called "Wi-Fi distinction" as shown in Fig. 4. In Fig. 4, the patterns of RSSI were measured and learned in advance in each area. Dots plot on the "RSSI Learning Data" in Fig. 4 indicates these pattern of RSSI. Also, the area in which the UE exists is distinguished by the machine learning method. The machine learning compare the SSID and its RSSI received by the UE with learned RSSI data. Then, the machine learning module calculates the hyperplane to determine the border of these areas. The training data including various changes of RSSI are able to gather easily. In addition, the authors can obtain reliable area information by smoothing RSSI with the moving average method and screening the output when it is not easily distinguishable. Some location-based services check when a pedestrian walks into and out of an area without using detailed positions. This method, therefore, is effective for preventing mistakes made when determining the area.
- *NFC:*
  Because the above three methods depend on radio waves, there are cases in which they cannot accurately estimate the position, depending on the environmental conditions. For example, many people carry mobile Wi-Fi routers. The NFC(Near Field Communication)[16] method as shown in Fig. 5 is used to always obtain accurate positions. This NFC detects a smartphone touch event to an IC card reader whose position is pre-registered. Although this method is the most reliable and accurate of the four mentioned, users are required to consciously to touch the smartphone to the IC card reader. There are, therefore, limitations in the practical application of this method.
- *Layout Map:*
  Though the layout map is not a positioning method, it provides the weight coefficient to the particles as

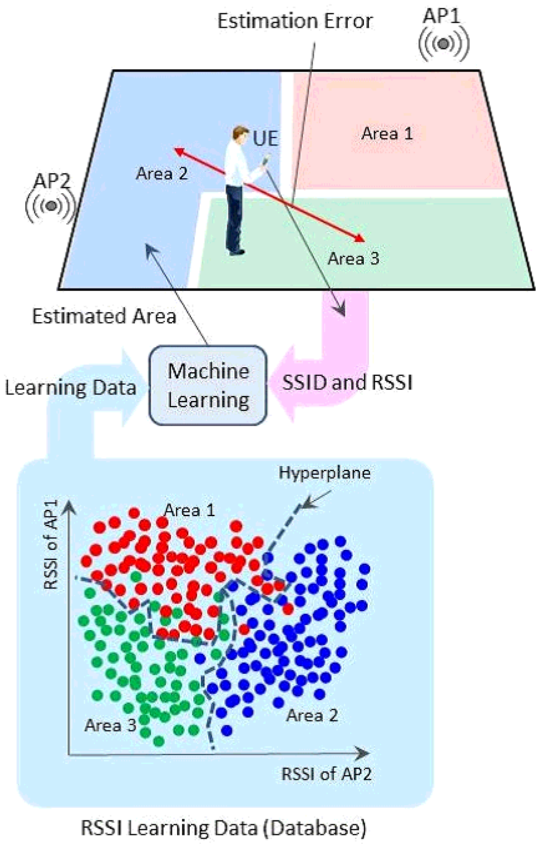

Fig. 4 Wi-Fi Area Distinction

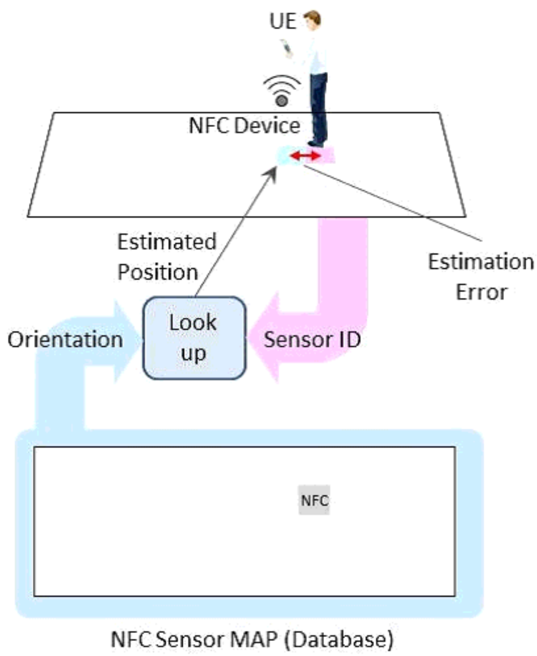

Fig. 5 NFC

other positioning methods. The layout map provides the maximum weight coefficient for the accessible area, and the minimum weight coefficient for the in accessible area. The positioning accuracy is expected to be improved by applying this layout map.

3.2 Theory of Combining using Particle Filter

A particle filter is deployed to combine these positioning methods and the layout map. The output of the particle filter indicates the estimated positions of the UE. Fig. 6 is a block diagram of that particle filter. In Fig. 6, first of all, the particle filter activated by something new event signals from sensors. After that, particles are initialized. These first particles are spread randomly inside of the area. Next, particles are updated by the relative locomotion data from the PDR module. Then, these updated particles are weighted particle by particle, by the weight coefficient determined by the sensors and the layout map. Finally, estimated position is output by resampling of particles. The resampled particles are feed backed to the updating process of the future particles.

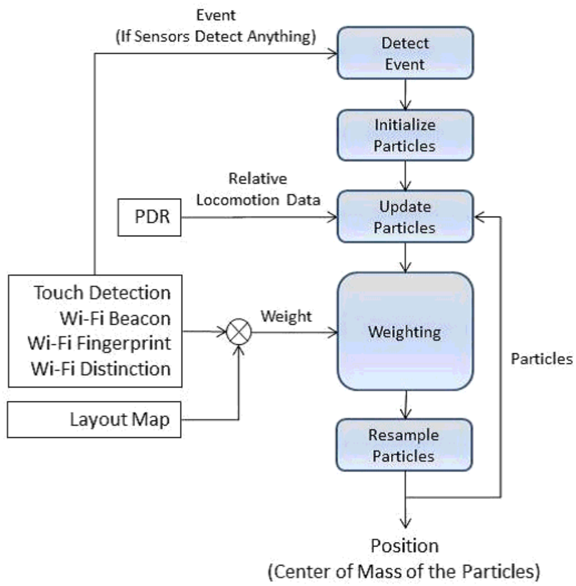

Fig. 6 Particle Filter

Fig. 7 show the theory of weighting for the particle filter. As shown in Fig. 7, it is thought that the particle filter can combine the outputs of each positioning method by multiplying the weights acquired from each positioning method. Thus, it can continue estimation without changing the process, regardless of whether there are inputs.

The weight algorithm is decided depending on the type of the positioning method. The type of the positioning method is roughly classified int the following three types.

- *a) Center Position Type:*
  The beacon method and the NFC method fall under this type. Two parameters, d_{zone} and d_{att}, need to be determined in advance depending on the sensor. d_{zone} is the distance that indicates the detection range. d_{att} is the distance that indicates the speed with which the weight is reduced outside the detection range. When the sensor is detected, the distance d from the position of the sensor to the position of each particle is calculated. As shown in Fig. 8, the weight of the *Center Position Type* W_{ceter} is constant as a maximum value within the

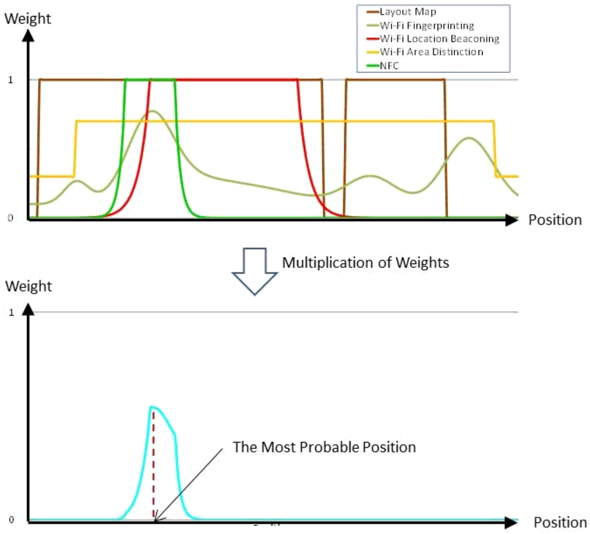

Fig. 7 Theory of Weighting for the Particle Filter

range of d_{zone}, and it decreased exponentially outside the range according to d as shown in equation (1). Because in very close zone to the sensor as $d \leq d_{zone}$, it is thought that the possibility of its location is very high. Also, with more far zone as $d > d_{zone}$, it is thought that the possibility of its location depends on theory of radio wave propagation.

$$W_{center} = \begin{cases} 1.0 & (d \leq d_{zone}) \\ exp\{\frac{(d-d_{zone})ln0.1}{d_{att}-d_{zone}}\} & (d > d_{zone}) \end{cases} \quad (1)$$

If the weights of all particles are below a certain threshold, all particles are discarded once, and new particles are initialized around the position of the sensor within the range of d_{zone}.

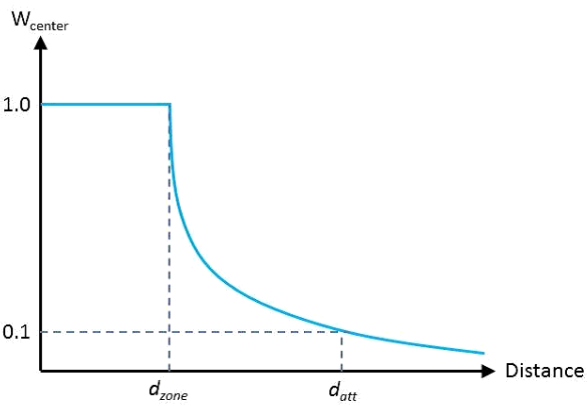

Fig. 8 Weighting for *Center Position Type*

Where, d_{zone} is 1m for NFC, and 3m for Wi-Fi. Also, d_{att} is d_{zone} plus 0.5m for NFC, and d_{zone} plus 1m for Wi-Fi, respectively.

- *b) Area Type:*
The area distinction method and the layout map fall under this type. Each area to be distinguished needs to be defined by the polygon and so on. As shown in Fig. 9, by checking whether the position of the particle is included in the area, the weights of particles inside the area are W_{in}, and the weights of others are determined as 1.0$\sim$ W_{in}. Here, the weight for the *Area Type* W_{area} is shown in equation (2).

$$W_{area} = W_{in} = \begin{cases} 0.7 & (AreaDistinction) \\ 1.0 & (LayoutMap) \end{cases} \quad (2)$$

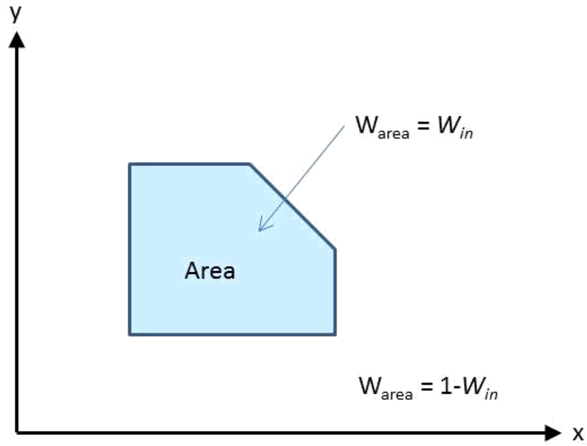

Fig. 9 Weighting for *Area Type*

- *c) Grid Type:*
The Wi-Fi fingerprint method falls under this type. Grid cells are determined in advance, and certain values are stored in them. As shown in Fig. 10, after searching a grid cell in which the position of the particle is included, the weight for *Grid Type* is calculated using the values extracted from the grid cell and certain expressions.

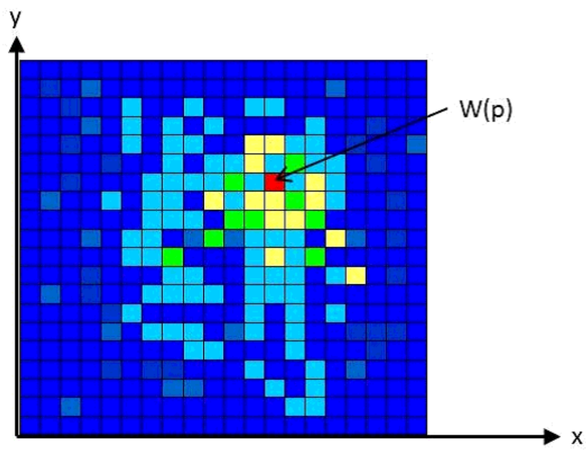

Fig. 10 Weighting for *Grid Type*

Here, the color of each grid indicates the weight at the grid p. The weight of each grid p is calculated as $W(p)$ by equation (3).

$$\begin{cases} W(p) = w_1(p) \times w_2(p) \times w_3(p) \times \cdots \times w_n(p) \\ w_n(p) = \frac{1}{\sqrt{2\pi\sigma_n^2}} exp\{-\frac{1}{2}\frac{(s_n-\mu_n)^2}{\sigma_n^2}\} \end{cases} \quad (3)$$

where, s_n, μ_n, σ_n^2 are the n_{th} AP's measured RSSI, the n_{th} AP's average RSSI, the n_{th} AP's variance of RSSI, respectively. The s_n is the newest measured value at the moment of resampling. And the μ_n and the σ_n^2 are the value which is recorded in advance on the RSSI map. Moreover, -5dB of offset was added on the s_n, and 2 was multiplied by the σ_n^2 for the margin to adapt various kinds of terminals.

4. Evaluation

To evaluate the proposed system, two experimental studies were done. One was done in the office and the other was done in the exhibition hall.

4.1 Test in Office

For the first experiment, to test the effect of the combination, both the performance of each positioning method and the performance of a combined system are checked in an office.

The test condition is shown in Table.1. The blue line in Fig. 11 shows the provided pathway in the office for the experiment. The tester walked the course shown in Fig. 11 ten times. The accuracy of the estimated position is calculated by averaging each result.

Table 1 Test Condition (Office Environment)

Room Size	$640m^2$
Number of AP	6
Number of Location Beacon	0
Number of NFC	0
Height of APs	2.4m
WiFi	IEEE 802.11g(2.4GHz)
UE	F-12C (Fujitsu)
Tester	Male (29 years old, 170cm tall)
population density	0.07∼0.17 person/m^2
Walking Speed	1.0 m/s∼1.3 m/s
UE's Position	Handheld

And a sample of trajectory path estimated by PDR is shown in Fig. 12. As shown in Fig. 12, it is too hard to estimate the trajectory using only PDR because the estimation error increased.

The positioning error by the PDR, Wi-Fi fingerprinting and layout map is shown in Table 2. And a sample of trajectory path estimated by combining the PDR, the Wi-Fi fingerprinting and the layout map is shown in Fig. 13. As shown in Fig. 13, the trajectory path estimated using this method is close to the provided pathway shown in Fig. 13. This result indicates that the effectiveness of the combination.

Table 2 Positioning Error in the Office

Average	Maximum	Minimum	Variance
5.1m	7.0m	1.5m	$2.1m^2$

4.2 Test in Exhibition hall

As shown in the chapter 4.1, the method that combined the PDR, the Wi-Fi fingerprinting and the layout map performed effectively. Therefore, Wi-Fi beacons and NFC were added to the method. The performance of this method was tested in the exhibition hall during "Fujitsu Forum 2012"[17]. The condition of this test is shown in Table3. Fig. 14 shows the arrangement of the AP(red circle), location beacon(blue circle) and NFC(green circle). In Fig. 14, 10 APs for Wi-Fi fingerprinting and 57 beacons for Wi-Fi location beaconing are arranged.

Table 3 Condition, Test in Exhibition Hall

Hall Size	$5000m^2$
Number of AP	10
Number of Location Beacon	57
Number of NFC	1
Height of APs	2.5m
WiFi	IEEE 802.11g(2.4GHz)
UE	F-07D, IS-12F (Fujitsu)
Tester	151 people(visitors of the exhibition)
population density	1.04∼1.18 person/m^2
walking speed	depend on the tester
UE's position	handheld

Fig. 15 shows the positioning result in the exhibition hall by combining PDR and Wi-Fi fingerprint. This result indicates that the estimated trajectory path by combination of the Wi-Fi fingerprinting, the PDR and the layout map can not track exact pathway in part of the place. It is probable that the result of Fig. 13 performed better than the result of Fig. 15 is due to the condition difference. To describe the details, the exhibition hall has a wide space and a high ceiling, and there were many mobile-routers that use Wi-Fi carried by the exhibition hall visitors.

The positioning error by the PDR, Wi-Fi fingerprinting, layout map, Wi-Fi location beacon and NFC is shown in Table 4. Fig. 16 shows the positioning result in the exhibition hall by combining the Wi-Fi fingerprint, the PDR, the layout map and Wi-Fi location beacon. These results indicates that the combination of Wi-Fi location beacons are able to reduce the error.

Table 4 Positioning Error in the Exhibition Hall

Average	Maximum	Minimum	Variance
7.8m	12.7m	2.0m	$18.6m^2$

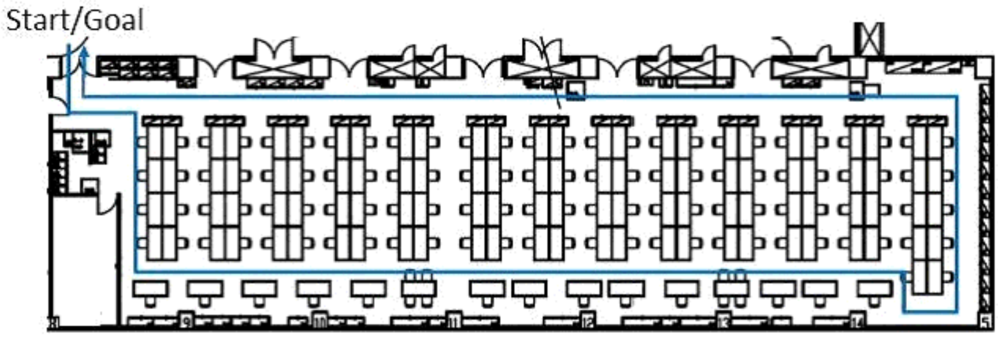

Fig. 11 Provided Pathway in the Office

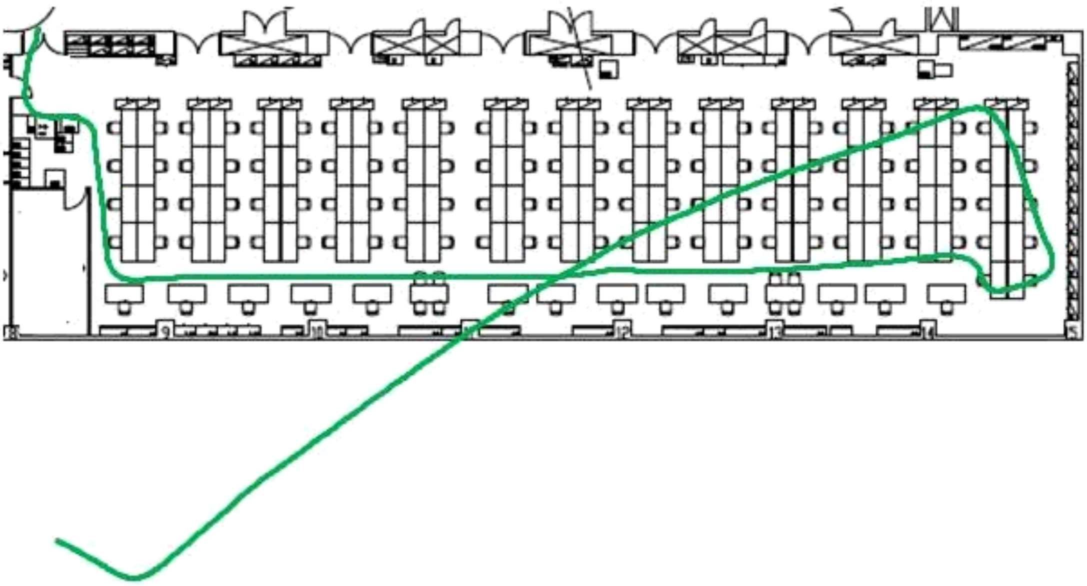

Fig. 12 A Sample of Trajectory Path Estimated Using the PDR

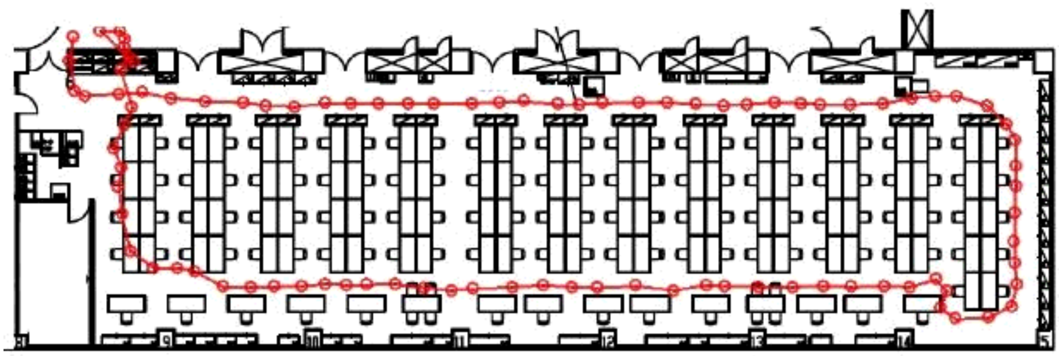

Fig. 13 A Sample of Trajectory Path Estimated by Combining PDR, Wi-Fi Fingerprinting and Layout Map

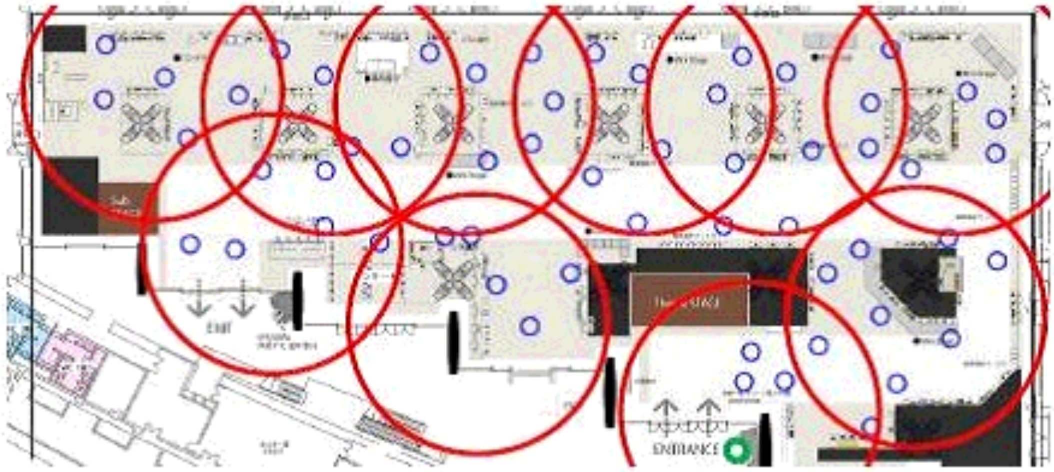

Fig. 14 Arrangement of AP, Location Beacon and NFC

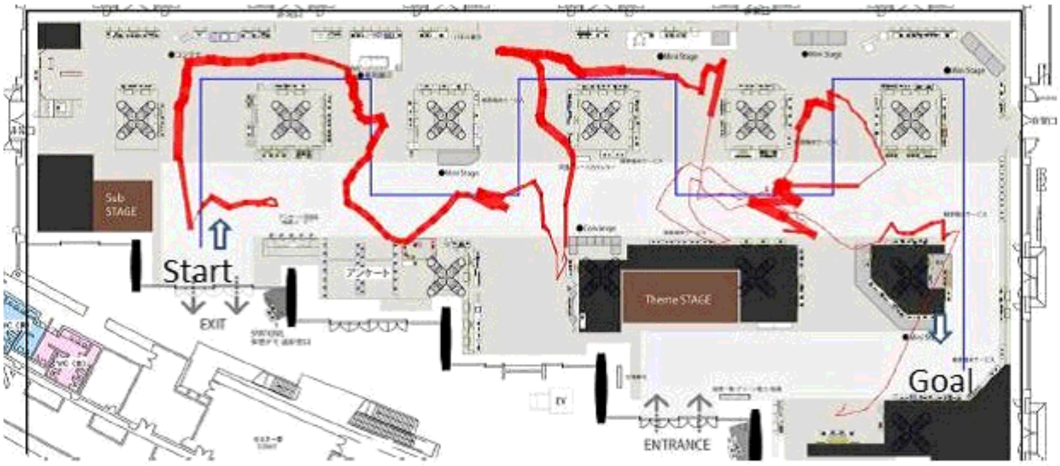

Fig. 15 A Sample of Trajectory Path Estimated by Combining PDR, Wi-Fi Fingerprint and Layout Map

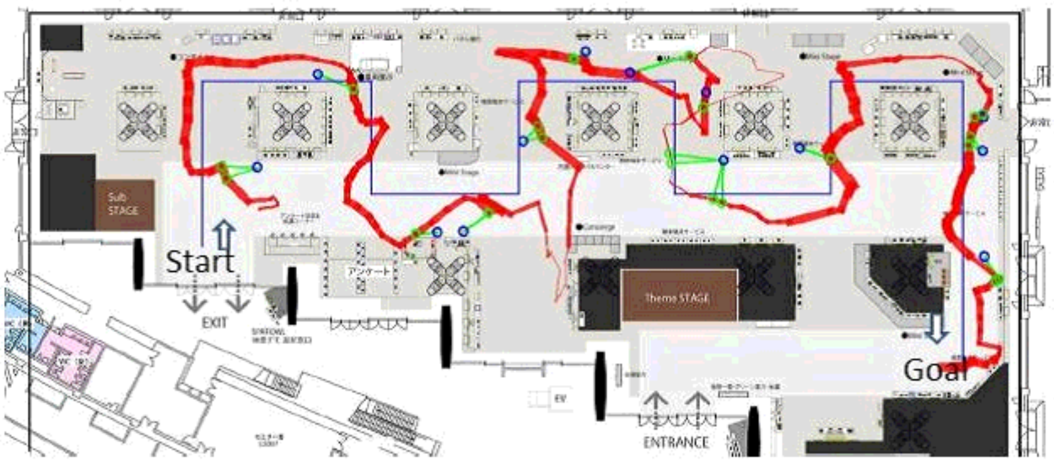

Fig. 16 A Sample of Trajectory Path Estimated by Combining PDR, Wi-Fi Fingerprint, Layout Map, Wi-Fi Location Beacon and NFC

5. Discussion

5.1 User Impressions

Fig. 17 plots the tracking result of a visitor's position every two seconds. The red points show the positions in which the change in the position was 70cm/s or less, and that the user remained in one place. The blue points indicate other positions and that the user was moving; also, they show that the user browsed the entire exhibition hall.

Fig. 17 Result of the Questionnaire Survey of Users

In total, the smartphones were assigned to 151 visitors over a two-day period. The number of smartphones assigned at any given moment was at most 17, and the average number was about 10. The authors conducted a questionnaire survey of the visitors, and received a total of 51 comments. Fig. 18 shows the result of the questionnaire survey. More than 70% of the comments were positive (not "Bad"), and very few comments criticized the performance of the positioning.

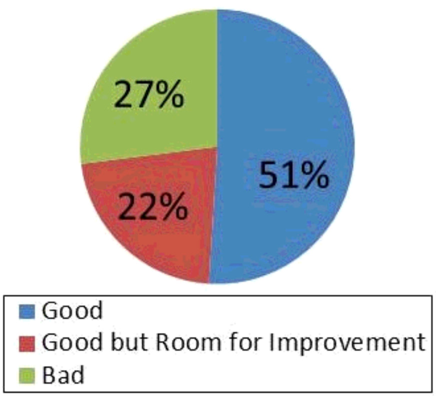

Fig. 18 Result of the Questionnaire Survey of Users

5.2 Grid size of RSSI map

Here, the consideration result of the grid size of RSSI map for Wi-Fi fingerprinting is shown. It is thought that the grid size is effective for accuracy. So the authors studied about its effect. Figs. 19 to 22 shows the results which were calculated using different types of RSSI map. These results indicate that the grid size is not so sensitive (see Figs. 19 to 22) but of course the system which has the smallest grid size (3m) performed the best And slso it indicates that the measurement work is necessary, because the calculated map is not usable(see Fig. 22).

Fig. 19 Trajectory Path Estimated Using a 3m Grid Size RSSI Map

Fig. 20 Trajectory Path Estimated Using a 6m Grid Size RSSI Map

Fig. 21 Trajectory Path Estimated Using a 16m Grid Size RSSI Map

Fig. 22 Trajectory Path Estimated Using calculating the RSSI Map

6. Conclusion

This paper described a new positioning system that combined several positioning methods with different features in order to improve the robustness and positioning accuracy of the system. The experimental results show that the proposed system was effective. Moreover, the effectiveness and the robustness of the system in a large-scale exhibition hall were confirmed by many visitors. Since this fact, it is thought that the location based service using the proposal method has a potential in the future.

In future, the development of the methods that decrease the time taken to gather the Wi-Fi information required for positioning in advance is planned. And the development of a system architecture that maintains seamless positioning services when the user makes a transition from indoors to an outdoor environment is also planned.

References

[1] K. Kobayashi, Y. Ban and K. Uehara, 3D Personal Position Acquisition Method for Wearable AR System Using Independent Position Tracking Unit and 2D Visual Markers, IEICE Tech. Rep., PRMU, Vol.104, No.572, pp.25-30, 2005.

[2] N. Kohtake, S. Morimoto, S. Kogure, and D. Manandhar, Indoor and Outdoor Seamless Positioning using Indoor Messaging System and GPS, Proc. IPIN2011, 2011.

[3] Troyk P.R., DeMichele G.A., Kerns D.A., Weir R.F., IMES: An Implantable Myoelectric Sensor, Proc. EMBS2007, pp.1730-1733, 2007.

[4] K. Taniguchi and R. Kohno, Positioning Algorithm Based on TDOA Measurements Using Layered Particle Filter in Sensor Network, IEICE Trans. Vol.J89-A, No.12, pp.1068-1078, 2006.

[5] H. Liu, Darabi H., Banerjee P., J. Liu, Survey of Wireless Indoor Positioning Techniques and Systems, IEEE Trans. System Man and Cybernetics, Vol.37, No.6, pp.1067-1080, 2007.

[6] M. Kaji, T. Hara and S. Nishio, On-line Radio Map Generation for WiFi Localization and Its Characteristics, IPSJ Journal, Vol.50, No.1, pp.51-63, 2009.

[7] B. Hofmann-Wellenhof, H. Lichtenegger and E Wasle, GNSS - Global Navigation Satellite Systems, Springer Vienna, ISBN:978-3-211-73012-6, 2008.

[8] P. Bahl and V. Padmanabhan, RADAR: an in-building RF-based user location and tracking system, Proc. INFOCOM2000, pp.775-784, 2000.

[9] P. Prasithsangaree, P. Krishnamurthy, and P. K. Chrysanthis, On Indoor Position Location With Wireless Lans, Proc. PIMRC2002, pp.720-724, 2001.

[10] M. Kourogi and T. Kurata, Personal Positioning based on Walking Locomotion Analysis with Self-Contained Sensors and a Wearable Camera, Proc. ISMAR2003, pp.103-112, 2003.

[11] P. Robertson, M. Angermann, and B. Krach. Simultaneous Localization and Mapping for Pedestrians using only Foot-Mounted Inertial Sensors, Proc. Ubicomp2009, pp.93-96, 2009.

[12] F. Evennou and F. Marx, Advanced Integration of WiFi and Inertial Navigation Systems for Indoor Mobile Positioning, EURASIP Journal on Applied Signal Processing, Vol.2006, No.1, page.164, 2006.

[13] P. Kemppi, T. Rautiainen, V. Ranki, F. Belloni, and J. Pajunen, Hybrid positioning system combining anglebased localization, pedestrian dead reckoning and map filtering, Proc. IPIN2010, 2010.

[14] N. Kotharia, B. Kannanb, E. D. Glasgwowc and M. Bernardine Diasb, Robust Indoor Localization on a Commercial Smart Phone, Procedia Computer Science, Vo.12, pp.1114-1120, 2012.

[15] J. Fujimoto, S. Hotta, K. Sawada, Y. Hada, K. Hida and S. Mori, Hybrid positioning system combining spatially continuous and discrete information for indoor location-based service, Proc. UPINLBS2012, 2012.

[16] ISO/IEC, International Standard ISO/IEC 18092:2004, Information technology – Telecommunications and information exchange between systems – Near Field Communication – Interface and Protocol (NFCIP-1), 2004.

[17] http://forum.fujitsu.com/2012/tokyo/