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A Design Methodology for Positioning Sub-Platform on Smartphone Based LBS

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SUMMARY This paper presents a design methodology for positioning sub-platform from the viewpoint of positioning for smartphone-based location-based services (LBS). To achieve this, we analyze a mechanism of positioning error generation including principles of positioning subsystems and structure of smartphones. Specifically, we carry out the experiments of smartphone positioning performance evaluation by the smartphone basic API (Application Programming Interface) and by the wireless LAN in various environments. Then, we describe the importance of considering three layers as follows: 1) the lower layer that caused by positioning sub-systems, e.g., GPS, wireless LAN, mobile base stations, and so on; 2) the middle layer that caused by functions provided from the platform such as Android and iOS; 3) the upper layer that caused by operation algorithm of applications on the platform.
key words: *systems innovation, location based services, smartphone positioning, smartphone basic API, wireless LAN*

1. Introduction

There are various location-based services (LBS) such as [1]. Examples of LBS are navigation [2], maps [3], check-ins [4] and so on. The accurate and precise positioning in all locations is required for providing high quality service of LBS. The global positioning systems (GPS), that is widely used as the first positioning social infrastructure, does not work properly in a building, an underground mall, or an outdoor area of multistoried buildings. On the other hand, smartphones are spreading rapidly in recent years. A lot of people have smartphones, so the smartphones can be considered as one of social infrastructures. And also, under the premise of the diffusion of smartphones, positioning sub-systems that can be used from LBS increase. Examples of positioning sub-systems that are available on smartphones are GPS, wireless LAN (WLAN), mobile base stations (MBS), short-distance communications (Bluetooth, near field communication (NFC), infrared communication, etc.), and so on. However, in order to realize the accurate and precise positioning using smartphones, it is important to design not only the positioning sub-systems but also the positioning sub-platform.

This paper presents a design methodology for positioning sub-platform from the viewpoint of positioning for LBS under the premise of smartphones. In order to do that, first of all, we should clarify the positioning performance, including the mechanism of positioning error generation, of existing smartphones. So we evaluate the positioning performance using smartphones under various environments and analyzes the mechanism of positioning error generation including principles of positioning sub-systems and structure of smartphones.

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2. Systems Innovation Theory and Smartphone Positioning

2.1 Fundamentals of Systems Innovation [5]–[12]

The authors have shown the fundamentals of systems innovation in [5]–[12]. In these papers, we have proposed some principle of systems innovation. For example:

- Existing technology should be made the most use of; even if modification is needed, the least modification should be done. When utilization of legacy systems or subsystems is impossible, we try to do the systems or subsystems innovation.
- Platforms are common property of all humankind. Platforms should be designed with following "the platform's cardinal rule" and should be nonexclusively created with collaborative activity; applications on the platforms and devices to support the platforms should be competitively supplied. In addition, the basic design should be considered under the premise that systems will continue to migrate and evolve.

Here, "the platform's cardinal rule" proposed by the authors mean basic design scheme that is independent of not only particular applications on the platform but also particular sub-platforms under the platform. In addition, the premise of systems migration means that platforms have the property of buffers (vertical division) without their final forms, and have basic design to continue to evolve.

And also, the authors call "the three major impacts in information technology fields", that is "PC impact" in 1980, "Internet impact" in 1995, and "smartphone and cloud impact" in 2010. In particular, real-world oriented systems such as LBS have increased. Moreover, many people have mobile phones since about 1995. At that time, the feature of the mobile phones was the information communication only. This is the first dimension. The positioning feature by GPS and MBS was added to the mobile phones since about 2000. This is the second dimension. Then, the sensing feature, e.g., accelerometers, gyroscopes, magnetic field

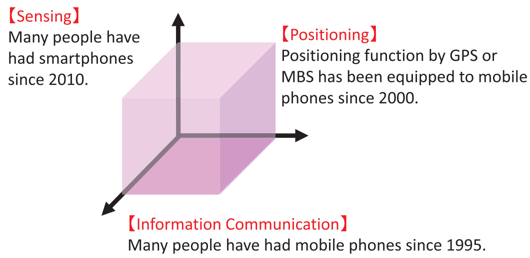


Fig. 1 Development and expansion in the fields of mobile-phones and smartphones.

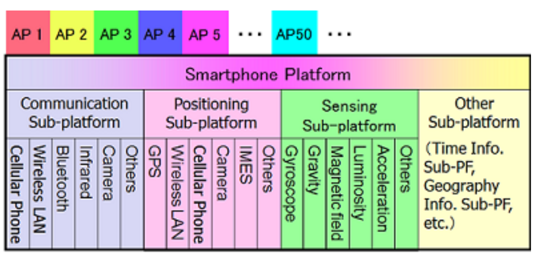


Fig. 2 Smatphone platform.

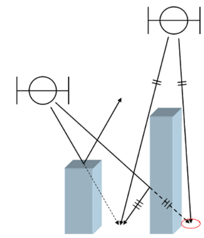


Fig. 3 Positioning situation that GPS does not work propely.

sensors and so on, can be used by smartphones that many people have since about 2010. This is the third dimension. Figure 1 illustrates the development and expansion in the fields of mobile-phones and smartphones. Then, the meaning of the second dimension of Fig. 1 (positioning) changed by "smartphone and cloud impact". That is, the information relating to position can be obtained from not only the existing positioning methods (e.g., GPS and MBS), but also the communication techniques (e.g., WLAN and short range communications).

With these basic concepts in mind, this paper advances the discussion about smartphone positioning.

2.2 Smartphone Positioning

A view of the smartphone platform structure (Fig. 2) is shown in [10]. The smartphone positioning sub-systems are GPS, WLAN, and MBS etc.

GPS is widely used as the first positioning social infrastructure. It provides the accurate smartphone positioning in the open sky. However GPS does not work properly in a building, an underground mall, or an outdoor area of multistory buildings, because of reflection, shielding, and attenuation of radio waves from GPS satellites [6]. Figure 3 illustrates the situation that GPS can not work well. For example, the positioning performance of GPS equipped mobile phones in the west exit area of Shinjuku Station was reported that the average error was 79.95 m and the maximum error was 812.61 m [13]. The positioning methods using WLAN are becoming the second positioning social infrastructure. However there are some problems of the stability of positioning performance caused by NLOS (non-line of sight) or unsteadiness of RSSI (received signal strength indicator), e.g., [14], [15]. The positioning methods by MBS use Cell ID or the advanced forward link trilateration (AFLT) based on the location of MBS and the radio wave intensity. However the positioning errors sometimes reach several kilometers due to the arrangement or density of MBS. Other positioning methods are as follows: M-CubITS (M-sequence Multimodal Markers for ITS; M-Cubed for ITS) [16] arranges the binary bit stream of m-sequence as markers onto the ground, spatially. Users take a picture of the markers their own camera equipped mobile devices, then the system specifies the positon and direction. IMES (Indoor Messaging System) [17] sets the transmitters and sends the location information by the same message structure as GPS and QZSS (Quasi-Zenith Satellites System). The IMES receivers get the location information from the message. iBeacon [18] sets the beacon transmitters and broadcasts the IDs by the Bluetooth Low Energy (BLE). The receivers get the location information by collating the received ID with databases. The transmitter can control the transmitting power, so the available range of positioning is changeable.

Typical operating systems of smartphones are two kinds, Android (e.g., [19]) and iOS (e.g., [20]). There are two methods that acquire the location information by the positioning social infrastructure as follows: 1) by the smartphone basic API (Application Programming Interface), 2) by implementing by developers.

In terms of 1), in the case of Android, *android.location* manages the location information and provides latitude, longitude, altitude, accuracy and so on. In the case of iOS, *CoreLocation.framework.CLLocationManager* manages the location information and provides latitude, longitude, altitude, horizontal accuracy, vertical accuracy and so on. In iOS, developers can select the desired accuracy from *best, 10 m, 100 m, 1 km, 3 km*.

In terms of 2), there are three methods that developers implement the second positioning social infrastructure (WLAN) to smartphones. The typical methods of WLAN are three kinds [21]. Proximity [22] is a technique that lists received signal strength from the access points observed by the estimation terminal and then estimates the position of the strongest signal access point as a position of the terminal. There is the disadvantage of lower position estimation ability than those of the other techniques, but it is possible to make estimates even in the past, since the estimation algorithm is easy and these are few access points. Trilateration (Triangulation) [23] is a technique for estimating a position

Table 1 List of experiment condition.

(a) Section 3: smartphone basic API.

Scheme	GPS, WLAN/MBS
Device	Android smartphone, Android tablet, iOS smartphone, iOS tablet
Place	outdoor
Condition	stationary, walk, in-vehicle

(b) Section 4: wireless LAN.

Scheme	WLAN
Device	Android smartphone
Place	indoor
Condition	stationary

Table 2 Smartphone & tablet specifications.

OS	Vendor	Model
Android	ASUS	Nexus 7 (2012)
Android	Samsung	Galaxy Nexus (SC-04D)
Android	Samsung	Nexus S
Android	SHARP	Aquos Phone Xx (SBM206SH)
Android	SHARP	Aquos Phone ZETA (SH-02E)
Android	Sony	Xperia SX (SO-05D)
Android	Sony	Xperia Z (C6603)
Android	Sony	Xperia Tablet S
iOS	Apple	iPhone 4S
iOS	Apple	iPhone 5
iOS	Apple	iPad (4th Gen.)
iOS	Apple	iPad mini (1st Gen.)

by using a relative position to the access point where the terminal observes the signal. The distance from the access point is calculated according to a wireless distance characteristic. Then, the position is estimated from the access point at three or more points. Scene analysis [24] is a technique that uses electrical wave reception strength to estimate a position by sampling in advance; this technique then uses the data acquired at two or more positions in the estimation area. The main advantage of this technique is accuracy at several meters. We use this technique in Sect. 4. However, it has the disadvantage of taking much time for prior sampling in the area where the system is used.

In this way, the positioning sub-systems on smartphones are increasing. However, there is no positioning sub-system realizing the accurate and precise positioning everywhere by simplex positioning sub-system. So the authors consider that it is important to design the positioning sub-platform, that integrates or aggregates the positioning results from several positioning sub-systems, for providing the high quality location information to various LBS. This paper presents a design methodology for the positioning sub-platform from the viewpoint of positioning for LBS under the premise of smartphones. So, through experiments of positioning performance evaluation under various environments, this paper analyzes the mechanism of positioning error generation including principles of positioning sub-systems and structure of smartphones.

The rest of this paper is organized as follows: The authors collect the location information by smartphone applications in order to evaluate the positioning performance of the smartphone basic API in Sect. 3. We carry out the experiments of smartphone positioning performance evaluation by the wireless LAN, that is the second positioning social infrastructure, in various environments in Sect. 4. Table 1 depicts the list of experiment condition in Sects. 3 and 4. Section 5 shows a design methodology for positioning sub-platform on smartphone based LBS through the experiments in Sects. 3 and 4.

3. Smartphone Positioning Using Smartphones Basic API

In this section, we carry out the experiments to clarify the positioning performance by the smartphone basic API, one of the methods that acquire the location information by the positioning social infrastructure.

3.1 Collecting Location Information by Smartphone Applications

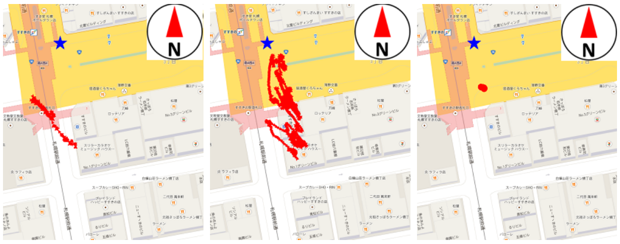
The authors collect the location information by smartphone applications in order to evaluate the positioning performance of the smartphone basic API. We developed the Android application that collects the positioning information of GPS and WLAN/MBS every second. The properties about positioning performance, *minimum time interval* and *minimum distance*, were set to the minimum value (zero). In the case of iOS devices, we utilized the general application that could get from App Store. The property about positioning performance, *desired accuracy*, was set to *best*. As above, the positioning information by iOS is the integrated result from GPS/WLAN/MBS. Experiment areas and conditions are as follows: 1) walking measurements in the central part of Sapporo, 2) in-vehicle measurements around Sapporo, and 3) stationary measurements at the Susukino intersection. The mobile devices for evaluation are shown in Table 2.

3.2 Positioning Results

The positioning results are shown in Figs. 4–10 (after that, the upper direction of maps is north, unless otherwise stated).

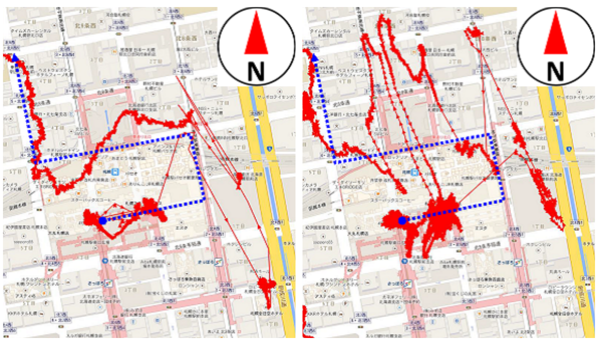
First, we carry out the experiment to clarify the positioning performance of the Android devices under the stationary condition. Figure 4 shows the stationary measurement results by GPS at the Susukino intersection. The measurement was carried out simultaneously at the northeast corner of the intersection. The positioning results were quite different in spite of the same measurement condition.

Second, we carry out the experiments to clarify the positioning performance of the Android devices in outdoor walking under various environments. Figure 5 depicts the walking measurement results by GPS around the Sapporo Station. Here, the real route was shown in the blue dashed line and the measuring route was shown in red solid line (the same hereinafter). We started from the south exit of the station and walked along the east side and the north side. Figure 5 were measured simultaneously. The south-east of



(a) Nexus 7. (b) Xperia Tablet S. (c) Xperia Z.

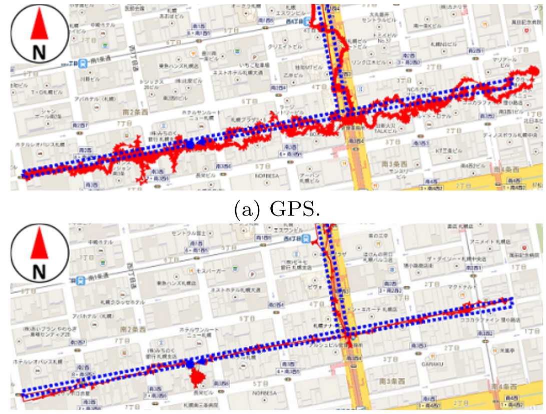
Fig. 4 Stationary measurement at Susukino intersection (Android, GPS, North is upper). The blue-colored stars show the measurement point.



(a) Nexus 7. (b) Xperia Tablet S.

Fig. 5 Walking measurement around Sapporo Sta. (Android, GPS).

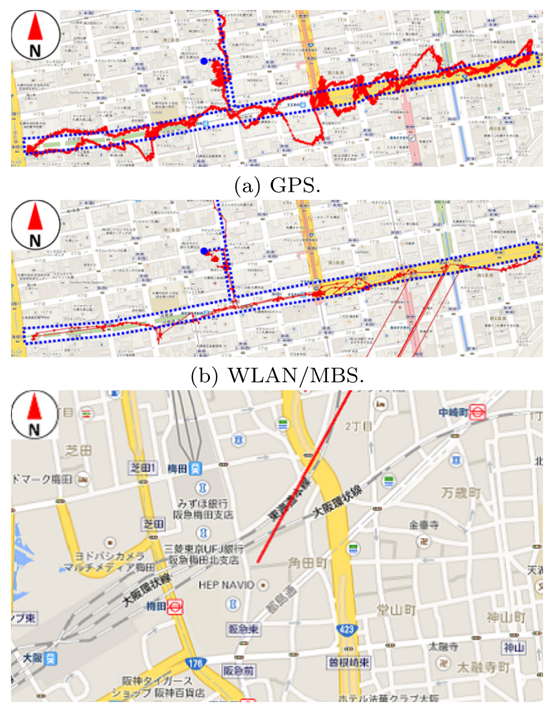
the station is the Sapporo Station bus terminal that is the first floor of a 10-story commercial building. GPS signals could not receive in there, so the positioning error was large. The east side of the station is a 38-story skyscraper. The large positioning error was caused by the same as Fig. 3. The north side of the station is a nine-story station building. The positioning error reason was the same as the case of the east-side. Figure 6 shows the walking measurement results along the Tanukikoji shopping street. Here, we compare GPS with WLAN/MBS. There are arcades along the street and access points (AP) of WLAN at several stores in the street. We walked back and forth along the street. Figure 6(a), the case of GPS, shows that the several positioning results are outside of the shopping street. In contrast Fig. 6(b), the case of WLAN/MBS, shows the almost positioning results are inside of the street. Figure 7 illustrates the walking measurement results along the Sapporo South 4th street. We walked on the sidewalk of the north side to the west direction, and on the sidewalks of the south side to the east side. There were many buildings in the environment, so the positioning error by GPS was large. Although we walked on sidewalks, the positioning results by WLAN/MBS were to a center of the roadway. In Fig. 7(b), some of positioning results were into Osaka City. It shows in Fig. 7(c) and the reason is described in 5.1.2. Figure 8 shows the walking measurement results in Hokkaido University. Here, the number of APs that can be observed is changed during a movement. If the observable AP of WLAN decreased, e.g., a place that was far from buildings, the positioning error became large. Consequently, the existing positioning subsystems, i.e., GPS,



(a) GPS.

(b) WLAN/MBS.

Fig. 6 Walking measurement along Tanukikoji street (Xperia Z).



(a) GPS.

(b) WLAN/MBS.

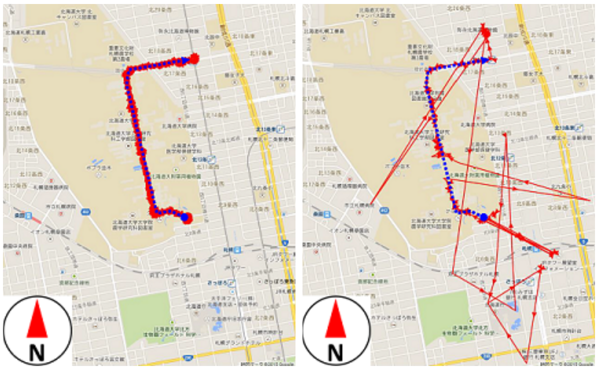
(c) Example of position specified at Osaka (WLAN/MBS).

Fig. 7 Walking measurement along South 4th Street (Xperia Tablet S).

WLAN, and MBS, on Android devices can not realize the accurate and precise positioning singly.

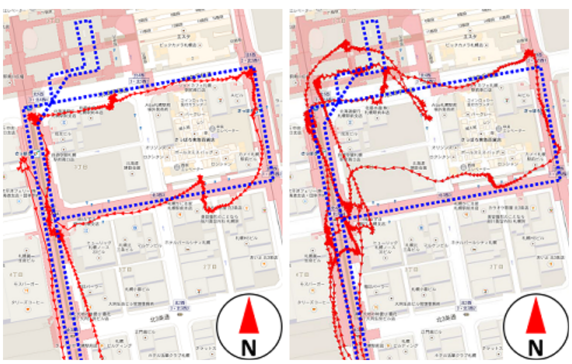
Third, we carry out the experiments to clarify the positioning performance of the Android devices during the vehicle running. Figure 9 is illustrated the in-vehicle measurement results around the Sapporo Station. It shows that the positioning error is large because there are many buildings. These results show that it is impossible to specify the driving lanes on roadways.

Last, we carry out the experiments to clarify the positioning performance of the iOS devices. Figure 10 shows the measurement results by iOS devices. These results show the accurate positioning is realized where smartphones can



(a) GPS. (b) WLAN/MBS.

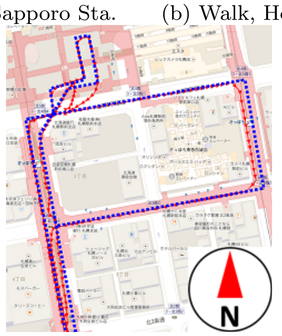
Fig. 8 Walking measurement in Hokkaido Univ. (Nexus S).



(a) Sapporo Sta. (Galaxy Nexus). (b) Sapporo Sta. (Xperia Tablet S).

Fig. 9 In-vehicle measurement (Android, GPS).

(a) Walk, Sapporo Sta. (b) Walk, Hokkaido Univ.



(c) In-vehicle, Sapporo Sta.

Fig. 10 Dynamic measurement (iOS).

receive direct radio waves from GPS satellites. However, it is not enough to realize the accurate and precise positioning by the integration of positioning subsystems on iOS.

4. Smartphone Positioning Using Wireless LAN in Various Environment

In this section, we carry out the experiments to clarify the positioning performance by implementing by developers, one of the methods that acquire the location information by the positioning social infrastructure. We use the scene analysis [24] as a WLAN positioning technique.

4.1 Basic Experiment

The WLAN positioning by the scene analysis [24] is based on RSSI. Then, as the basic experiment, we investigated the relation between AP-terminal distance and RSSI, the influence shielding by humans. The experiment was carried out at an outdoor ground and an indoor corridor in Saitama University. The outdoor ground is by the side of the athletics track where there are no obstacles causing reflection or shielding of radio waves, and the indoor corridor is shown in Fig. 11. We used the WLAN access point, Buffalo WHR-300 (IEEE 802.11n/g/b, 2.4 GHz band), and set it at a height of 2 m. We used the smartphone, Samsung Galaxy S (SC-02B), as the receiver, and installed the smartphone application that acquires the value of RSSI every second. The smartphone was set on a tripod in order to keep the height stable. The height of the smartphone was 1.2 m considering that people hold it in their hand. The measurement was carried out at six points between AP and the smartphone at intervals of 5 m, and observed the value of RSSI for 30sec on each measurement point. In this experiment, LOS is the condition opposing human and AP, the smartphone is between them, and NLOS is the condition that human is between AP and the smartphone.

The experiment results at the outdoor ground and indoor corridor are shown in Fig. 12(a) and Fig. 12(b) respectively. At the outdoor ground, the average RSSI drops as the AP-terminal distance becomes longer. The average RSSI of NLOS dropped below 10 dBm against LOS. In the case of the indoor corridor, there was no correlation between AP-terminal distance and RSSI. It was different from the outdoor ground. These results show that the indoor radio wave environments are complex. It became clear that the radio wave shielding by humans influenced the average value of RSSI.

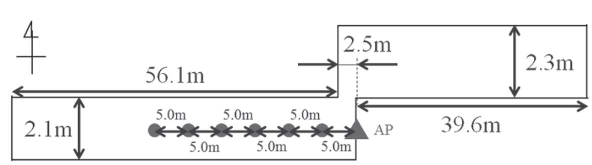


Fig. 11 Experiment environment at indoor corridor.

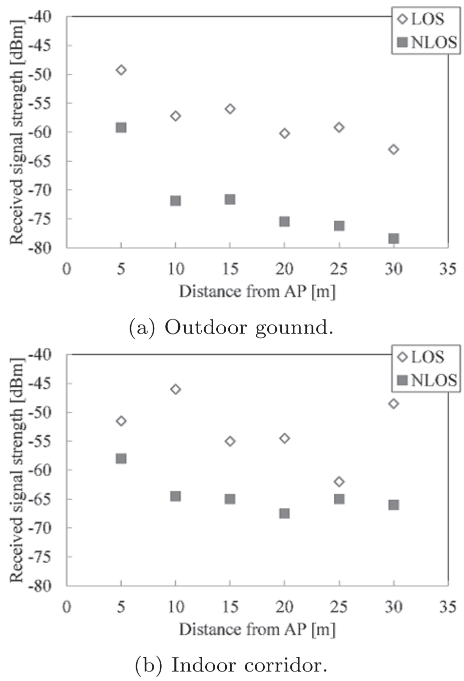


Fig. 12 Distance characteristics of WLAN RSSI.

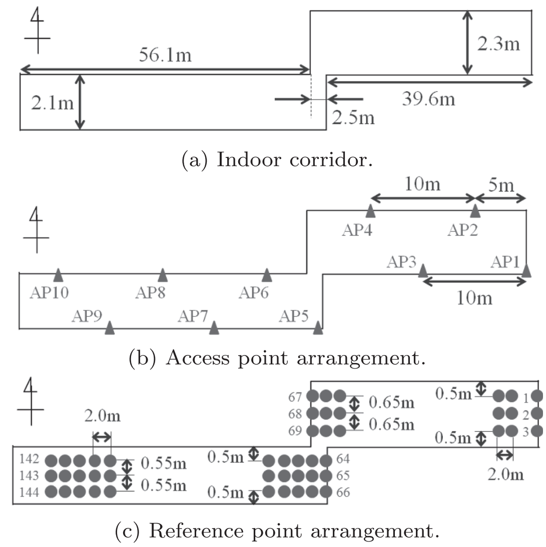


Fig. 13 Experiment environment.

4.2 Positioning Experiment in Indoor Corridor

4.2.1 Influence of Radio Wave Shielding by Humans

We carry out the experiment that the radio wave shielding by humans influences the positioning performance in the indoor corridor. The smartphone, AP, and their installation methods are the same as 4.1. The experiment environment is shown in Fig. 13(a). Figure 13(b) is shown the arrangement of the 10 access points. Figure 13(c) shows the arrangement of the 144 reference points (measurement points).

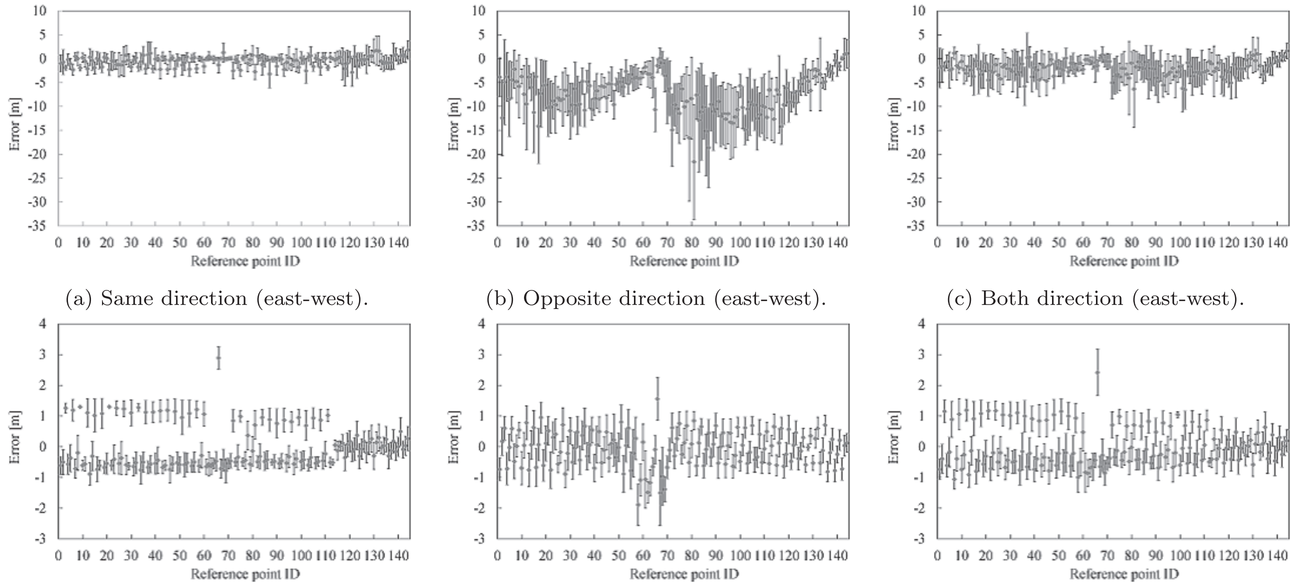
The scene analysis [24] was used as the positioning method in this experiment. Database structure† and positioning algorithm†† are the same as [24]. The data of the access points for the scene analysis method is two kinds: for database (below is called learning data) and for positioning performance evaluation (below is called evaluation data). The learning data and the evaluation data were gathered 30sec at each reference point. Here, we evaluate the influence of the radio wave shielding by humans, so the evaluation data is obtained in one direction (the user is facing the West) and the learning data is obtained in two directions (the user is facing the West and East, respectively). Then we construct three types of databases shown below: 1) The learning data direction was same as the evaluation data, i.e., West. We called it "*same*". 2) The learning data direction was NOT same as the evaluation data, i.e., East. We called it "*opposite*". 3) The learning data had two directions, i.e., both of West and East. We called it "*both*".

The experiment results are shown in Fig. 14 and Fig. 15. The error bars mean the standard deviation. Figures 14(a)–(c) depict the error in east-west direction (positive in the east direction), Figs. 14(d)–(f) illustrate the error in north-south direction (positive in the north direction), and Fig. 15 shows the total error in east-west direction (positive in the east direction). Here, the average errors of RP#65 of Figs. 14(d)–(f) are larger than the other RPs. RP#65 is a singular place that is alongside the wall in the crank corridor, as indicated in Fig. 13(c). It is likely that the radio wave propagation environment in such a place is very complex because of shielding, reflection, interference and so on. The *same* was the best positioning performance in accuracy and precision, and the *opposite* was the worst. It shows that the positioning performance deteriorates in the opposite observed direction between learning data and evaluation data, in other words the radio wave shielding by humans. The *both* did not reach the *same* but the average errors at each reference point were within approximately five meters (Fig. 14(c)). In Fig. 15, all of them were negative values. When gathering the evaluation data, the measurer was facing the west direction. RSSI of APs behind the measurer is affected by the radio wave shielding and absorption by humans and it becomes weaker. That is, the RSSI frequently distribution of APs behind the measurer becomes dissimilar to the actual position and becomes similar to the West of the actual position.

Consequently, from the viewpoint of the positioning performance by WLAN, it is important that the database should be constructed in several directions at the environments that the moving direction of people is not determined.

†Database is configured by a probability distribution $P(a|b, c_j)$, observed RSSI α, observed BSSID β, and state $c_j = (x_j, y_j)$.

††Positioning algorithm is based on Bayesian inference.



(a) Same direction (east-west). (b) Opposite direction (east-west). (c) Both direction (east-west).

(d) Same direction (north-south). (e) Opposite direction (north-south). (f) Both direction (north-south).

Fig. 14 Positioning error at each reference point in different measuring directions.

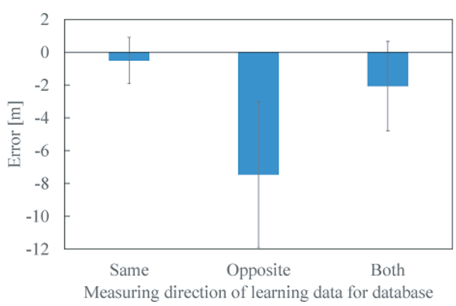


Fig. 15 Positioning error comparison with different measuring directions (east-west).

4.2.2 Attribution Difference of Access Points for Positioning

In 4.2.1, we evaluated the positioning performance by the dedicated access points for the experiment (below is called the dedicated AP). The scene analysis method can use the existing access points that are installed for other purpose, e.g., communications (below is called the general AP), because the installed location information of AP is not required. Then, we evaluate the relation between the attribution difference of access points for positioning and the positioning performance. The experiment environment is the same as 4.2.1. In the environment, the 103 general APs were observed. The construction direction of database is the same direction. Here, we evaluated average error and standard deviation in the east-west direction about dedicated AP (10 APs; same as 4.2.1), general AP (103 APs), and both of dedicated AP and general AP (113 APs) at each reference point.

Figures 16 and 17 show the experiment results. If there were many access points available for positioning, the positioning accuracy became high. In particular, the accuracy was improved by adding the dedicated AP at the rate of 10% based on the number of the general AP.

Consequently, the dedicated AP, that is the exclusive AP for positioning, is effective for the positioning performance using WLAN.

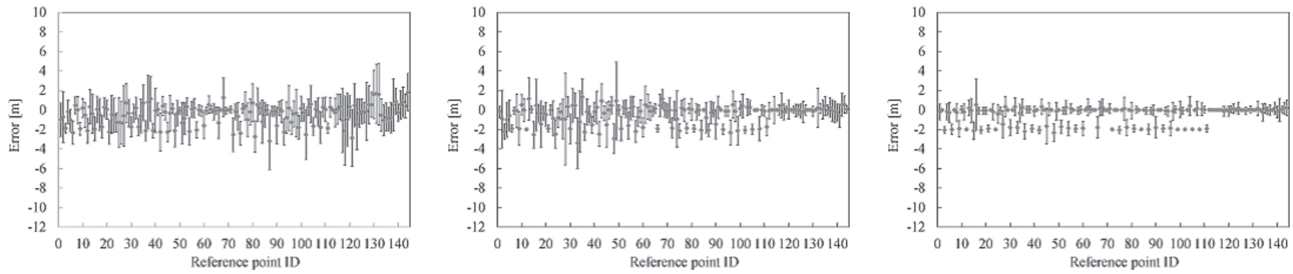
4.3 Positioning Experiments at Gymnasium, Ground, Courtyard, and Parking Lot

To verify the experiment result of 4.2.2, we carry out experiments in the different positioning environments — gymnasium, ground, courtyard, and parking lot — in Saitama University. Figure 18(a) shows the experiment places and the number of general AP at each place. Figure 18(b) depicts the arrangement of the 10 dedicated AP and the 20 reference points. Those arrangement are used in each experimental place of Fig. 18(a). The construction direction of database is the same direction. Other experiment conditions are the same as 4.2. Here, we evaluated average error and standard deviation in the east-west direction about dedicated AP, general AP, and both of dedicated AP and general AP at each experiment place.

Figure 19 shows the experiment results. The same as 4.2, we checked that the positioning performance was improved by adding the dedicated AP into the general AP.

4.4 Positioning Experiment in Event Site

In order to evaluate the positioning performance in event site that is an environment requiring LBS such as pedestrian navigation systems, we carried out experiments in the exhibition site of ITS World Congress Tokyo 2013 held at



(a) Didicated AP. (b) General AP. (c) Didicated + general AP.

Fig. 16 Positioning error at each reference point in different attributes of AP.

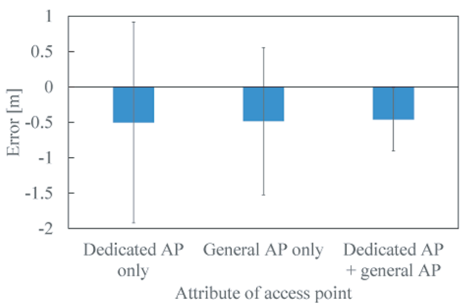
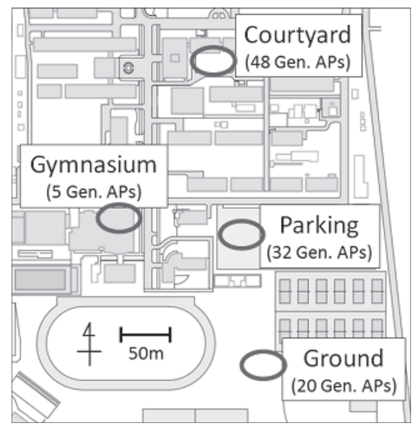
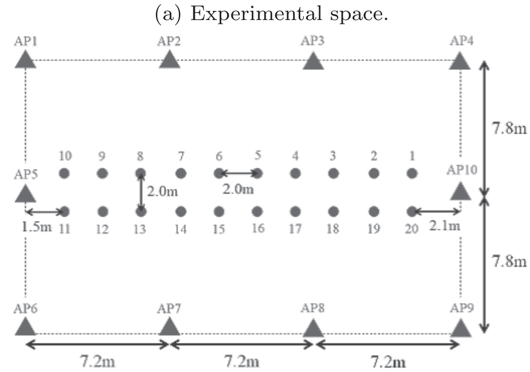


Fig. 17 Positioning error comparison with different attributes of AP (east-west).



(a) Experimental space.



(b) Access point and reference point arrangement.

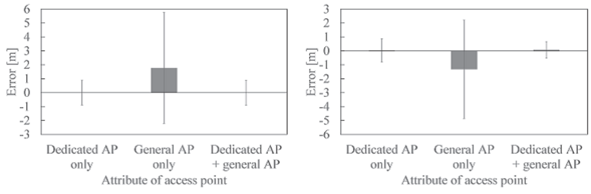
Fig. 18 Experiment environments.

Tokyo Big Sight (West Hall 1 and 2) from Oct. 14th, 2013 to Oct. 18th, 2013. The experiment environment is shown in Fig. 20. The 22 access points, the same as the previous experiments, were used. The reference points gathering the learning data are 232 places, and they show as white circles in Fig. 20. Meanwhile 14 places were combined with the measurement points gathering the evaluation data (white diamonds in Fig. 20). The measurement methods are the same as the previous experiments. Data were collected in multiple directions at each reference point for considering the radio wave shielding by humans. Specifically, collecting data 15 sec in the upper direction of Fig. 20 at first, then rotating smartphones 90° to clockwise (the right direction of Fig. 20). Data collected in four directions by the procedure as a set. The learning data collection date was Oct. 14th, 2013, it was before the event. The evaluation data collection date was Oct. 18th, 2013, it was during the event. The evaluation index was the mean value and the standard deviation of the positioning error that is the distance from the true position, at the 14 measurement points. Table 3 shows the smartphones of the experiment.

The experiment result is shown in Fig. 21(a). The bar graphs are the mean value and the error bars are the standard deviation. The places that the average positional error was less than 10 m were #21 and #164. #53 was the mean value 55.12 m and the standard deviation 76.15 m. The positioning performance like this will lower the quality of LBS such as pedestrian navigation. Improvement is required.

4.4.1 Utilization of General AP

We carried out the evaluation adding the general AP based on the experiment results of 4.2 and 4.3, in order to improve the positioning performance. Here, the general AP was the included AP in both of the learning data and the evaluation data. The total number of general AP was 132. The experiment result is shown in Fig. 21(b). The positioning performance at #47, #50, #53, and #174 were improved by adding the general AP. On the other hand, #21, #26, and #152 deteriorated the positioning performance. Improvement is still required.



(a) Gymnasium. (b) Ground. (c) Courtyard. (d) Parking lot.

Fig. 19 Positioning results at various environments.

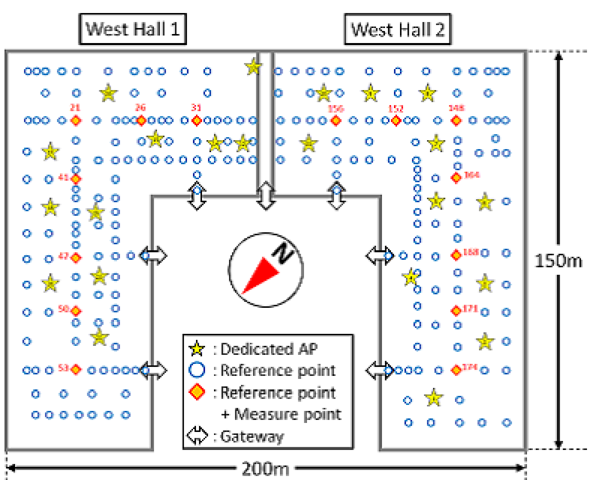


Fig. 20 Experiment environment.

Table 3 Smartphone specifications.

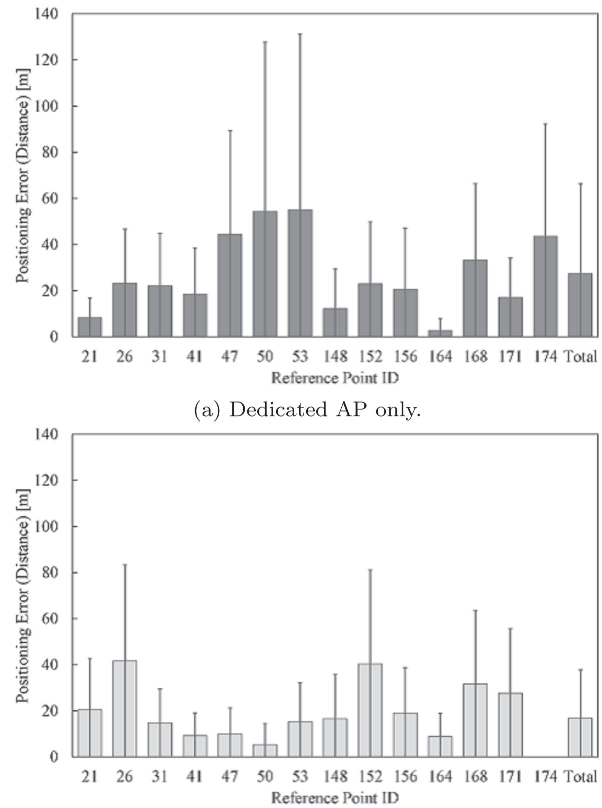
OS	Vendor	Model
Android	Panasonic	ELUGA X (P-02E)
Android	LG	Nexus 4
Android	Samsung	Galaxy Nexus (SC-04D)
Android	Samsung	Galaxy S II LTE (SC-03D)
Android	Samsung	Nexus S
Android	SHARP	Aquos Phone Xx (SBM206SH)
Android	SHARP	Aquos Phone ZETA (SH-02E)
Android	Sony	Xperia P (LT22i)
Android	Sony	Xperia SX (SO-05D)
Android	Sony	Xperia Z (C6603)

4.4.2 Investigating BSSID and RSSI of Learning Data and Evaluation Data

The results in the event site were not satisfactory, and differed from [25], [26]. Then, we investigated BSSID (Basic Service Set Identifier) and RSSI of the learning data and the evaluation data.

First, the investigation of variation of BSSID was carried out. Table 4 shows the BSSID variation of the dedicated AP at each measurement point. Here, "+" means the increase of BSSID from the learning data, and "-" means the decrease of BSSID from the learning data. There was the BSSID variation at many measurement points. In particular, nearly half of BSSID of the dedicated AP were changed at #53.

Next, the investigation of RSSI frequency distribution was carried out. Here, Fig. 22 shows the RSSI relative frequency distribution at the four representative measurement points, #21, #53, #148, and #174. There was unevenness in the distribution at some measurement points. These varia-



(a) Dedicated AP only.

(b) Dedicated AP + general AP.

Fig. 21 Positioning results in event site.

Table 4 BSSID variation of dedicated AP.

AP\RP	21	26	31	41	47	50	53	148	152	156	164	168	171	174
1						+	+	−	−					
2						+	+	−	−	−				
3						+	+		−	−				
4						+	+		−				+	+
5									−	−				
6										−				
7										−				
8										−				
9			−										−	
10			+										−	−
11			+	−							−			−
12	−	−	+					+	+				+	
13		−								−			+	
14		−			−	−								
15	+	+	+					+	+	+				
16		−	+	−	−		+	−						
17							−		+	+				
18			+	+	+	+	+							
19	+	+	+	+	+	+	+							
20		+			+	+	+							
21	−	−	−											
22				+	+	+	+							
+	2	3	7	3	4	8	9	2	3	2	0	0	3	1
−	2	5	2	2	2	1	1	3	5	7	1	0	2	2

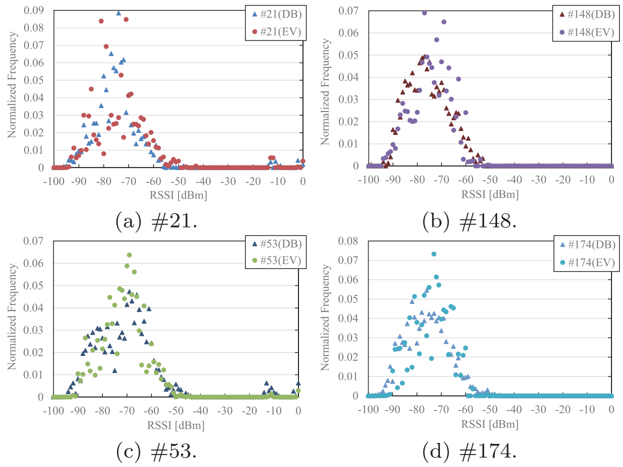


Fig. 22 RSSI relative frequency distribution.

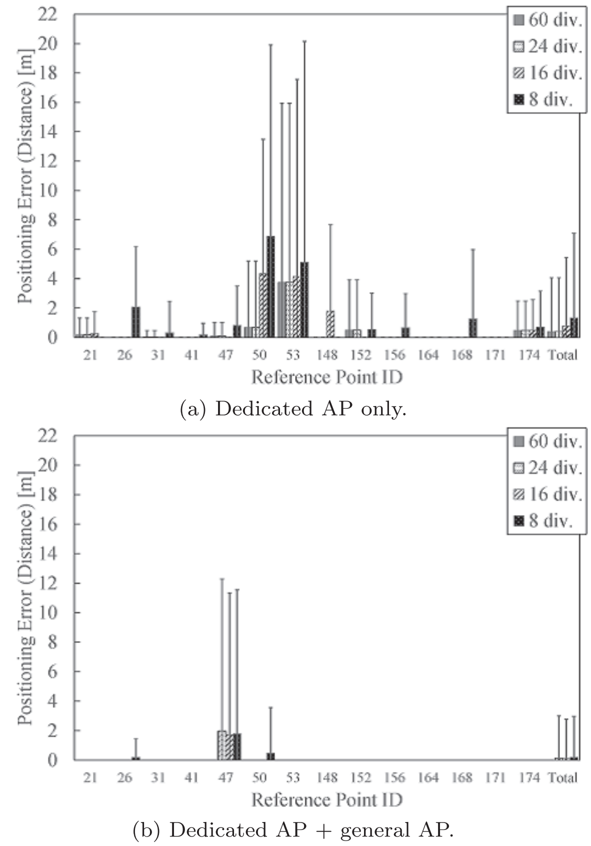


Fig. 23 Investigation of the positioning performance without data variations.

tions are caused by increase of people, that is, 1) shielding and attenuation by many people; 2) channel interference by increase of mobile routers or tethering devices; 3) packet collision by increase of WLAN communication devices.

Last, we carried out the investigation of the positioning performance in the case that the data did not include these variations. Then, we divided the evaluation data into two types. One was used for database, the other was used for evaluation. The original evaluation data include four measurement directions, so we should divide them uniformly. Hereupon, we divide the original evaluation data into 8, 16, 24, and 60. Then, the odd-numbered divided groups are used for database, and the even-numbered divided groups are used for evaluation. The result shows in Fig. 23. We were able to get a favorable result.

5. A Design Methodology for Positioning Sub-Platform from the Viewpoint of Positioning for Smartphone-Based LBS

This section presents a design methodology for the positioning sub-platform from the viewpoint of positioning for LBS under the premise of smartphones in keeping with the experiment results of Sects. 3 and 4. Smartphones have the platform structure as described above, so it is important to consider the three layers as follows for describing the design guidelines; 1) lower layer: caused by positioning subsystems, e.g., GPS, WLAN, MBS, and so on; 2) middle layer: caused by functions provided from the platform such as Android and iOS; and 3) upper layer: caused by operation algorithm of applications on the platform.

5.1 Lower Layer

5.1.1 GPS

As described in Sect. 2, GPS does not work properly in a building, an underground mall, and an outdoor area of multistory buildings, because of reflection, shielding, and attenuation of radio waves from GPS satellites. The same results were observed in Figs. 5, 6(a), 7(a), and 9. The places convenient for use of GPS are within the direct reach of radio waves from GPS satellites, that is seas, mountains, plains, airports, and residential areas etc. [6]. Devices without communication functions cannot use the Assisted GPS (A-GPS), so the initial positioning needs time.

5.1.2 Wireless LAN

Presupposing smartphones, the positioning by WLAN can be used by most devices. The scene analysis method can use the existing access points that are installed for other purpose, e.g., communications, and may be realized by the low infrastructure investment. On the other hand, as described in Sects. 3 and 4, the positioning methods by WLAN have some problems of the positioning performance stability. Those were shown in Figs. 7(b), (c), 8(b), 21 and so on. In particular, the database construction, the database update, the algorithm considering the unsteadiness of RSSI. The database construction methods are necessary to consider two cases: 1) using the smartphone basic API, 2) preparing by application developers.

In the case utilizing the smartphone basic API, application developers are not needed to construct the database for the WLAN positioning. However, the consideration of the database constructing method is needed. In the case of Android, there can be classified into the following four types:

A. The places that are provided Google indoor maps (stations, airports, commercial buildings, etc.): It is realized by Google staffs collect the WLAN's BSSID/RSSI and the location information at each lattice point in target areas.
B. The places that are provided Google street view (major cities etc.): It is realized by the street view cars collect the WLAN's BSSID/RSSI and the location information of the car navigation system. This is the reason that the positioning result by WLAN/MBS is to a center of the roadway when we have walked on sidewalks of the Sapporo South 4th street (Fig. 7(b)).
C. The places that GPS positioning is available (except A and B): Users that their smartphone can use both GPS and WLAN provide automatically the information of BSSID and RSSI of WLAN binding the location information of GPS for Google's servers. In this case, the positioning accuracy by WLAN depends on the positioning performance of GPS. In other words, if the positioning results by GPS have errors, the data for the WLAN positioning (it includes the errors), are stored on database servers.
D. Others: The accurate and precise positioning by the smartphone basic API cannot be expected.

If application developers construct databases, the following points should consider.

- Location information linking BSSID and RSSI of WLAN: The location information can be input by the following two ways: 1) Measurers input the location information manually; 2) Utilization of the results from other positioning systems, e.g., GPS. In the latter case, it is necessary to be careful to learning the data including the positioning errors of the positioning systems.
- Measurement environments: It needs to take care in the case the changes in radio wave environments are large between the learning data and the evaluation data as mentioned in 4.2(humans' walking directions) or 4.4(the number of people). The causes of the large changes are as follows: radio shielding by humans, existence of mobile routers or tethering terminals, changes of transmission state.

The database update in the case using the smartphone basic API depends on the database constructing methods. The database construction method A is that the databases are not updated unless re-investigations by Google. The database construction method B and C are that the databases are continuously updated as long as there are users that their smartphone can use both GPS and WLAN. However, it takes time to reflect the changed data in positioning results because it is required to store the multiple data. Figure 7(c) is an example of it. An access point was stored in databases of Google when it was at Osaka, but the access point was at Susukino when we visited there. In the case preparing by application developers, the mechanism updating cautiously is needed at the places that the radio wave environments change frequently.

An example of consideration about algorithm compatible with the unsteadiness of RSSI is [27].

5.1.3 Mobile Base Station

As described in Sect. 2, the positioning methods by MBS use Cell ID or AFLT. However the positioning errors sometimes reach several kilometers due to the arrangement or density of MBS, e.g., [28].

5.1.4 Short Distance Radio Communications

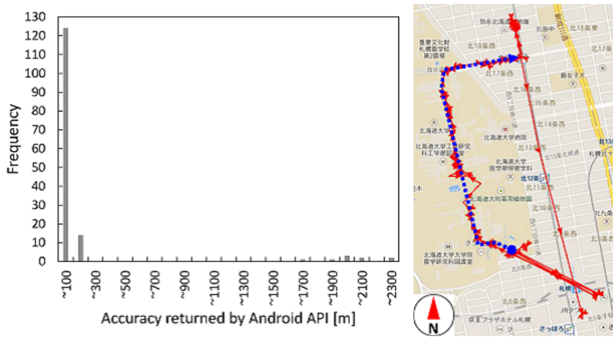
It became possible to get the location information by various positioning sub-systems by the smartphone and cloud environment since 2010. In particular, it became possible to get the information about locations by the short distance radio communications. IMES [17] can be used by rewriting the firmware of GPS chips mounted on the various mobile devices. This is a skillful technique. However, it is needed to set the transmitters for positioning, and the infrastructure investment is required. iBeacon [18] uses Bluetooth 4.0. Bluetooth is equipped in many smartphones. The iBeacon transmitters are not expensive than the IMES transmitters, but the infrastructure investment is needed too.

5.2 Middle Layer

It is important to consider dividing Android and iOS. As mentioned in Sect. 2.2, the location information of iOS is managed by *CoreLocation.framework.CLLocationManager*. The iOS basic API provides the estimated location by the algorithm of iOS from data of GPS/WLAN/MBS (e.g., Fig. 10). The Android basic API deals with the location information of GPS and WLAN/MBS separately (e.g., Figs. 6, 7, and 8). Specifically, the data acquisition of GPS location information realizes by setting the property of *LocationManager* to *GPS_PROVIDER*. And the data acquisition of WLAN/MBS location information realizes by setting the property of *LocationManager* to *NETWORK_PROVIDER*. The provided results of WLAN/MBS cannot be separated to WLAN and MBS on the application side. Therefore, if the positioning by WLAN is not available, the positioning result of MBS are provided from API. It was shown in Fig. 8(b) obviously. However, if the SIM (Subscriber Identity Module) is not inserted into the mobile devices, the positioning results by WLAN only.

5.3 Upper Layer

In the recent year, applications that work almost similarly on Android and iOS are developed. However, it is often difficult to develop the applications that work with the same algorithm, because the functions provided from the middle layer are different as it was previously mentioned. The iOS



(a) Accuracy frequency distribution. (b) After exclusion.

Fig. 24 Considering the positioning results of WLAN/MBS by Android.

API provides the location information that is estimated from GPS/WLAN/MBS. On the other hand, the Android API separately provides the information of GPS and WLAN/MBS. On the Android API, it is impossible to separate the results of WLAN and MBS. Here, we obtain the frequency distribution of the accuracy provided from API of Fig. 8(b), and show in Fig. 24(a). Then, Fig. 24(b) shows the results excepting the data that the accuracy is more than 300 m. It is shown that the filtering by the accuracy value from API can be used for high-quality smartphone positioning.

The systems constructed on the platform like Android or iOS are easy to spread, because the installation is realized by application downloading. However, it is required to develop the applications for each platform. On the other hand, web-based systems, e.g., HTML5 and Phone Gap, do not depend on OS, so the cost will be made lower. However, it is required to understand the mechanism of the added frameworks in addition to the smartphone platform.

6. Conclusion

This paper has presented a design methodology for the positioning sub-platform from the viewpoint of positioning for smartphone-based LBS. To achieve this, we have analyzed the mechanism of positioning error generation including principles of positioning sub-systems and structure of smartphones. Specifically, we have carried out the experiments of the smartphone positioning performance evaluation by the smartphone basic API and by the WLAN in various environments. Then, we have described the importance of considering the three layers as follows for describing the design guidelines: 1) the lower layer that caused by positioning sub-systems, e.g., GPS, WLAN, MBS, and so on; 2) the middle layer that caused by functions provided from the platform such as Android and iOS; 3) the upper layer that caused by operation algorithm of applications on the platform. As future work, we will construct the smartphone seamless positioning framework based on the design methodology.

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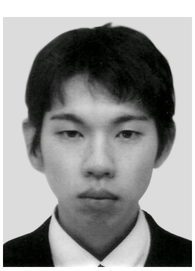

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