NAVIGATION FOR LOCATION-BASED DATA ACQUISITION USING GEOFENCES

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ABSTRACT

Users require navigation for many location-based applications using moving sensors. In indoor environments, instabilities in sensor position data acquisition remain, because the indoor environment is more complex than the outdoor environment. On the other hand, simultaneous localization and mapping processing is better than indoor positioning for measurement accuracy and sensor cost. However, it is not easy to estimate position data from a single viewpoint directly. Thus, we focus on geofencing techniques to improve position data acquisition. We propose a methodology to estimate more stable position or location data using unstable position data based on geofencing in indoor environments.

1. INTRODUCTION

Various location-based data acquisition systems have been proposed for indoor-outdoor applications, such as mobile services, traffic analyses, evacuation planning, autonomous robots, mapping, and infrastructure asset management. In many applications using moving sensors, such as autonomous robot control, mapping route navigation, and mobile infrastructure inspection, users require 2D or 3D navigation with location-based data acquisition. In an outdoor environment, global navigation satellite system (GNSS) receivers, mounted on smartphones and tablet PCs, are generally used to estimate a sensor's position. In particular, precise position data can be acquired using real-time kinematic GNSS. Acceleration and magnetic direction sensors are mounted in recent smartphones and tablet PCs. Therefore, navigation for location-based data acquisition can be conducted easily.

On the other hand, in indoor environments, WiFi (Liu et al. 2012), radio-frequency identification (RFID) (Athalye et al. 2015), Bluetooth (Ahmed et al. 2014), and indoor messaging systems (IMESs) (Manandhar et al. 2008) have also been developed for use as indoor positioning and navigation services. These indoor positioning systems when combined with GNSSs can provide seamless indoor-outdoor positioning and navigation services. Mobile hardware development has improved the availability of positioning services, which requires quality improvement of the positioning services themselves. However, the instability in sensor position data acquisition remains, because the indoor environment is more complex than the outdoor environment. In addition, although positioning accuracy is an important issue in location-based services, many other significant issues, such as availability, integrity, and reliability must be considered in the quality improvement of positioning services.

When precise sensor position data are acquired in indoor environments, simultaneous localization and mapping (SLAM) (Durrant-Whyte et al. 2006, Bailey et al. 2006) processing is better than simple indoor positioning in terms of measurement accuracy and sensor cost. However, it is not easy to estimate position data from a single viewpoint directly. In particular, because the indoor environment consists of repetitive features, it is not easy to find corresponding features among images and point clouds.

Based on these technical issues, we focus on geofencing techniques (Nakamura et al. 2015) to improve of position data acquisition. Geofencing techniques use positioning data and a preset polygon on a map, called a virtual fence. In this paper, we propose a methodology to estimate more stable position or location data using unstable position data based on geofencing in the indoor environment. We verify our methodology through some experiments in the indoor environment.

2. METHODOLOGY

A general geofencing technique combines GNSS positioning with a virtual fence. The geofencing technique provides active and push-based controls in location-based service for a mobile device with detection when entering the entrance to the virtual fence or exiting from the virtual fence.

Geofencing can be applied to indoor positioning. When discrete beacon-based positioning is applied, a polygon preset can be omitted, as shown in Figure 1. Moreover, it is possible to improve resolution of virtual fences with fingerprint-based positioning.

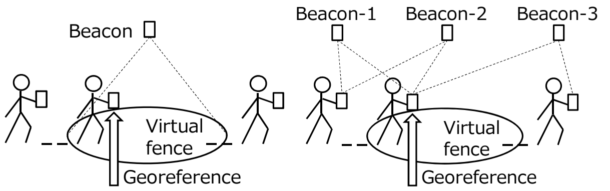

Fig. 1 Geofencing using beacons (left image: geofencing using the strongest signal from beacons, right image: fingerprint-based geofencing using beacons)

Our geofencing-based positioning methodology is based on indoor positioning techniques. There are popular indoor positioning algorithms, such as time of arrival (ToA), time difference of arrival (TDoA), angle of arrival (AoA), and received signal-strength indication (RSSI) positioning (Golden et al. 2007). In an actual indoor environment, ToA, TDoA and AoA positioning are deeply affected by multipath transmission. On the other hand, RSSI positioning is more robust than the other methods. Moreover, RSSI can provide position data without precise synchronization among transmitters. In particular, cheap transmitters, such as iBeacon, have recently been used for RSSI positioning. Therefore, we apply RSSI positioning using the iBeacon to estimate sensor position data in this research. We test two types of geofencing positioning approaches.

2.1 Nearest neighbor-based positioning

Our first positioning approach is nearest neighbor-based positioning (Figure 2). First, position data are determined for each transmitter by surveying. Second, signals from transmitters are received at a point. Received signal-strength (RSS) values from the transmitters are measured. Each signal from an iBeacon transmitter has a unique identifier. Thus, the strongest signal can be distinguished from the other signals. Therefore, we can identify the transmitter nearest to the receiver point. Third, the distance from the nearest beacon transmitter to the receiver is estimated from the measured RSS values. The distance can be calculated using the following equation based on the Friis transmission formula:

$$\text{Distance} = 10^{((\text{TxPower} - \text{RSSI}) / 20)},$$

where, the TxPower is the RSS value at 1 m point from an iBeacon transmitter.

Finally, geofencing is applied to estimate the receiver point. A virtual fence is assumed as a circle or ball with the transmitter as the center and the distance as the radius of the circle or ball. When the virtual fence or geofence includes the receiver point, the nearest transmitter point data are assigned to the receiver.

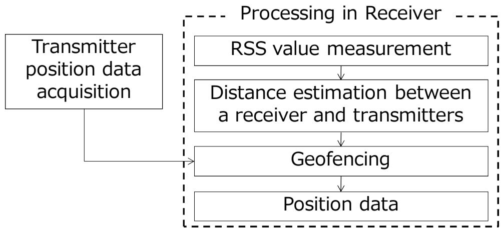

Fig.2 Nearest neighbor-based positioning

2.2 Fingerprint-based positioning

The second positioning approach is fingerprint-based positioning (Jiang et al. 2015). In a general fingerprint localization methodology, the access point with the highest RSS value is denoted as the important access point (IAP). At the localization stage, the fingerprints with the same IAP as the estimated fingerprint are chosen from the database to estimate the location.

In our research, fingerprint-based positioning consists of fingerprint map generation and position data estimation with geofencing, as shown in Figure 3. First, a fingerprint map is generated. Generally, RSS values are measured at 1 m or 2 m pitch in a space to generate the fingerprint map. However, these RSS measurements often require a huge amount of work. Thus, in this research, interpolation using measured values at discrete measurement points is applied to reduce the RSS value measurement work. RSS values from all transmitters are measured, with transmitter positioned at approximately 10 m pitch. Then, RSS values are interpolated into the space with 1 m pitch. In this research, the spline interpolation is applied to estimate the fingerprint map. Second, an adequate position value is estimated by finding a minimum of subtracted values between RSS values from the fingerprint map and RSS values of all signals at the receiver position.

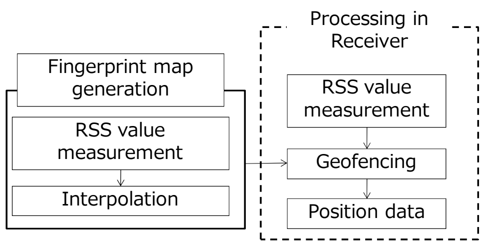

Fig. 3 Fingerprint-based positioning

3. EXPERIMENT

We conducted experiments in an indoor space. We selected corridors in our campus, including one 97.2 m long (2.0 m width and 2.8 m height), as shown in Figure 4. First, we prepared our 3D data acquisition system. This system consisted of a time-of-flight (TOF) camera (SR4000, mesa), a front camera (QBiC MS-1, ELMO), a horizontal panorama camera (Kodak PIXPRO SP360), an attitude and heading reference system (MTi-G, XSENS), and a laptop PC (MacBook Air, Apple) with the bleacon Node.js library as an iBeacon receiver. These sensors were synchronized within 1 sec with the PC clock. This system mainly measured point cloud data with the SLAM using the TOF camera, as shown in Figure 5. This system can receive signals from all iBeacon transmitters within approximately 1 Hz.

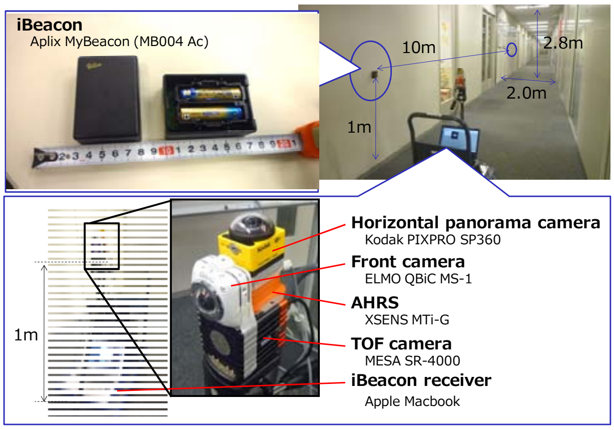

Fig. 4 Study area and indoor 3D data acquisition system

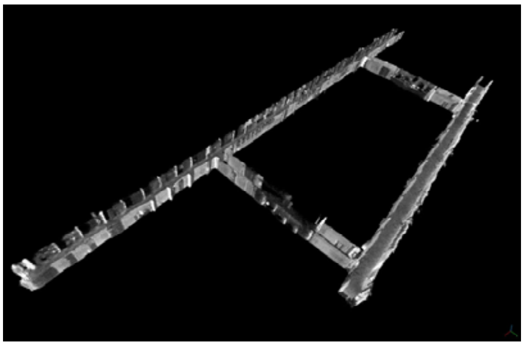

Fig. 5 Generated 3D map

Second, we prepared six iBeacon transmitters (MyBeacon MB004 Ac, Aplix). All transmitters were set 1.0 m from the floor and every 10.0 m along a wall from points b1 to b6 with the same major id numbers and unique minor numbers, as shown in Figure 6.

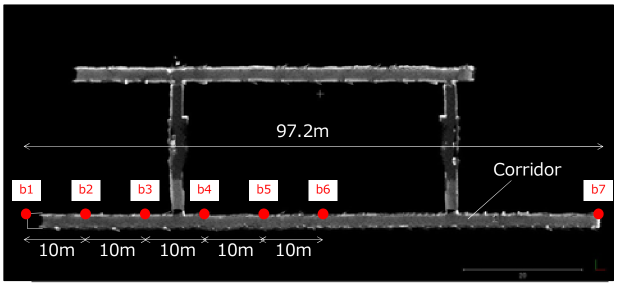

Fig. 6 Positions of iBeacon transmitters

We conducted two types of experiments involving pedestrian monitoring, and RSS mapping with a 3D map update in the indoor environment. In the first experiment, we acquired pedestrian data, first at point b5, and then at b4. Pedestrian data were extracted from TOF images based on a background subtraction using intensity values. In the second experiment, we shuttled once between points b1 and b7 with RSSI data acquisition. We acquired RSSI values for 60 sec at every transmitter point to generate fingerprints.

4. RESULT

4.1 Sensor location data estimation in the pedestrian extraction experiment

Figure 7 shows estimated distances from all transmitters to the receiver in the pedestrian extraction experiment. The vertical axis in each graph indicates distance values and the horizontal axis in each graph indicates the signal-receiving time. Moreover, bold points indicate RSS values more than the -63 dBm (TxPower). Although the minor ID 5 at point b5 and the minor ID 4 at point b4 show values less than 1 m stably, actual distances of other data were unstable. Here, there are categories of distance from a transmitter to a receiver, such as “near (less than 1 m),”“far (more than 1 m),” and “unknown” in the specification of iBeacon. In other words, distance values less than 1 m are reliable. Therefore, our geofencing approach can detect the appropriate position. The minor ID 5 also indicated the shortest distance from the transmitter to the receiver. Thus, the position of the 3D measurement system was estimated as the 40 m point in this case. After the position estimation, the extracted pedestrian data were overlaid on the 3D map, as shown in Figure 8. These results show that our geofencing-based positioning can be applied to approximate sensor location data acquisition in 3D mapping in the indoor environment.

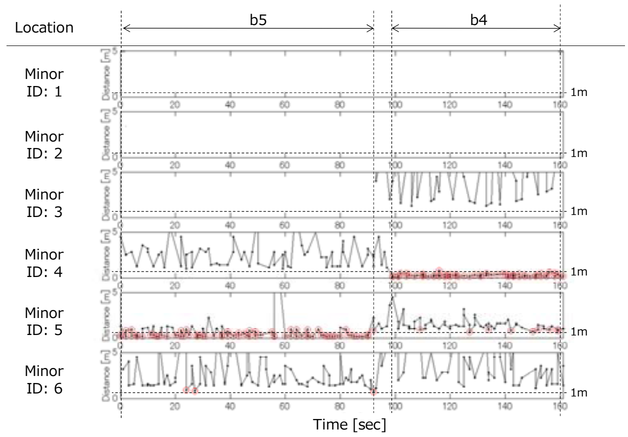

Fig.7 Estimated distances from iBeacon transmitters to the iBeacon receiver

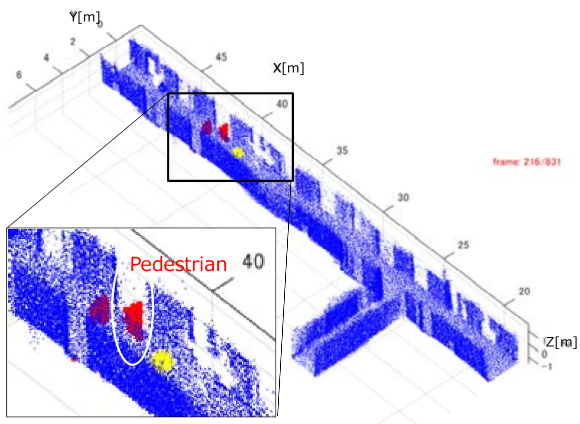

Fig. 8 Extracted pedestrian data overlaid with 3D map

4.2 Fingerprint-based sensor location data estimation

Figure 9 shows estimated distances from all transmitters to the receiver in the second experiment. The vertical axis in each graph indicates distance values, and the horizontal axis in each graph indicates signal receiving time. Bold points indicate RSS values more than the TxPower.

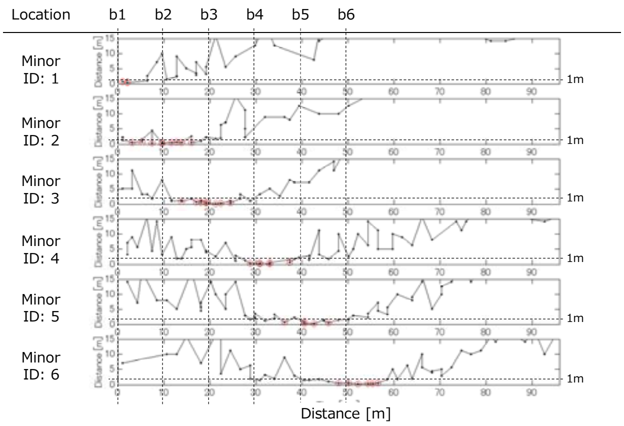

Fig. 9 Estimated distances from iBeacon transmitters to iBeacon receiver in the second experiment

A fingerprint map was generated using RSS values measured at six transmitter points. However, the measured RSS data consisted of discrete points. Therefore, we tried to generate a continuous fingerprint map for geofencing-based positioning. We applied this fingerprint map to our geofencing-based positioning, as shown in Figure 10. The vertical axis indicates the estimated position and the horizontal axis indicates the signal-receiving time. Although estimated results were smooth, the results were unstable at some points. We expect to improve the positioning accuracy with an approach based on fingerprint positioning in our future works. Height and rotation data, such as roll, pitch, and yaw, have not been estimated using beacons in this experiment. We expect to estimate these parameters in our future work.

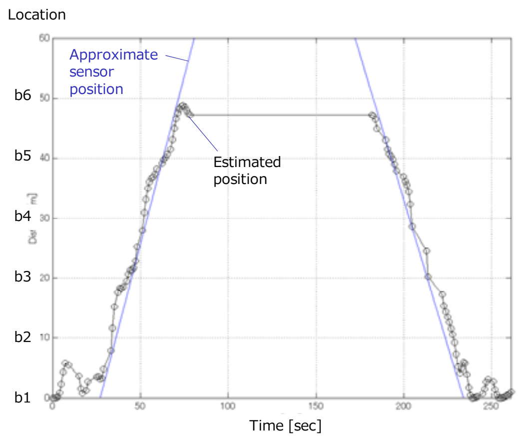

Fig. 10 Estimated position based on fingerprinting with the spline function

5. SUMMARY

We proposed a methodology to estimate more stable position or location data using unstable position data based on geofencing in indoor environments. We verified our methodology through some experiments, such as 3D map generation, RSS value mapping, sensor location data estimation in the pedestrian extraction experiment, and fingerprint-based sensor location data estimation in indoor environments.

ACKNOWLEDGEMENT

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