Outdoor Positioning Method for Tourism Apps Using BLE Beacon and GNSS

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***Abstract*— The tourism app "Okunikko Navi" is designed for the Senjogahara area in Oku-Nikko, Tochigi Prefecture. This app utilizes Bluetooth Low Energy (BLE) beacons to estimate user locations and display local tourist information on user's smartphones. However, the current method suffers from low positioning accuracy. Although Global Navigation Satellite System (GNSS) is widely used for outdoor positioning, its accuracy tends to be low in this area as well. In this paper, we propose a new positioning method that combines BLE beacon-based estimation with GNSS, and present the results of comparative experiments with conventional methods.**

Keywords—BLE beacon, GNSS, Outdoor positioning, Tourism app.

I. Introduction

There are various smartphone apps that utilize user location (Location-based service applications). Google Maps, Pokémon GO, and Swarm are prime examples. In the field of tourism apps, there are also apps that utilize location information to provide tourist information in the vicinity. We are developing a tourism app called "Okunikko Navi" targeting the Oku-Nikko Senjogahara area in Tochigi Prefecture. This app stores tourism information locally and estimates the user's location using Bluetooth Low Energy (BLE) beacons placed on hiking trail signs in the area. Fig. 1 shows an example of the trail sign. We have deployed BLE beacons at 18 locations shown in Fig. 2. Although the locations are numbered from #1 to #21, beacons are currently not installed at #3, #13, and #16. As the user comes within proximity of a beacon, relevant information is presented on their smartphone based on their current location. The following is a usage scenario of the Okunikko Navi app. For example, when a user begins hiking along the Senjogahara trail, they launch the Okunikko Navi app on their smartphone. As they approach a trail sign equipped with a BLE beacon, the app automatically detects the beacon signal—even if the phone is in sleep mode—and displays the estimated time to reach nearby bus stops and location-specific content. This allows users to learn about the local vegetation, and plan their route more effectively, enhancing their overall hiking experience.

However, with the current method using BLE beacons, the range of radio waves varies depending on surrounding obstacles, and sometimes the radio waves reach distant locations, causing tourist information to be displayed in unintended locations. These issues can confuse users and reduce convenience. Kato et al. developed a method using Global Navigation Satellite System (GNSS), which is widely used for outdoor positioning, and conducted comparative experiments in Senjogahara[1]. The results showed that the GNSS-based method achieves higher positioning accuracy than the BLE-based method. However, hiking trails have diverse environments such as open spaces and forests, and accuracy varies depending on the location. Therefore, there is a need for a positioning method that can handle such diverse environments and provide higher accuracy. The objective of this study is to enhance positioning accuracy specifically at locations equipped with BLE beacons by integrating GNSS data with BLE beacon signals. This approach helps ensure that tourist information is delivered only at the intended physical locations, thereby preventing user confusion caused by unintended content displays.

The remainder of this paper is structured as follows. Section II introduces the related research. In Section III, we

Fig. 1. A trail sign with a BLE beacon attached to the top-left corner

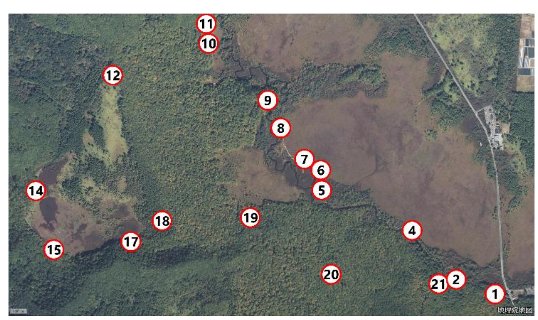

Fig. 2. BLE beacon deployment locations

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explain our positioning methods. In Section IV, we present the results of the experiments and provide a detailed discussion of their implications. Finally, we present our conclusions in Section V.

II. Related Work

The utilization of BLE beacons in outdoor positioning systems has been a topic of interest. A comparative study in location-based gaming applications examined BLE beacons and GPS positioning across various outdoor environments[2]. The research demonstrated that BLE beacons provided more stable positioning performance compared to GPS systems.

Integration approaches that combine BLE beacons with GNSS have also been explored. Luo et al. investigated methods to improve smartphone positioning accuracy in urban environments where GNSS signal reception is difficult[3]. Their approach utilized an Extended Kalman Filter (EKF) to integrate sensor information from BLE beacons, GNSS, and Pedestrian Dead Reckoning (PDR) systems. This hybrid methodology demonstrated a superior positioning accuracy compared to GNSS-only approaches in densely built-up areas.

III. Positioning Methods

In the conventional implementation of Okunikko Navi, a user is considered to be near a beacon location when their smartphone receives a signal emitted by a nearby BLE beacon. Fig. 3 illustrates that the conventional method yielded an average positioning error of 17.88 meters, which is considered inadequate for precise location-based services. Error bars represent the standard deviation.

In contrast, the GNSS-based positioning method utilizes a threshold based on observed error margins. At Senjogahara, the maximum GNSS error was measured at 9.56 meters[1]; therefore, the system was configured to determine that a user is near a beacon when their positioning coordinates fall within a 10-meter radius of the beacon. Fig. 4 illustrates the positioning error observed when using the GNSS-based application. The average error of GNSS-based method was 7.51 meters. While the GNSS-based method is more accurate than the BLE beacon method, it does not consistently achieve the same performance across all environments at Senjogahara. This variability arises from the presence of both open areas, where GNSS signals are highly accurate, and forested regions, where signal degradation leads to reduced positioning precision.

In the proposed method, BLE beacons and GNSS are used together, and by detecting entry into the vicinity of the beacon with GNSS, the use of BLE beacon radio waves is limited to the vicinity of the beacon. GNSS is used to determine the user's position and monitor proximity to the beacon while walking. When the user approaches within a certain distance from the beacon location coordinates, it is determined that the user is near the beacon, and changes in Received Signal Strength Indicator (RSSI) from the BLE beacon are monitored. To mitigate the impact of noise in the received signal, the RSSI values are not used directly. Instead, they are smoothed using a 5-tap moving average filter. The system stores four preceding smoothed RSSI values. As the RSSI decreases three times, the system identifies that the user has started to move away from the beacon, and the user is closest to it. Since the beacon transmits signals approximately every 0.3 seconds, a sequence of three decreases corresponds to an elapsed time of 0.9 seconds. Assuming an average walking speed of 1.4 m/s

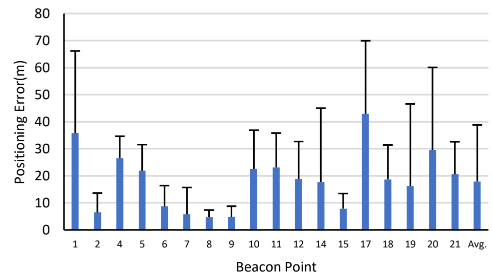

Fig. 3. Positioning error (BLE beacon method)

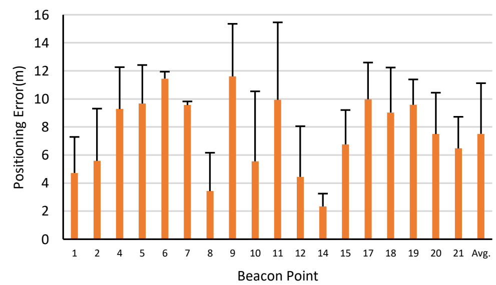

Fig. 4. Positioning error (GNSS method)

for an adult, a displacement of 1.26 meters within 0.9 seconds can be regarded as sufficiently close to the beacon point for practical purposes.

IV. Experiment

A. Experimental Method

To evaluate the positioning performance, four methods were employed to measure positioning error and success rate in a large open field environment. Fig. 5 shows the experimental site along with the location of the beacon point. The beacon point is indicated by a red circle. The beacon setting environment is shown in Fig. 6. The beacon was placed at a height of 1 meter above the ground.

To evaluate positioning accuracy, experimenters walked in a straight line toward the beacon from a distance of 100 meters. They stopped when the smartphone displayed a screen indicating proximity to the beacon. The straight-line distance from that stopping point to the actual beacon location was then measured and defined as the positioning error. The success rate is defined as the number of successful positioning events divided by the total number of experimental trials. A positioning attempt is regarded as a failure if the screen indicating proximity to the beacon does not appear. The beacon was custom-made and powered by solar cells. The BLE module used was equipped with Nordic's nRF52832, with a TX power of 4 dBm. The transmission interval of the signal was set to 300 msec. Two Pixel 6a smartphones were used as the receiving terminals for the experiment. In the experiment, we compared four methods: (1) BLE beacon only, (2) GNSS only, (3) BLE beacon only with RSSI reduction-based proximity judgement, and (4) the proposed method. Each method was tested 50 times. In the two methods using GNSS, the threshold distance for determining proximity to the beacon was set to 5 meters. This is because the accuracy of GNSS is better than that of Senjogahara due to the flat ground.

B. Results

The experimental results are shown in Fig. 7. The average error was 93.47 meters for the BLE beacon-only method, 3.34 meters for the GNSS-only method, 12.48 meters for the BLE beacon only with RSSI reduction-based proximity judgement, and 1.10 meters for the proposed method. The positioning success rate is shown in TABLE I.

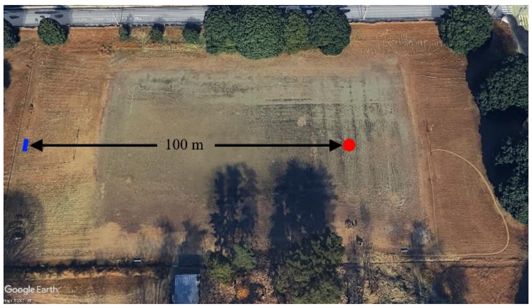

Fig. 5. Experimental field (red circle indicates beacon position; blue line shows the experimenter's starting point)

Fig. 6. BLE beacon and stand

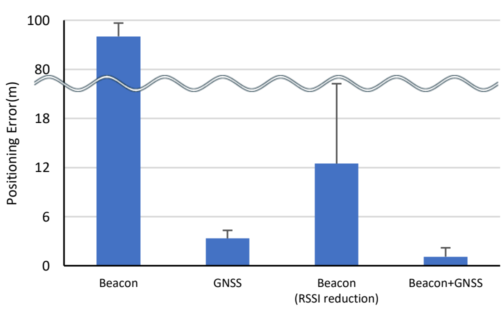

Fig. 7. Comparison of positioning errors for four methods

TABLE I. SUCCESS RATE

Beacon	GNSS	Beacon (RSSI reduction)	Beacon+ GNSS
1.00	1.00	0.98	0.94

C. Discussion

The proposed method exhibited the smallest positioning errors among all methods evaluated. These results suggest that utilizing GNSS positioning data to restrict the use of beacon signals to short-range detection is effective in improving positioning accuracy. However, although the BLE beacon-only method and GNSS-only method achieved a 100% positioning success rate, the two methods using RSSI reduction exhibited success rates between 94% and 98%. The lower success rate is likely due to cases where the RSSI did not drop three times in a row near the beacon, which was required for proximity detection. This condition was not always met, even when the user was actually close to the beacon.

In this experiment, the proximity detection threshold of 5 meters using GNSS is sufficient for accuracy on flat ground. However, the detection success rate is expected to be lower in Senjogahara. This is because Senjogahara has forested areas, and it is generally known that GNSS accuracy is low under forest canopies[4]. Therefore, it is necessary to consider an appropriate GNSS proximity detection threshold when deploying this method in Senjogahara.

V. CONCLUSION

We conducted experiments on outdoor positioning methods using BLE beacons and GNSS data. The results confirmed that the positioning accuracy of the proposed method was higher than that of methods using only BLE beacons or only GNSS. Currently, we are in the process of examining the appropriate GNSS proximity detection distance and the number of RSSI decreases for application in the Senjogahara field.

To further improve the accuracy of the proposed method, adjustments to the moving average window size and the number of reductions, as well as monitoring of upward trends, can be considered. Additionally, sensor fusion using a Kalman filter and RSSI peak detection using a machine learning model can be considered.

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