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Design of System for Accurate Tracking Services in Environments with Obstacles

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Abstract

Since the first commercialization of beacon-based services in 2011, various services have been provided to improve Bluetooth performance, and research has been conducted to accurately recognize user locations using beacons. The various measurement methods of indoor positioning systems (IPS) include methods using receiver signal strength indicator (RSSI) the strength of which varies greatly in accuracy depending on whether there are obstacles such as cement walls or doors. In this paper, we present a method to provide accurate positioning services even in the presence of obstacles in indoor spaces. To this end, we connect the HM-10 module supporting the beacon with Arduino Uno, to place beacons in three directions in real-world indoor space, and derive an optimal trilateration equation. Based on the derivation, we select the optimal expression for calculating the distance between the beacon and the moving station and use it to verify the coordinate determination for the moving station.

Index Terms: Receiver signal strengh indicator, Trilateration, Beacon positioning, Distance

I. INTRODUCTION

The global positioning system (GPS) is already widely used as a positioning system that provides relatively accurate positioning information with error ranges in meters in outdoor environments. However, because GPS is difficult to measure in indoor spaces such as shopping malls and hospitals, the pedestrian-centered location-based service market using IPS is growing rapidly. A typical example of an IPS is a beacon using low-power Bluetooth technology. The position concept of a beacon is based on wireless technology as shown in Figs. 1 and 2.

First, the beacon continuously broadcasts RSSI (Received Signal Strength Indicator), and the terminal receiving it determines its position through various localization techniques based on the strength of the RSSI. Here, RSSI is an RF signal, which includes the identification ID of the device that transmits the signal and the strength of the signal. Most

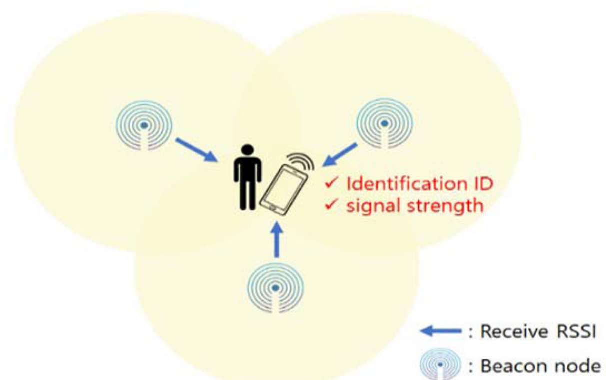

Fig. 1. Beacon Concept of Positioning.

wireless technology-based indoor positioning environments, mainly use RSSI techniques [3, 4].

In this study, we conducted a study to analyze algorithms

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that improve the accuracy of user positioning techniques using RSSI. To this end, we designed experiments to analyze the efficiency of indoor localization using beacons to collect and analyze signals using a beacon embedded in the Arduino HM-10 module.

II. RELATED WORKS

The Pink light in Fig. 2 is a case that is being implemented for pregnant women in Busan, Korea. The project utilizes a beacon, a representative IoT wireless communication device for location measurement. The Busan Metropolitan Government is implementing the "Pink light" project, an IoT-based system to induce passengers in urban railways to give up their seats to pregnant women by detecting the signals from a keyring transmitter (beacon) carried by pregnant women. Pink light is based on a simple principle [5, 6].

First, a Beacon Pendant, an NFC technology that uses Bluetooth, is issued. A pregnant woman carries the beacon pendant and gets on the subway. When there is a seat within a 2 m radius of the pregnant woman, the Pink light automatically responds, along with a message asking for concessions for pregnant women. More than 90% of passengers on urban railways give up their seats for pregnant women through Pink light without directly informing them. Beacon is a near-field communication technology through low-power Bluetooth, enabling more sophisticated localization than GPS, making it suitable for this system [7-8].

The Pink light receiver is equipped with LED lamp flashing and speaker function to induce concessions through voice messages for the convenience and safety of pregnant women riding urban railways. The radius of transmission and reception of the beacons carried by pregnant women can be adjusted from 0.5 m to 2 m, However, Pink light has a harmful component that blocks certification as determined by an authorized agency using a variety of tests on harmful ingredients such as electromagnetic wave blocking and lead. Through electromagnetic waves, the beacon functions normally, even if pregnant women do not hold the beacon directly in their hands and carry it in their bags. A campaign was carried out to address situations in which ordinary passengers did not give up their seats to women early in their pregnancy because it was difficult to distinguish them from others. The purpose of promoting a plan to expand Pink light is so that pregnant women can use public transportation conveniently while spreading the culture of caring for pregnant women. Fig. 2 illustrates the operation of Pink light [9, 10].

III. DESIGN OF A USER POSITION SYSTEM

The HM-10 module consumes a small amount of power and continuously sends small amounts of data to modules for wireless communication with various instruments. The use of the built-in capabilities of the beacon enables external communication through broadcast and connection, making it ideal for signal implementation and user positioning experiments. Fig. 3 shows the HM-10 module

Arduino is an open-source computing platform and software development environment based on microcontroller boards. It accepts values from various sensors such as temperature sensors, water level sensors, light sensors, and infrared sensors, and controls external electronic devices such as LEDs and motors, making it easy to manufacture products that can interact with the environment.

Figs. 4 and 5 illustrate the detection range of beacons taking into consideration the existence of obstacles in conceptual diagrams. Fig. 4 shows a space without obstacles where the signal strength between beacons and devices remains constant. The maximum detection distance for beacons was maintained at approximately 100 m, an ideal situation for locating individuals.

At first, when the signal is broadcast, the signal strength is maintained, but when it hits obstacles such as walls and cement, the signal weakens. To accurately measure the location of the user, a method is required to reduce the distance error

Fig. 2. Pink Light Technology for Pregnant Women.

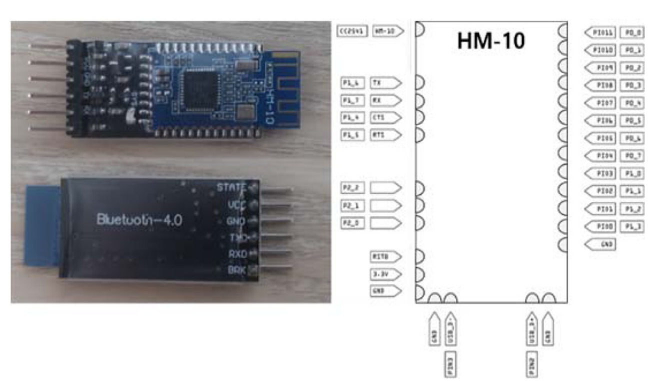

Fig. 3. HM-10 Module structure.

even for the situations depicted in Fig. 4. The next figure, Fig. 5, shows the signal strength in the presence of an obstacle.

The design process follows the following order: First, connect the Arduino and HM-10 modules, and then activate the built-in features of the beacon. Beacons connected to Arduino Uno and HM-10 transmit data to portable terminals that act as clients. At this point, RSSI signals are sent, and the distance and RSSI values are displayed in the dedicated application. A total of three beacons are used, assuming indoor space, and the RSSI values are compared when there are no obstacles to the accuracy of the trilateration measurement. For accurate error measurement, the difference in the distance between the portable terminal and the beacon and the difference in the user's travel speed was set to the experimental standard. The user-side system model is illustrated in Fig. 6.

Triangulation is a geometric method used to estimate the real-time position of an object moving in a two-dimensional plane [11-12]. Assuming that a portable terminal user is an object moving in a two-dimensional plane, at least three reference points are required to estimate the location in real-time. These reference points are called AP1, AP2, and AP3, and the coordinates of each AP are assumed to be (x_1, y_1), (x_2, y_2), (x_3, x_3), as shown in Fig. 7. The moving object is represented by MO, and its current position is (x, y). The distance from the moving object MO to the three reference points was assumed to be d_1, d_2, and d_3. where AP is the Bluetooth low energy (BLE) beacon node enabled by connecting the Arduino Uno and HM-10 modules.

In Fig. 7, the distance values of d1, d2, and d3 can be calculated simply by the Pythagorean theorem, as shown in eqs. (1), (2), and (3).

$$d_1^2 = (x-x_1)^2+(y-y_1)^2 \quad (1)$$

$$d_2^2 = (x-x_2)^2+(y-y_2)^2 \quad (2)$$

$$d_3^2 = (x-x_3)^2+(y-y_3)^2 \quad (3)$$

Based on the Pythagorean theorem, the formula for obtaining the d values varies depending on the situation. In this study, we proceed with user position estimation with triangu-

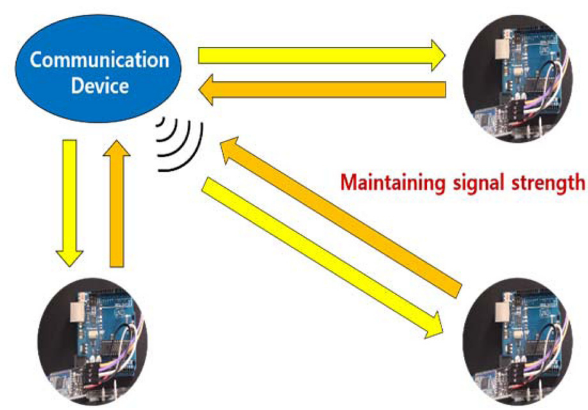

Fig. 4. Signal strength in an obstacle-free space.

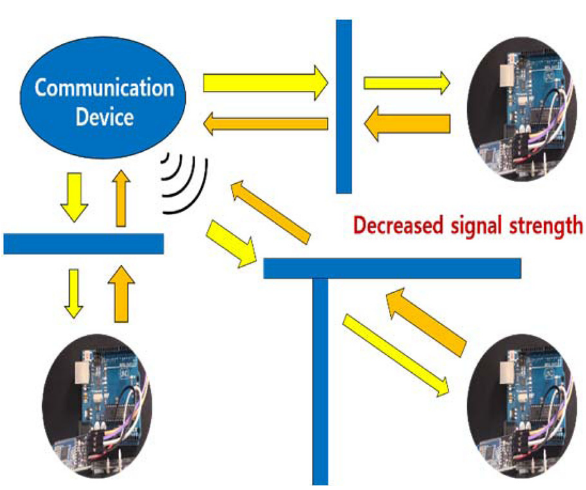

Fig. 5. Signal strength in the obstruction space.

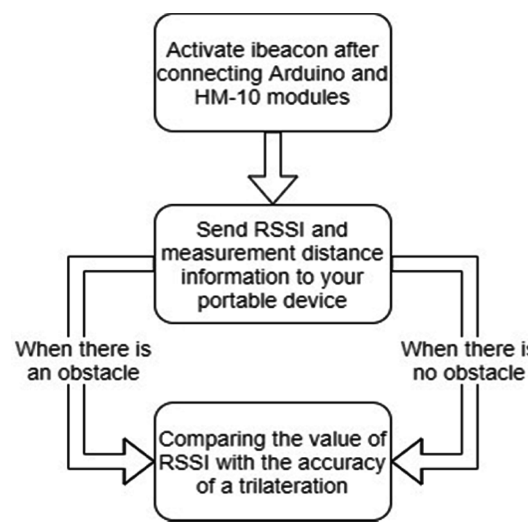

Fig. 6. User Position System Model.

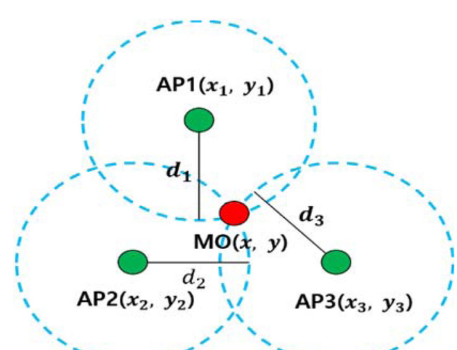

Fig. 7. Triangulation Calculation Configuration Plot.

Table 1. Parameters set for the experiment

Parameters	Set Value
Measurement Tools	beacon built into HM-10
Positioning Method	Triangulation
Minimum Distance	1 / 2 / 4 / 6 / 8 / 10 m
User Speed	3 / 6 km/h
Rate of change in user speed	0.3 Hz

lation using a receiver signal strength indicator (RSSI) [13]. In the case of RSSI, the distance between data points from a handheld terminal user is obtained by the Friis formula, which is given by eq. (4).

$$L = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)[\mathrm{dB}] \tag{4}$$

The Friis formula expresses the transmit-receive power relationship of a wireless link over free space, using the difference between the signal transmission power of a given AP and the intensity of the received signal in a moving object. where λ represents the wavelength of the propagation and has the same unit as distance *d*. Eq. (4) is expressed as the distance d between two points, which is equivalent to eq. (5), where c is the propagation speed and f is the frequency. Eq. (5) is obtained for the other two data in the same way, and the coordinate value of the user's current position (x, y) can be obtained by substituting eqs. (1), (2), and (3).

$$d = \frac{\lambda}{2\pi}\cdot 10^{L/20} = \frac{C}{4\pi f}\cdot 10^{L/20} \tag{5}$$

First, the Arduino UNO and HM-10 modules were connected for coordinate value measurement; the beacon was activated, and then fixed at a specific location in the room. We built an Android application to display the distance measurement results in real-time. The measurement was performed under two circumstances, with and without obstacles in the interior space of a typical household. The building to be used for the test on outdoor/indoor measurements, was designated as a general household with one living room and three rooms with a floor space of 30ea. The test was conducted in two situations: with obstacles and without obstacles [14, 15]. The parameters used for the experiments are listed in Table 1.

Fig. 8 shows the Arduino board connected to the HM-10 module and the basic distance, RSSI value, RX value, TX value, etc., when measured.

Table 2 assumes that the user has a constant speed of 3 km/h and a constant speed of 6 km/h, and compares the average accuracy. First, at 3 km/h, the average position error was 3.6 m for the "trilateral measurement algorithm in the presence of obstacles". The "trivial measurement algorithm in the absence of obstacles" had a mean position error of 3.0 m and displayed more accurate localization performance.

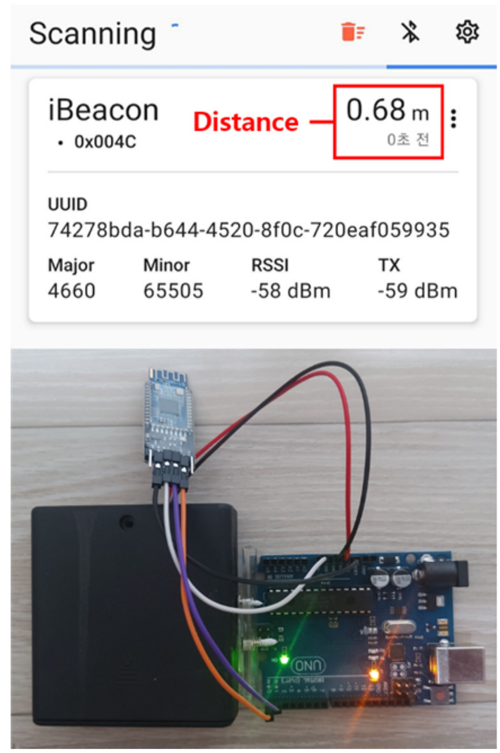

Fig. 8. Screen displayed during beacon signal scan

Table 2. Compare Mean Misdiscrimination Accuracy

	Trilateral measurement when obstacles are present	Trilateral measurement without obstacles
Average position error (3 km/h)	3.6 m	3 m
Average position error (6 km/h)	4.5 m	3.4 m

At 6 km/h, the average position error for the "trivial measurement algorithm in the presence of obstacles" increased to 4.5 m. The "trivial measurement algorithm in the absence of obstacles" displayed an average position error of 3.4 m, with a slight increase in error [10].

IV. CONCLUSIONS

The goal of this study was to analyze accurate measurement methods to apply to various indoor beacons, including homes and department stores. The results obtained through a derivation of the triangulation equation were compared with and without obstacle cases as follows.

First, to analyze the positioning potential of beacons, we computed the received RSSI data by placing the beacons at various distances. The calculation of planar coordinates could then be optimized for the environment or the site. To verify the localization accuracy of the distance calculated using RSSI and the signal strength of the beacon, we confirmed that there was a constant difference in the comparison analysis between the obstacles and obstacles.

As a result, accurate location information for terminal users can be obtained, enabling the establishment of stable pedestrian-centered location-based services. More precise measurement accuracy can also be obtained with further analysis and consideration of outdoor environmental components. However, the distance measurement algorithm using RSSI signals assumes that the maximum communication range of many beacons overlaps with the user's portable terminal, and there is a limitation in that the error increases rapidly when the communication strength weakens. Further research is of essence to the development of an optimal algorithm in determining the user's location in the event that the maximum communication distance between beacons does not overlap.

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