Design and Implementation of Indoor Positioning System using Bluetooth Low Energy

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Abstract. Most of the positioning systems nowadays require GPS. In indoor environments, however, GPS signals cannot be received properly due to the obstructions of the walls in the building. Therefore, other techniques such as RFID, Zigbee, WIFI or Bluetooth, are used based on the power loss, cost, or transmission range considerations. Our study, conducted at the AI+ Experience Center of Chung Hua University, adopts Bluetooth 5.0-based equipment and uses the received signal strength indication (RSSI) and triangulation method to perform indoor positioning. Our results show that Bluetooth positioning is more accurate in the sense that when the distance is within 1~3 meters, the error with the actual position is about 1 meter, which is more accurate than the RFID or WIFI positioning with the error of 2~3 meters.

1. Introduction
To the vast majority of people, GPS is the most popular positioning technique. It cannot, however, be applied indoors, for the signal is impeded or diverged by the wall, yielding incorrect results. Instead, other technologies such as WIFI, Bluetooth or RFID work better for indoor positioning. Bluetooth 5.0, in particular, has recently improved its extension of signal and greatly reduced its power consumption, so that the working life of the device can be further extended. In this paper, we use a device equipped Bluetooth 5.0 indoors to receive the RSSI sent from the tags through the station. We collect and clean the data afterwards, and utilize the triangulation method to derive the signal of the indoor tags that identifies their positions.

2. Related Works

2.1. Indoor Positioning
The varieties of wireless technologies have enhanced a growing application in indoor positioning. Many industrial applications need to know the physical location of objects [10, 12]. In contrast to the outdoor location sensing system, the Global Positioning System (GPS) is mature, however, GPS has an inherent problem of accurately determining the location of objects located inside buildings. Indoor location sensing system applying Bluetooth is a popular research topic in the location-aware system. Other indoor positioning technologies based on RSSI include Wi-Fi, ZigBee, GSM. LTE, RFID [1, 4, 5, 6, 7], etc.
due to the barriers between building walls and cement walls that prevent electronic devices or label devices from getting access to the GPS, in which case one can only perform indoor positioning through the RSSI.

2.2. Bluetooth
Bluetooth is a wireless communication technology that uses Ultra High-Frequency radio waves ranging from 2.4 to 2.485 GHz ISM for communication. Frequency hopping is used to avoid interference from the same frequency devices. From the previous version of high-speed Bluetooth, data exchange and transmission are mainly used, and Bluetooth Low Energy (BLE) avoids interference from the same frequency devices and connects multiple devices to form a personal area network (PAN) [2, 3, 8, 9, 11]. It can even connect devices that do not need to occupy too much bandwidth, and increase the theoretical value of the effective transmission distance to a hundred meters in low power consumption mode. Bluetooth also can be used in indoor positioning, which is based on the received signal strength indication (RSSI) principle. We use Bluetooth 5.0 for indoor positioning in our experiment, followed by a geometric analysis using the triangulation method.

2.3. Devices
The equipment that we use is the portable Bluetooth two-way tracker tracMo developed by TRACMO Technology, as shown in Figure 1. It uses Bluetooth 5 as its transmission interface, and with the CR2032 button-type battery capable of supporting up to 18 months, it has an extremely low energy consumption rate. Its transmission distance can reach 300 meters. Capable of being made into the size of a key ring that weights 8 grams, it can be installed on a variety of tiny equipment so that a department store specialist or a disaster relief fire-fighter, for instance, is able to locate their respective environment through the tracMo device. Positioning techniques using Bluetooth 5.0 require devices such as iBeacon or Bluetooth router to receive signals. We use tracMo Station developed by the TRACMO Technology, as shown in Figure 2. Through tracMo Station, we can capture the signal resources of tracMo and establish a real-time location system (RTLS) for indoor environment through the Wi-Fi side of the domain.

3. Proposed Bluetooth Indoor Positioning System
We construct an RTLS system by means of the tracMo two-way Bluetooth tracker and the tracMo Station Bluetooth router for indoor environment positioning, as shown in Figure 3.

3.1. tracMo & tracMo Station
Under the settings of tracMo and tracMo Station, a tracMo tag continuously transmits signals to tracMo stations via Bluetooth broadcasting within a range of 0.6 to 1.2 seconds. Relative distances of the tracMo tags are then sensed according to the different signal strengths received by those tracMo stations. It is, however, insufficient to calculate the indoor environment location with a single tracMo Station. In addition to the unknown tracMo point, three more tracMos are still needed.

3.2. tracMo Station Router
A tracMo station transmits signals through a wireless router. To begin with, a tracMo station is paired with a wireless access point (WAP) to identify the domain at which the tracMo Station is located. In
order to ensure the efficiency of the real-time indoor positioning, we include our tracMo Station in the private network of IPv4, so that the information and signal quality sent by the tracMo Station can be monitored. Through the IPv4 private network, we let tracMo Station broadcast in the same domain while receiving the signals from tracMo tags, so that the information in all tracMo Stations can be accessed.

3.3. RSSI Server
When tracMo Station shares information through domain broadcasting, it collects information via the cluster server, receive all tracMo Station messages, and store data in the JavaScript Object Notation string format. This way the data processed by the key-value storage can be efficiently processed, and the inconvenience between data transmissions can also be greatly reduced. However, the RSSI value is not as stable as expected after the data is acquired, as noises in the environment and location of the device can greatly affect the quality and signal strength of the RSSI. Therefore, the RSSI server must first process the RSSI value that tracMo stations obtain. The flow chart of RSSI Server is shown as Figure 4.

3.4. The Proposed Real-time Locating System (RTLS)
The RTLS is the main processing system for indoor positioning. The RSSI processing server calculates the location of the indoor environment through the RTLS system, so that the system can indicate the relative position of the indoor environment personnel on the system diagram. The flowchart of the RTLS system is shown as Figure 5.

3.4.1. Indoor Positioning Technology. In the indoor environment where GPS positioning is not available, it is necessary to locate the detection point through alternative methods. We use triangular geometry to
determine the position and distance of the target via three or more detectors. In indoor positioning, two or more receiving ends serve as base points of known positions to obtain their distances from the transmitting end through the RSSI signal.

### 3.4.2. The Triangulation Method.

After the data is collected, the circle centered at the transmitting end and the three non-collinear circles centered at the receiving ends are drawn. The intersection of the three circles is precisely the location of the transmitting end. Suppose there are \( n \) receiving ends with coordinates \((x_1, y_1), \ldots, (x_n, y_n)\) and distances \(d_1, \ldots, d_n\) from the transmission. Then the coordinate \((x, y)\) of the transmitting end satisfies

\[
\begin{align*}
(x_1 - x)^2 + (y_1 - y)^2 &= d_1^2, \\
(x_2 - x)^2 + (y_2 - y)^2 &= d_2^2, \\
&\vdots \\
(x_n - x)^2 + (y_n - y)^2 &= d_n^2,
\end{align*}
\]

The situation when \( n = 3 \) is shown as Figure 6.

![Figure 6. Three-point positioning concept map](image)

In fact, to identify the location \((x, y)\) of the output signal, it is enough to consider \( n = 3 \), i.e. an arbitrary choice of three receiving nodes. Using polar coordinate centered at \((x_3, y_3)\), we parametrize \( x = x_3 + d_3 \cos \theta \), \( y = y_3 + d_3 \sin \theta \), where \( \theta \) is the angle to be determined. Since \((x, y)\) must satisfy the first two of above simultaneous equations, \((x_1 - x_3 - d_3 \cos \theta)^2 + (y_1 - y_3 - d_3 \sin \theta)^2 = d_i^2, i = 1, 2\) must hold. Simple algebra gives

\[
(x_3 - x_i) \cos \theta + (y_3 - y_i) \sin \theta = \frac{d_i^2 - d_3^2 - (x_3 - x_i)^2 - (y_3 - y_i)^2}{2d_3}.
\]

In matrix notation this can be written as

\[
\begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix} \begin{bmatrix} \cos \theta \\ \sin \theta \end{bmatrix} = \frac{1}{2d_3} \begin{bmatrix} d_1^2 - d_3^2 - (x_1 - x_3)^2 - (y_1 - y_3)^2 \\ d_2^2 - d_3^2 - (x_2 - x_3)^2 - (y_2 - y_3)^2 \end{bmatrix}.
\]

Since the solution for \( \theta \) must be unique, it equals

\[
\cos^{-1} \left( \frac{(y_3 - y_2)(d_2^2 - d_3^2 - (x_1 - x_3)^2 - (y_1 - y_3)^2) + (y_1 - y_3)(d_3^2 - d_2^2 - (x_2 - x_3)^2 - (y_2 - y_3)^2)}{2d_3(x_1y_1 - x_2y_1 - x_1y_3 + x_2y_3)} \right).
\]

### 4. Experimental Results and Analysis

In this paper, the wireless network was composed of five Bluetooth routers, an RSSI server, and one WIFI gateway, as shown in Figure 7 and Figure 8.
We carried out the indoor positioning experiment in a classroom of the AI+ Experience Center at Chung Hua University, of 13 m times 7 m with multiple objects including tables, chairs, digital broadcasting, etc. We placed five Bluetooth routers at the same height with coordinates A(0,520), B(0,20), C(670, 0), D(1340, 390), and E(640, 700), all in centimeters, and then placed the WIFI gateway at a fixed location. The coordinates of the Bluetooth tags were (171, 422) and (264,293). The transmission interval of the tag frame of all of the four Bluetooth nodes was set to be 600 ms, and RSSI were collected continuously 70 times. The raw RSSI values collected by the RSSI server and by the RSSI by the WIFI gateway are shown in Figure 9 and Figure 10, respectively.

It can be seen from the tag C124F3F2 in Figure 9 that signal strength of the BLE 1m away from the BLE router is relatively stable. However, if the tag power of the signal is insufficient, the signal stability will be degraded, as can be seen from tag 52CDD986. The stability of signals 5 meters away from the BLE router (Figure 10) is relatively poor: tag C124F3F2, which was originally stable in the 1-meter range, changes greatly in the amplitude of the signal as the overall signal value, which was from -54 ~ -68 DBm, now becomes -65 ~ -92 DBm. We conclude that the signal strength is related to the distance as well as to the power supply of the tag.
5. Conclusion and Future Work
We found that the signal source of Bluetooth 5.0 at the same distance was still very unstable, which
would seriously affect the accuracy of indoor positioning despite of its improvement in distance. The
RSSI Server was capable of eliminating the excessive signal jumps, but this was still not enough for us
to locate the labels effectively.
During the experiment, it was found that the label with stronger signal was smoother. Therefore, the
establishment of multiple tracMo stations can improve the accuracy of the positioning. The error in our
prediction is about one to two meters. Our subsequent research efforts will be on analysing the RSSI
signal processing, which is going to improve the signal and distance conversion and therefore make the
indoor positioning more accurate.

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References
[1] Astafiev, A., Zhiznyakov, A., & Privezentsev, D. (2019). Development of Indoor Positioning
Algorithm Based on Bluetooth Low Energy beacons for Building RTLS-Systems. 2019
International Russian Automation Conference (RusAutoCon). Sochi, Russia: IEEE.
[2] Czurak, P., Maj, C., Szemer, M., & Zabierowski, W. (2018). Impact of Bluetooth low energy on
energy consumption in Android OS. 2018 XIV-th International Conference on Perspective
Technologies and Methods in MEMS Design (MEMSTECH) (pp. 255 - 258). Lviv, Ukraine: IEEE.
[3] Hada, H., & Mitsugi, J. (2011). EPC based internet of things architecture. 2011 IEEE International
Conference on RFID-Technologies and Applications (pp. 527 - 532). Sitges, Spain: IEEE.
[4] Jürgens, M., Meis, D., Möllers, D., Nolte, F., Stork, E., Vossen, G., Winkelmann, H. (2019).
Bluetooth Mesh Networks for Indoor Localization. 2019 20th IEEE International Conference on
Mobile Data Management (MDM). Hong Kong: IEEE.
[5] Kawecki, R., Korbel, P., & Hausman, S. (2019). Influence of User Mobility on the Accuracy of
Indoor Positioning with the use of RSSI and Particle Filter Algorithm. 2019 Signal Processing
Symposium (SPSymp0). Krakow, Poland: IEEE.
[6] N.Patwari, A. M. (2003, 8). Relative location estimation in wireless sensor networks. IEEE
Transactions on Signal Processing, pp. 2137 - 2148.
[7] Pei, L., Liu, J., Guinness, R., Chen, Y., Kröger, T., Chen, R., & Chen, L. (2012). The evaluation of
WiFi positioning in a Bluetooth and WiFi coexistence environment. 2012 Ubiquitous
Positioning, Indoor Navigation, and Location Based Service (UPINLBS), pp. 1 - 6.
[8] Shen, X., Yang, S., He, J., & Huang, Z. (2016). Improved localization algorithm based on RSSI
in low power Bluetooth network. 2016 2nd International Conference on Cloud Computing and
Internet of Things (CCIoT), pp. 134 - 137.
[9] Theshani Nuradha, I. G. (2019). Beacon Placement Algorithm for Hybrid Indoor Positioning with
Wi-Fi and Bluetooth Low Energy. 2019 Moratuwa Engineering Research Conference (MERCon).
[10] Wu, C.-C., Yu, K.-M., Chine, S.-T., Cheng, S.-T., Huang, Y.-S., Lei, M.-Y., & Lin, J.-H. (2013).
An intelligent active alert application on handheld devices for emergency evacuation guidance.
2013 Fifth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 7 - 11.
[11] Yaakop, M. B., Malik, I. A., Suboh, Z. b., Ramlil, A. F., & Abu, M. A. (2017). Bluetooth 5.0
throughput comparison for internet of thing usability a survey. 2017 International Conference on
Engineering Technology and Technopreneurship (ICE2T), pp. 1 - 6.
[12] Yu, Kun-Ming, Ming-Gong Lee, Hung-Nien Hsieh and Wu-Cheng Lai “Implementation of an
RFID-Based Virtual Signal Mechanism for an Indoor Location Sensing System,” Journal of
Internet Technology, Vol. 14 No. 4, pp. 631-642, July 2013.