Empowering Accessibility: A Hybrid Bluetooth-based Approach for Indoor Navigation

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***Abstract*—Indoor positioning is an ever-evolving IoT research topic that is expected to usher in a new era for the way we interact with environments such as theatres, shopping malls, airports, hospitals, etc. Bluetooth-based solutions present numerous advantages, given the widespread use of Bluetooth-enabled devices like smartphones and wearables by a majority of individuals on a daily basis. The positioning is achieved through Bluetooth beacons, small devices that consistently emit Bluetooth signals, detectable by smartphones or other compatible devices. In this article, the use of Bluetooth technology for indoor positioning is examined and a hybrid method based on both AoA (angle of Arival) and RSSI signals is introduced. Finally, a navigation mobile application for enhancing the accessibility of a theater environment to the visually impaired people is demonstrated.**

***Index Terms*—Indoor Positioning, Buildings, IoT, Spatial Inclusion**

I. Introduction

The advances in indoor positioning technology and mobile applications enable accurate indoor navigation (e.g. through audio instructions), offering a promising solution for improving the accessibility of current building infrastructures, e.g. by providing independence to visually impaired people [1] [2].

A conventional method, described in the literature, relies on trigonometry, taking into account only the decrease in signal strength (RSSI) when the user's device (e.g. mobile phone) moves away from strategically placed Bluetooth beacons [3]. By getting signals from three or more beacons, the device is able of calculating the position coordinates. However, Bluetooth signal's fluctuations make the accuracy of using conventional or Low Energy (BLE) Bluetooth quite limited. Results in the literature indicate an accuracy level of some meters [3].

Promising and accurate indoor positioning solutions utilize alternative signals like Ultra Wide Band (UWB) [4] [5], achieving errors of less than 0.5m. However, this type of solutions require more expensive and less accessible infrastructure, unlike basic Bluetooth receivers/transmitters. Moreover, they consume more energy and are more challenging to implement.

A modern Bluetooth-based solution, known as Angle of Arrival (AoA), uses advanced technology to calculate position by measuring the angle from which signals reach devices called anchors [6] [7]. This approach offers several advantages over the traditional RSSI-based method, including the following [8]:

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TABLE I
Comparison between the traditional BLE RSSI-based and the modern Bluetooth AoA solution

	RSSI-BLE Beacons	Bluetooth AoA
Price	✓	
Availability	✓	
Accuracy		✓
Ease of installation		✓

- High Accuracy: Bluetooth AoA provides high accuracy as it is based on angle measurement. For this purpose each device contains a number of antennas reading signal at different times, minimizing the final error.
- Reduced noise and interference: Angle measurement is not affected significantly from interference, making the system reliable even in environments with a large number of devices.
- Wide Coverage: AoA technology can cover large areas providing optimal calculations at distances of 15 meters. This makes the installation of the system easier as a smaller number of devices (anchors) is needed.

However, Bluetooth AoA is affected by walls and obstacles that increase multipath effects [8]. As a result, it is better suited for wide spaces and large rooms. Another drawback is that most of the mobile phones don't support this technology yet and, as a result, a small token-device (such as a card or bracelet) is required on the user's side. This device transmits the signal which is read by the anchors to determine the angle.

Table I provides a summary and comparison of the characteristics of each of the two presented Bluetooth-based technologies. The introduced approach aims to exploit the advantages of both solutions by constructing a hybrid method supported by a single mobile application.

II. INDOOR POSITIONING APPROACH

The presented study started by testing the traditional RSSI-based solution, known for its limited accuracy due to RSSI signal fluctuations. Users need to be in close proximity to the beacon, posing limitations in large rooms and complicating installation, particularly in high-ceiling rooms. However, we argue that the traditional approach remains viable for linear indoor positioning, especially near walls, as indicated in Figure 1. As users move away from the beacon (in this case, a

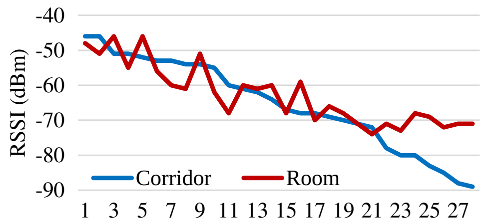


Fig. 1. RSSI noice problem, when using BLE Beacons in larger rooms

TABLE II
RSSI VALUES RECEIVED FROM 2 BEACONS IN 3 METERS DISTANCE

Distance from PICO 1 (m)	PICO 1 RSSI (dBm)	PICO 2 RSSI (dBm)
0	-35	-65
1	-51	-60
2	-60	-52
3	-67	-40

Raspberry Pi Pico W), RSSI signal strength decreases. In large rooms we observe significant variations in RSSI compared to corridors.

A. BLE RSSI-only Method

1) Fuzzy approach: The simplest method for calculating the user's position is based on identifying the closest beacon device. In this approach, the space is divided into equal sections, each monitored by a Bluetooth beacon (Rpi Pico). The user's position is determined by the beacon from which the mobile phone receives the strongest signal. Although this method is straightforward to implement, its accuracy is very low, since it depends on the distance between beacons. Covering the entire space requires a large number of devices, increasing costs and installation complexity. Additionally, placing beacons too close together results in more signal strength fluctuations, further reducing position estimation accuracy.

2) Statistical Approach (Linear Regression): To explore a more complex solution, values from multiple beacons were combined linearly. The following experiments were performed to test the effectiveness of such an approach:

- Using two beacons: Two beacons, placed 3 meters apart, were used for RSSI signal measurements. A Samsung Galaxy A71 mobile device, held by the user at arm's height ($\sim$1.3m), captured the signals while the beacons were placed on the floor. Table II illustrates a sample of the received values, which are utilized to built a linear model presented in Equation 1.

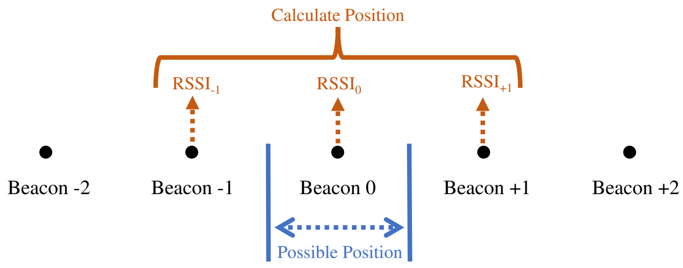


Fig. 2. Combination of BLE RSSI-based methods for position calculation

- Using four beacons: The initial experiment was extended to include 4 beacons, with Pico devices placed every 2 meters along a 6-meter route, including a turn. The resulting linear model exhibited inaccuracies, particularly near the turns, where walls intervene and make adaptation to new environments difficult. Table III presents the experiment's results, comparing two scenarios: (i) right turn at 4 meters and (ii) left turn at 2 meters. In order to use identical linear models, we have to measure almost the same RSSI values. However, significant differences were observed, especially near the turns (highlighted areas).

$$Pos = -0.047 * RSSI_1 + 0.062 * RSSI_2 + 2.363 \quad (1)$$

3) Combination of the two approaches: The observations mentioned above led us to explore a combination of the outlined solutions. Initially, we employ a fuzzy approach to detect the closest beacon device to the user. Subsequently, a linear regression model is applied, considering only the RSSIs of neighboring beacons. This approach allows us to minimize the impact of Bluetooth devices that do not influence the current position calculation, while mitigating the issues arising from varied placements and obstacles like walls.

We construct a model per three beacons, which computes a relative position to the middle beacon (represented as a real number within the range [-0.5, 0.5]), as presented in Equation 2. This value is then multiplied by the distance between the beacons in meters and added to the position of the middle beacon to determine the overall position. A graphical representation of this approach is presented in Figure 2.

$$Pos = -0.059 * RSSI_{-1} - 0.015 * RSSI_0 - 0.02 * RSSI_{+1} - 5.94 \quad (2)$$

B. Bluetooth AoA Method

Bluetooth AoA technology uses the direction (angles) of the receiving signal to calculate the position of the user. The user

TABLE III
COMPARING SIGNAL STRENGTH MEASUREMENTS FROM 4 BEACONS ALONG A 6-METER ROUTE IN TWO DIFFERENT SCENARIOS

Distance from PICO 1 (m)	PICO 1 RSSI (dBm)		PICO 2 RSSI (dBm)		PICO 3 RSSI (dBm)		PICO 4 RSSI (dBm)	
	Right at 4m	Left at 2m	Right at 4m	Left at 2m	Right at 4m	Left at 2m	Right at 4m	Left at 2m
0	-52	-51	-60	-63	-64	-76	-83	-87
1	-68	-62	-54	-56	-53	-74	-72	-87
2	-71	-66	-53	-47	-54	-58	-69	-72
3	-80	-72	-62	-60	-51	-49	-67	-64
4	-78	-78	-68	-73	-46	-59	-61	-61
5	-88	-84	-80	-72	-55	-65	-51	-48
6	-89	-85	-85	-77	-70	-71	-46	-55

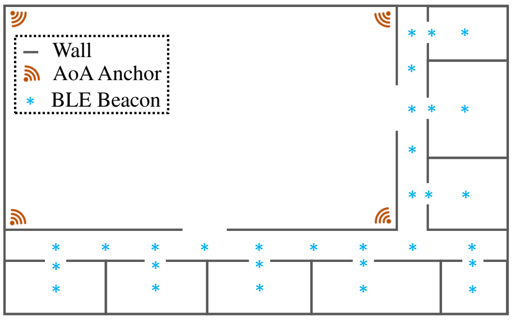


Fig. 3. Example of applying the proposed technique on a building infrastructure

has a token (card or wearable) that sents a bluetooth signal and the anchors, that are placed in known-positions in the room, are able of reading the angle of the receiving signal. This information enables the position calculation through trigonometric functions. More specifically, each of the anchors measures the size of two angles, namely the azimuth and the elevation angles. In a simplified explanation, we might say that the azimuth angle concerns the horizontal plane and the elevation the vertical plane. Knowing these angles and the coordinates of the anchors, we construct the line equations (in the form of Equation 3). Solving the system of all the equations (one for each anchor) returns, as a result, the position (x, y) of the user.

$$\begin{aligned} y - y_i = tan(\theta_i) * (x - x_i),\ \text{where} \\ (x_i, y_i),\ \text{the position of Anchor } i \text{ and} \\ \theta_i, \text{the azimuth angle calculated by Anchor } i \end{aligned} \tag{3}$$

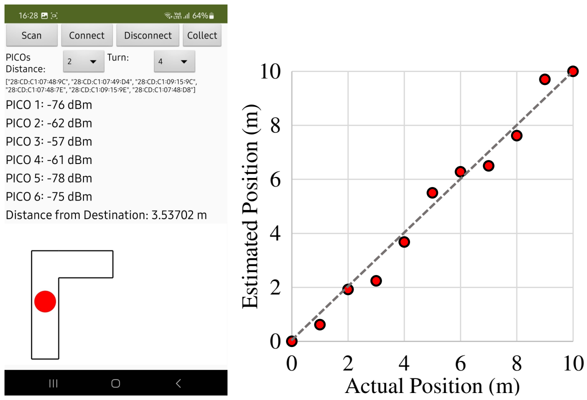
C. Hybrid Method

The introduced *Hybrid method*, illustrated schematically in Figure 3, effectively exploits the advantages of the two methods outlined in paragraphs II-A and II-B. In linear spaces such as corridors or small rooms (e.g., offices), the BLE RSSI-only method is employed to determine the position of the user and if the user enters or exits a room (BLE beacons are illustrated as blue stars). The Bluetooth 5.1 AoA method is utilized in larger halls where a 2-dimensional estimation of the user's position is required.

The Hybrid method simplifies the installation of indoor positioning systems in large halls by requiring fewer devices, mitigating the challenges posed by the RSSI fluctuations of an RSSI-only solution. Also, it addresses the multipath problem associated with the Bluetooth AoA solution and reduces infrastructure costs in corridors and offices.

III. EXPERIMENTAL RESULTS

In this Section, we analyze the first results regarding the introduced indoor positioning method. For the RSSI-only approach, used in corridors and offices, Raspberry Pi PICO W was selected as the beacon device. Raspberry Pi PICO W incorporates an ARM Cortex-M0+, 256KB of RAM and supports 2.4 GHz WiFi 4 and Bluetooth (BLE) 5.2. The beacons were placed on the floor, near the wall, and the tracking device was held by the user on a height of ~1.3m. To perform



(a) The testing app (b) The estimation results

Fig. 4. Results of Indoor Positioning using BLE Beacons in a corridor

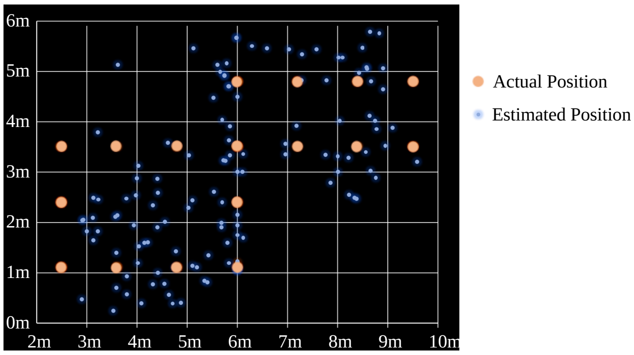


Fig. 5. Results of Indoor Positioning using Bluetooth AoA in a hall

the experiments, we designed a simple Android application (a screenshot is depicted in Figure 4a), which gives us the ability to monitor the RSSI values and to select different test routes. Figure 4b presents the indoor positioning results for walking in a 10m corridor, using 6 beacons. According to this analysis, we might claim that the results are quite accurate with an average error of less than 0.5m.

For the AoA part of the solution (in larger rooms and halls), well-known anchor devices like the XPLR-AOA-1 from Ublox can be utilized. A large number of solutions use this type of devices, while detailed datasets and measurements are available in the literature [8]. Figure 5 presents the results in a room. Large orange dots represent the actual position of the user, while smaller blue dots depict the estimated coordinates. The average error is ~1m. It is worth mentioning that these results are obtained by applying purely trigonometric equations, without using filters, dynamic calibration, data fusion, or time difference of the arrival etc., which are expected to significantly enhance accuracy [9] and are beyond the scope of this analysis.

IV. NAVIGATION APP: THE THEATER USE-CASE

Indoor positioning plays a crucial role in empowering accessibility and spatial inclusion in cultural events such as theater performances. The use of this type of technology makes theater venues much more welcoming and accessible to individuals with visual impairments, enhancing their overall participation

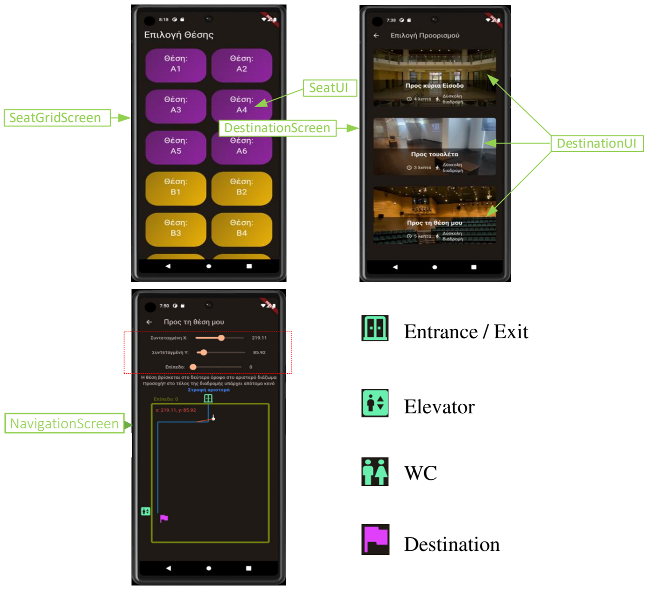


Fig. 6. The introduced Indoor navigation application

and engagement in the cultural life of the community. In this direction, in the context of this study, a complete indoor navigation system was designed including the previously described indoor positioning technique and offering a mobile application for navigating in theatre venues. This Section describes the design and functionality of the proposed application. It's worth mentioning that the presented solution is designed having in mind the Michael Cacoyannis Foundation's theatre, where the application will be firstly released to end-users.

The presented solution is implemented for assisting people on finding their seats, elevator, WC etc. Bluetooth AoA anchors are used for covering the large areas, such as the entrance, the hall etc., while BLE beacons are placed in corridors, WC, as well as for finding the seats. The mobile application is presented in Figure 6. The figure shows 3 screens of the application. In the first one, the users select their seat, in the second one the destination and the third one gives directions to the user. Of course, all the screens communicate with the user through voice instructions, however the application also includes a graphical interface. The application was designed using Flutter, an open-source software development tool created by Google. Flutter offers a single programming environment in Dart language that targets multiple platforms (Android and IoS), a large number of customizable widgets and is supported by an active community.

Regarding the navigation, a linear path (with 90 degrees of turning) near the walls is always prefered, if this is possible depending to any obstacles. This approach not only improves the positioning accuracy significantly, but also aligns with the preferences of individuals with reduced vision, who often rely on walls or stationary objects for navigation to enhance security and optimize their movement [1]. The red dotted line box is only found in the debugging mode. The user is depicted as a white dot, while the small white line shows the direction. Each moment, the angle and the direction of the user is

TABLE IV
NAVIGATION INSTRUCTIONS BASED ON THE CALCULATED ANGLE

Calculated Angle	Instruction
$< -335°$	Go Straight Ahead
$[-335°, -315°]$	Go Slightly Right
$[-315°, -225°]$	Turn Right
$[-225°, -135°]$	Turn Around
$[-135°, -55°]$	Turn Left
$[-55°, -25°]$	Go Slightly Left
$[-25°, 25°]$	Go Straight Ahead
$[25°, 55°]$	Go Slightly Right
$[55°, 135°]$	Turn Right
$[135°, 225°]$	Turn Around
$[225°, 315°]$	Turn Left
$[315°, 345°]$	Go Slightly Left
$> 345°$	Go Straight Ahead

recalculated in order for the right instructions to be produced. The navigation algorithm calculates an angle, that equals to the difference between the angle of the proposed path and the angle of the direction of the immediately preceding movement of the user. Table IV present the resulted instructions based on the calculated angle.

V. CONCLUSIONS

An exploration into leveraging Bluetooth technology to enhance building accessibility for visually impaired people is introduced. More specifically, a hybrid indoor positioning method that combines an RSSI-based solution using BLE Beacons and modern Bluetooth 5.1 AoA technology is presented, along with accompanying experiments and observations. Finally, a mobile application that supports indoor navigation during cultural events, particularly in theater venues, based on the proposed approach, is demonstrated.

REFERENCES

[1] N. Fernando, D. A. McMeekin, and I. Murray, "Route planning methods in indoor navigation tools for vision impaired persons: a systematic review," *Disability and Rehabilitation: Assistive Technology*, vol. 18, no. 6, pp. 763–782, 2023.

[2] R. N. Kandalan and K. Namuduri, "Techniques for constructing indoor navigation systems for the visually impaired: A review," *IEEE Transactions on Human-Machine Systems*, vol. 50, no. 6, pp. 492–506, 2020.

[3] Z. Jianyong, L. Haiyong, C. Zili, and L. Zhaohui, "Rssi based bluetooth low energy indoor positioning," in *2014 International Conference on Indoor Positioning and Indoor Navigation*, pp. 526–533, IEEE, 2014.

[4] I. Sofianidis, V. Serasidis, V. Konstantakos, and K. Siozios, "Application of energy efficient filtering for uwb indoor positioning," in *2022 11th International Conference on Modern Circuits and Systems Technologies (MOCAST)*, pp. 1–4, IEEE, 2022.

[5] Y. Xu, Y. S. Shmaliy, Y. Li, and X. Chen, "Uwb-based indoor human localization with time-delayed data using efir filtering," *IEEE Access*, vol. 5, pp. 16676–16683, 2017.

[6] H. Ye, B. Yang, Z. Long, and C. Dai, "A method of indoor positioning by signal fitting and pdda algorithm using ble aoa device," *IEEE Sensors Journal*, vol. 22, no. 8, pp. 7877–7887, 2022.

[7] F. A. Toasa, L. Tello-Oquendo, C. R. Peñafiel-Ojeda, and G. Cuzco, "Experimental demonstration for indoor localization based on aoa of bluetooth 5.1 using software defined radio," in *2021 IEEE 18th Annual Consumer Communications & Networking Conference(CCNC)*, IEEE, 2021.

[8] M. Girolami, F. Furfari, P. Barsocchi, and F. Mavilia, "A bluetooth 5.1 dataset based on angle of arrival and rss for indoor localization," *IEEE Access*, 2023.

[9] C. S. Mouhammad, A. Allam, M. Abdel-Raouf, E. Shenouda, and M. Elsabrouty, "Ble indoor localization based on improved rssi and trilateration," in *2019 7th International Japan-Africa Conference on Electronics, Communications, and Computations,(JAC-ECC)*, pp. 17–21, IEEE, 2019.