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Bluetooth Low Energy based Indoor Positioning System using ESP32

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***Abstract* — As of now, the Global Positioning System (GPS) is the leading outdoor positioning system, However, indoors, GPS is a flop because the signal does not penetrate easily through solid objects and there is no line-of-sight. Since GPS is unreliable in indoors the alternative technology emerged called Indoor Positioning System (IPS). Indoor positioning is accomplished using several techniques and devices. The proposed model prefers to use Bluetooth Low Energy-based positioning system. This paper focuses on implementing BLE based indoor positioning using ESP32-Node MCU.**

Keywords — Indoor Positioning System [IPS], Bluetooth Low Energy [BLE], ESP32, Trilateration, Received Signal Strength Indicator [RSSI], BLE Beacon, Transmitter, Receiver, Octave.

I. INTRODUCTION

In recent times buildings are getting wider and overcomplex, this increases the necessity of real-time positioning system in indoor. Global Positioning System[GPS] is known for navigation and positioning. But in indoor, the GPS does not work efficiently. Hence many techniques have evolved for navigation and positioning in indoor collectively called as Indoor Positioning System[IPS]. Some of the various methods involved in Indoor Positioning systems are:

- Ultra-Wide Band
- Infrared
- RFID
- Ultrasonic
- BLE

In recent times Bluetooth has improved a lot, capable of working with less power consumption high precision at low cost. In this paper, Bluetooth technology is used for indoor positioning owing to its improved performance at less cost. All smartphones and wearable devices have Bluetooth modules, this gives an additional advantage to Bluetooth.

UWB technology gives high accuracy positioning in indoor even in presence of severe multipath. The cost of UWB equipment is so high. In indoor such precise locations are not required. In comparison, BLE is cost-effective and provides accuracy to an extent that is sufficient for Indoor Positioning.

Infrared is suitable for sensitive communication, it can't be accessed outside the room or building. This system requires Line of Sight between sender and receiver as IR cannot penetrate through walls. In comparison, BLE doesn't require LoS and it won't diffuse due to direct sunlight or fluorescent lighting like infrared.

RFID-based Indoor Positioning system doesn't easily integrate with other systems. The range of RFID is very small and doesn't have communication capabilities. In comparison with BLE, it consumes more power and is not inherently secure.

Ultrasonic technology doesn't require LoS, does not interfere with electromagnetic waves. But obstruction leads to loss of signal, reflected signals create false data and high-frequency sound affects the signal. So it is hard to get accurate results.

WLAN requires a fingerprinting system, If an object even a table is moved in the environment the map has to be updated. On the other hand, ZigBee can be disturbed by a wide range of signals of the same frequency as they disturb ZigBee's radio communication. Though BLE might also be affected by signals of the same frequency, BLE requires low bandwidth, can handle multiple nodes, and have higher data transfer capability.

Bluetooth Indoor Positioning are classified into two main branches

1. Algorithm based on live RSSI.
2. Data Base method.

The trilateration Algorithm is opted for finding location due to its simplicity. Trilateration's accuracy depends on the number of transmitters which should be a minimum of three. Esp-32(node MCU) is made as a Bluetooth transmitter and receiver due to its robust design, Energy consumption, a high degree of customization, and a combined wi-fi Bluetooth chip are all features of this device. This paper focuses on the algorithm-based method.

II. EXISTING SYSTEM

Yan kai Wang et al[1] developed an indoor positioning system using which position is estimated with data base method and BLE beacon.

An Indoor Positioning Algorithm is proposed in[2].In this algorithm location is determined by triangulation method.

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Three inputs of triangulation are given by Kalman filtered distance calculated by preprocessed RSSI.

Bluetooth based Indoor positioning using machine learning algorithm[3] explains on Improving efficiency of IPS using Machine learning. Machine learning is used for location estimation through fingerprinting(database method). The machine learning algorithm is trained with RSSI samples at various points.

In[4] authors present improved BLE indoor positioning using Kalman Filtering. Using filtered RSSI distance from the beacon is estimated and results are processed by one dimensional Kalman Filter.

Indoor Positioning of Shoppers using network of BLE beacons[5] use BLE beacons to give location information. Position is estimated with Baseline method and weighted beacon pair rage estimation.

Guoquan Li et al [6] proposed a IPS algorithm with improved RSSI distance model. RSSI is corrected and further smoothened by Kalman Filter which is converted into distance by PSO-BPNN RSSI distance method.

Classroom attendance system based on BLE indoor positioning is developed in [7]. Smartphone's Bluetooth is used to find RSSI. Database method and Trilateration are used to estimate the distance. With unique Mac Address of student's smartphone attendance will be marked.

Development of mobile indoor positioning system application [8] explains about finding position by matching coordinates with trilateration method. Coordinates is found and compared with points in database by trilateration method.

In [9] Javad et al proposed a IPS with new placement technique for beacons. iBeacon Placement in Crystal shape (CiP) is a placement strategy in which beacons are placed in adjacent position of deployed beacons in equilateral triangle.

Yapeng Wang et al [10] developed IPS using Bluetooth 2.1 and position is estimated by trilateration. HCL interface is included in this systemcalled Inquiry with RSSI.

Smart Indoor Positioning using BLE[11] is a system in which BLE tag is deployed for position estimation. Using RSSI nearest BLE tag is selected and information of BLE tag is updated to web server for monitoring.

Nordic nRF52 SoC supports BLE[12] With nRF52 as peripheral and Central RSSI is gathered, filtered, distance is estimated with Kalman filter and trilateration is performed to estimate the position.

In IPS using BLE[13] CY8CKit-042 is directly connected with server which is a BLE tag. IPS APP and the tag is connected with wireless host. RSSI and Tx Power is obtained and distance is calculated.

Amit Singh et al[14] developed a Indoor positioning system using BLE beacons. Dijkstra's algorithm is used for finding shortest path between two available points using which navigation is introduced in indoor.

IoT based IPS using BLE explains about a system in which position is estimated by acquisition of RSSI and transferring to server with Kalman filtering and KNN linear search algorithm[15].

Indoor Positioning System using MQTT, Bluetooth and ESP32[16] is mainly focused on asset tracking and Results of a system that uses a BLE beacon as a transmitting device and an ESP32 as a scanning device. Scanned RSSI values in ESP32 is sent to server using MQTT and distance is calculated which is later used in trilateration to roughly calculate the position.

Zhu Jianyong et al[17] proposed BLE Indoor Positioning based on RSSI. RSSI values are collected and processed in real time and filtered using gaussian filter and log based piecewise fitting.

Bluetooth Indoor Positioning Based on RSSI and Kalman filter[18] explains about processing obtained RSSI by smoothing and applying Kalman filter. Position is estimated using four border positioning method and weighted least square after processing RSSI.

Bluetooth indoor positioning based on Inquiry is developed in[19]. Through WLAN the access points are connected with server and connection between smartphones and access points is established through Bluetooth. Using fingerprinting method position is estimated. Data training is done and location is determined in real time.

We can deduce from all of the preceding studies that BLE signals are utilized to obtain RSSI, which is subsequently converted to distance. The distance is then processed once more to approximate the position. The RSSI is converted into distance using either a formula or a pre-processed database technique. Over the acquired distances, a Kalman filter or any other filter is used for increased efficiency.

Trilateration, Triangulation, Baseline method, Fingerprinting method, Dijkstra's algorithm (for determining shortest path), Four border positioning, and Machine learning techniques are some of the most familiar methods for achieving indoor navigation or positioning.

III. WORKING AND METHODOLOGY

The transmitter code is uploaded to the ESP-32, and the transmitters are placed in their appropriate location. They are powered by a battery and can broadcast BLE data packets within their range.

The receiver Node-MCU is configured to accept data packets from transmitters and calculate the transmitter's estimated distance using the received signal strength.

The trilateration technique uses three distances from three known transmitters to determine the position of the receiver.

Fig 1. System Architecture

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Beacon deployment, signal gathering, and RSSI acquisition and trilateration are the methods utilized to locate the position.

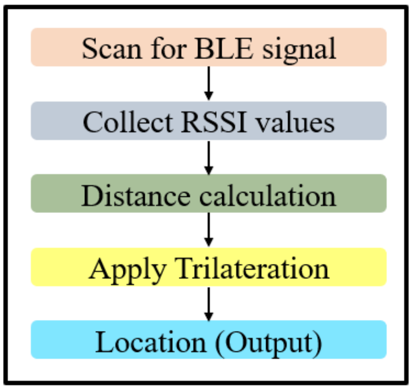

Fig 2. System Overview

A. Beacon deployment

Beacon deployment is a major task. The arrangement of Node MCU should be in such a way that it covers a large area with fewer BLE devices. The approximate range of ESP-32 is 15meters. BLE devices were placed in known positions. Those devices send empty advertisement packets through which RSSI value is found.

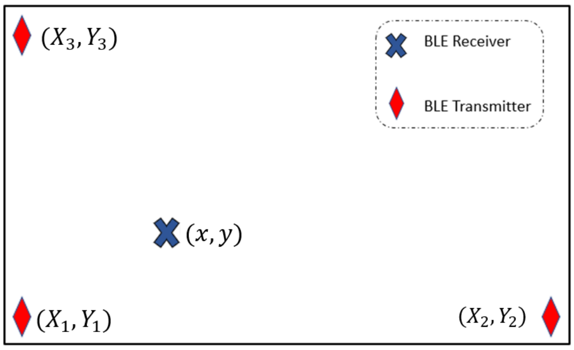

Fig 3. Beacon Deployment

B. RSSI to distance calculation

The Received Signal Strength Indicator (RSSI) is a metric that represents the beacon's transmitted signal strength on the intended receiver. The RSSI is affected by transmitted power, environmental factors, antenna type, and antenna orientation. The value ranges from -26 to -100 dBm at maximum transmitting power. The estimation of the distance between the user and the beacon is done using RSSI. Owing to factors such as interference, absorption, or diffraction the RSSI value will vary. The RSSI value becomes inconsistent as the beacon dissociate or starts to move.

The Measured Power constant is a factory-calibrated, read-only constant that shows the anticipated RSSI at 1 meter from the ESP-32. It is used along with RSSI to find out how far apart the transmitter and receiver are.

The devices that use Bluetooth Low Energy (BLE) do not broadcast continuously. Instead, they transmit discrete data packets. The period between each blink is referred to as the advertising interval. The number varies between 100 and 2000 milliseconds. The signal is more stable when the interval is shorter.

FORMULA USED:

$$Distance = 10^{\frac{Measured\ Power - RSSI}{10 * N}}$$

Here measured power is RSSI at a distance of 1meter(calibrated), RSSI is Received Signal Strength found at Receiver and N is Environmental Factor.
The obtained RSSI is computed into the distance in meter using the above formula.

C. Trilateration using distance found from RSSI

For calculating the target nodes position Trilateration method (Geometrical Method) is used. With the three Imaginary circles of the Bluetooth transmitter, the receiver node's position could be determined precisely. The Intersection of three imaginary circles is the position of target N. This method requires the coordinate points of the transmitter with distance calculated from RSSI value the system trilateral to estimate the coordinates of the target node. The three points of reference in the trilateration are coordinates of the Bluetooth transmitter.

The circle equations are:

$$(x - x_1)^2 + (y - y_1)^2 = r_1{}^2$$
$$(x - x_2)^2 + (y - y_2)^2 = r_2{}^2$$
$$(x - x_3)^2 + (y - y_3)^2 = r_3{}^2$$

Here [x_1, y_1], [x_2, y_2], [x_3, y_3] are co-ordinates of transmitter A, B, and C respectively and r1, r2, r3 are distances found using RSSI.

Simplification of above equation yields:

$$X = \frac{r_1{}^2 - r_2{}^2 + x_2{}^2}{2x_2}$$

$$Y = \frac{r_1{}^2 - r_3{}^2 + y_3{}^2}{2y_3}$$

The octave online uses the distance determined from RSSI in the targeted receivers and known coordinates of the ES32P- as input. Octave online determines the estimated location of the receiver using the Trilateration algorithm.

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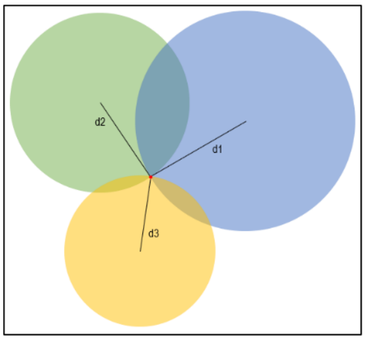

Fig 4. Trilateration

IV. EXPERIMENTATION AND RESULT

We have four esp-32s. Three Node MCUs have transmitter code pre-loaded for broadcasting empty data packets, whereas one Node MCU has receiver code uploaded. The laptop is connected to the receiver so that the transmitted signal's RSSI and distance can be viewed in Arduino IDE. The transmitters are connected to the power supply and are fixed in their appropriate positions. RSSI of the given transmitter was computed using the collected data packets.
The RSSI is then converted into a distance in meters using the algorithm.

```
Advertised Device: Name: A, Address: 24:62:ab:b0:90:ca,
Rssi: -85
Distance:6.31
Advertised Device: Name: B, Address: fc:f5:c4:2f:65:2a,
Rssi: -86
Distance:7.08
Advertised Device: Name: C, Address: 24:62:ab:dd:8e:7e,
Rssi: -80
Distance:3.55
```

Fig 5. Serial Monitor output of Receiver ESP32 in Arduino IDE

The estimated distance and known coordinates are given as input to the GNU octave to perform trilateration.
After the trilateration process is completed, the target's approximate position is determined and output can be obtained as a co-ordinate point.

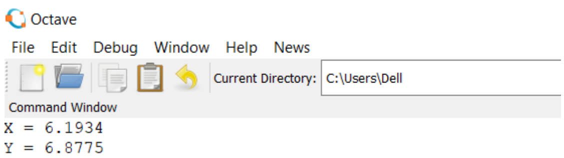

Fig 6. Position of User found in Octave

There is a considerable discrepancy between the real position and the trilateration co-ordinate point. The mean error was determined to be 13.708 percent on average.

R1	R2	R3	Trilateration	Actual Position
14	16.5	8.2	(4.3, 13.2)	(5,14)
14.4	15.5	9.2	(6.5, 12.9)	(7, 12)
8.13	14.2	12.6	(2.32, 7.8)	(2, 7)
5.4	11.6	16.2	(3.4, 4.1)	(5, 5)
14.4	12.9	12.2	(8.5,11.6)	(7.5, 10)
9	10.4	14.5	(6.1,6.8)	(5.5, 6)

Fig 7. Result Tabulation

V. CONCLUSION AND FUTURE WORKS

Our paper is to implement indoor navigation using ESP32. The approximate location of the user is identified by putting three ESP32 transmitters at a specified spot. This is accomplished by calculating the distance between known position transmitters and the RSSI of the transmitters. We get the estimated position of the user in co-ordinate format by giving the fetched data in octave for Trilateration.

Our extensive research goal is to improve indoor location accuracy by using filters to soften the RSSI. In addition, we want to develop an app that can identify the correct location and provide directional aid to the user.

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