ISSN 3032-7490

Implementation of Indoor Positioning System for Monitoring Geriatric Syndrome Patients Based on Bluetooth Low Energy

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A B S T R A C T S

Health issues commonly faced by the elderly include geriatric syndromes. The impact of these syndromes on older adults can lead to instability (disruption of balance, making them prone to falls) and intellectual impairment. Because of these concerns, monitoring is essential for individuals experiencing geriatric syndromes to prevent symptoms from worsening due to falls. As technology advances, object tracking systems using Global Positioning System (GPS) have developed significantly. However, GPS tracking systems are primarily suitable for outdoor tracking. Thus, there is a need for a method capable of detecting individuals with geriatric syndrome indoors and providing alerts if they fall. This study proposes a multi-room monitoring system for patients with geriatric syndrome to mitigate the adverse effects of falls by implementing an Indoor Positioning System (IPS) that utilizes Bluetooth Low Energy (BLE) technology and gyroscope sensors for fall detection. The proposed IPS employs BLE technology using the trilateration method. The ESP32 module is selected as the reference point for scanning BLE signals, measuring signal strength (RSSI), and transmitting data to a server for further processing via the Message Queuing Telemetry Transport (MQTT) protocol. The result of the test carried out during indoor conditions showed an average deviation in the x-cordinate of 0.28 meters and y-cordinate of 0.27 meters from the patients actual location.

K E Y W O R D S

Indoor Positioning System, Bluetooth Low Energy, Trilaterasi, ESP32, RSSI, MQTT.

1. INTRODUCTION

As healthcare systems advance, the proportion of the elderly population increases each year. The proportion of elderly individuals doubled from 4,5% in 1971 to 9,6 in 2019 [1]. Elderly individuals experiencing health issues are often associated with complaints related to geriatric syndromes, which are multufactorial in nature and vary bases on different background, including clinical, psychological, social factors, and other vulnerabilities [2]. Various types of geriatric syndromes increase the risk of poor health outcomes for the elderly, such as falls. The effects of falls experienced by the elderly can be fatal and may even lead to death. Based on this, monitoring for patients with geriatric syndromes is essential [3].

The advancement of technology, object tracking has also evolved, one example being the Global Positioning System (GPS) [4], [5]. To determine the coordinates of a point on Earth, a receiver requires signals from at least four satellites that can be received clearly [6], GPS is commonly used for tracking positions outdoors with an accuracy of less than 3 meters [7]. The use of GPS for determining location has limitations in environments obstructed by satellites, such as inside buildings or indoors [8], To detect positions indoors more accurately, indoor localization technology or indoor positioning technology has been developed to address the limitations of GPS [9]. There are several types of technologies that can be implemented in an Indoor Positioning System (IPS), including satellite-based, magnetic-based, inertial sensor-based, sound-based (audible sound, ultrasonic sound, acoustic sound), optical-based, and radio frequency-based (Wi-Fi, Bluetooth Low Energy, Radio Frequency Identification, and Ultrawideband) [10]. To determine the position within a room, radio frequency-based IPS, such as Bluetooth Low Energy (BLE), utilizes the Receive Signal Strength Indicator (RSSI), which indicates the strength of the received signal at a specific reference point [11].

The use of BLE technology as a communication medium (inter-vehicular communications) has been implemented, with a maximum range of 100 meters under low-traffic conditions and 50 meters in heavy traffic conditions [12], [13]. The implementation of BLE in IoT systems has been carried out, where the receiver must quickly discover nearby BLE devices. However, as the number of BLE devices increases, signal density rises, and the issue of collision becomes more severe. Simulation results from the research indicate that there is an optimal AdvInterval for a given number of BLE devices, which is 120 ms for 50 BLE devices [14], [15].

Based on these issues, this study proposes the implementation of an indoor positioning system (IPS) for monitoring geriatric syndrome patients using Bluetooth Low Energy (BLE). The aim of this research is to monitor geriatric patients by applying a positioning algorithm that utilizes the Received Signal Strength Indicator (RSSI) values from BLE devices. A key challenge in this study is implementing a multi-room positioning algorithm for patient monitoring. To predict the object's position based on RSSI values, the trilateration method is used.

2. RESEARCH METHODOLOGY

2.1 System Description

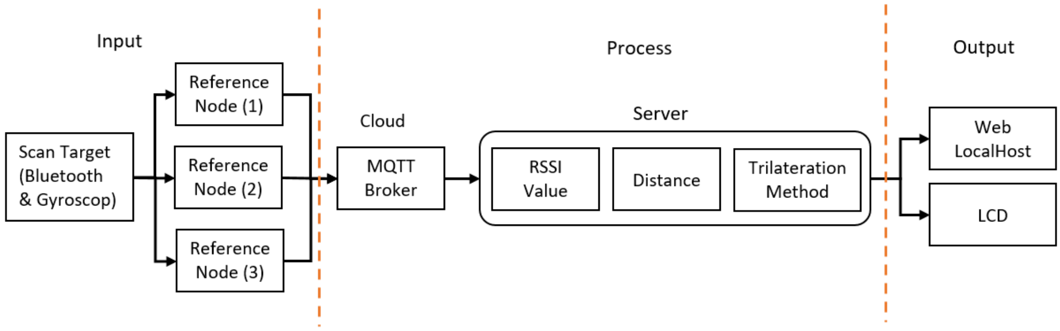

FIG 1. Block Diagram System

Based on Figure 1, The target device being scanned is equipped with a gyroscope sensor and an ESP32 module that continuously emits a Bluetooth signal to allow detection by reference points. Three reference points, each also equipped with an ESP32, serve as Bluetooth signal receivers. When a signal is received, the RSSI (Received Signal Strength Indicator) is measured and sent to an MQTT broker as a publisher. The MQTT broker acts as a data communication protocol between the Reference Points and the Server, streamlining data transmission. The reference points, acting as publishers, continuously update the RSSI data, while the server functions as a subscriber, retrieving data from the broker for processing.

The ESP32 module functioning as the data-gathering server subscribes to RSSI data from the MQTT broker. This server then calculates the estimated distance between the mobile device and each reference point based on the received RSSI values. Using trilateration, the data-gathering server processes these distance values from the three reference points to determine the position of the mobile device in X and Y coordinates.

The calculation results, along with information about the patient's safety status or potential fall, are displayed on an LCD and a local host web interface. This interface provides real-time X and Y coordinates and status information, serving as the communication link between the device and the user. This method leverages the known positions of the three reference points to estimate the location of the fourth point (the mobile device) by measuring the distance from each reference point. Figure 2 illustrates the placement of reference points within the room designated for monitoring.

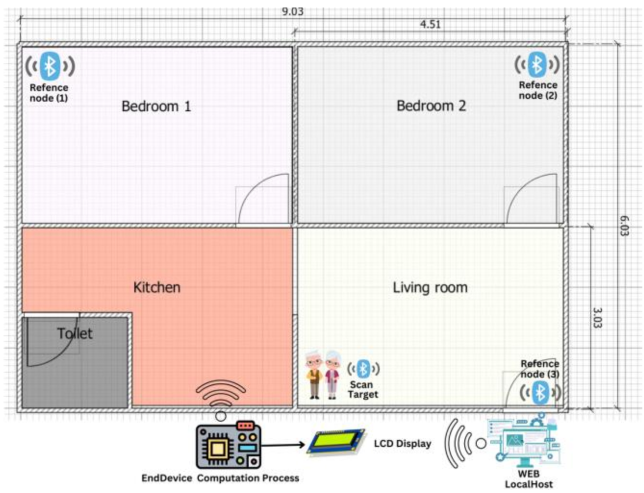

FIG 2. The design of the monitoring system utilizes three reference point devices.

2.2 Hardware Design

The setup consists of a reference device, a mobile device, and a data receiving device (server). The three reference devices share the same design. The mobile device is equipped with a gyroscope sensor. For the server device, an ESP32 serves as the data processor, and it is also connected to an LCD screen for display purposes. The electronic circuit of the system being developed is shown in Figure 3.

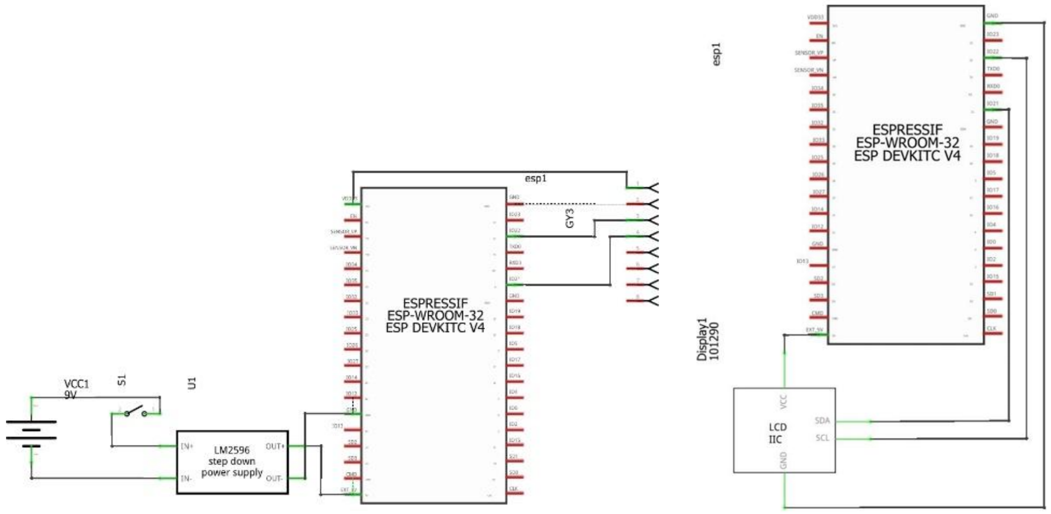

FIG 3. (a) Electronic circuit part reference node and mobile device, (b) Elelctronics circuit of server using ESP32

2.3 Software Design

Software design is carried out to form instructions that will be used in the tool's work system. In designing software, the first thing to do is create a program algorithm. The program algorithm in the form of a flowchart is shown in Figure 4.

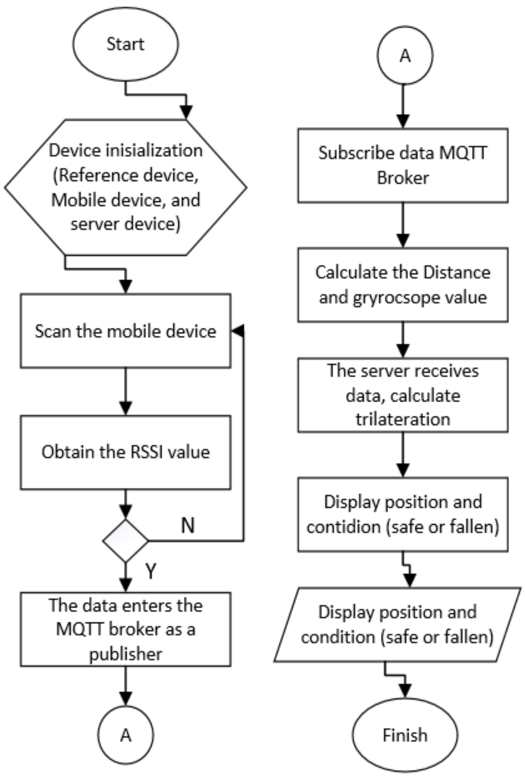

FIG 4. Flowchart of Indoor Positioning System for geriatric syndrom patients

Based on the flowchart, it can be explained that the device starts and then prepares all the components used. The ESP32 is configured to scan for Bluetooth devices, which includes initializing the BLE module and connecting to a WiFi network if necessary. The ESP32 begins scanning for nearby Bluetooth devices to find a specific device with a given MAC address (mobile device). Once the device with the correct MAC address is found, the ESP32 reads the RSSI (Received Signal Strength Indicator) value of the received signal. If the RSSI data cannot be obtained, the ESP32 returns to the scanning step. If the RSSI is successfully obtained, the data is sent to the MQTT broker through publication on a specific topic. The ESP32 continues scanning for new data.

The ESP32 server is set up to function as an MQTT client that will receive data from reference points. This includes connecting to the MQTT broker and initializing an LCD or other interface to display the results. The ESP32 server subscribes to several topics on the MQTT broker containing RSSI data from each reference point. The received RSSI data is used to calculate the distance between the mobile device and each reference point. This typically involves using a path loss model or specific formulas to convert RSSI to distance. Based on the calculated distance data from multiple reference points, the server performs trilateration to determine the position of the mobile device in the form of coordinates (x, y). The device's position coordinates are displayed on the user interface. This process repeats for each new scanning cycle.

3. RESULTS AND DISCUSSION.

Based on the specifications and design that have been determined, the tool prototype is shown in Figure 5.

(a) (b)

FIG 5. Prototipe Indoor Positioning Systems (a) Server Part (b) Mobile part and reference node

3.1 RSSI Reading Test

Testing was conducted in a room containing several electronic items and walls that act as partitions separating different areas. Figure 6 shows the placement of the reference points in the room.

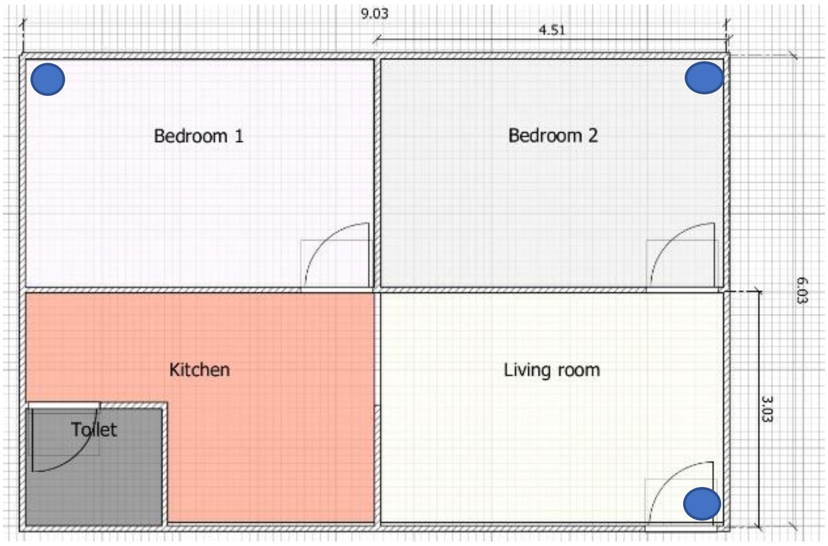

FIG 6. The placement of reference point in the room

The testing conducted in the room included three reference points placed strategically. The results of the RSSI measurement are shown in Table 1. The measurement results obtained were used as a reference for setting the parameters for trilateration calculations. To perform trilateration calculations using RSSI, the RSSI values must be converted to distance using path loss calculations.

TABLE 1. RSSI Measurement Results

Distance (Meter)	Ref 1 RSSI Value (dbm)	Ref 2 RSSI Value (dbm)	Ref 3 RSSI Value (dbm)
1	-41	-40	-41
2	-44	-43	-45
3	-48	-46	-48
4	-52	-50	-52
5	-56	-54	-56
6	-60	-59	-61
7	-64	-63	-63
8	-67	-67	-65
9	-71	-70	-68
10	-73	-74	-71

3.2. Sending data to the MQTT Broker test

Each reference point will publish the scanned signal strength data (RSSI) to a prepared topic address with a unique topic address to ensure the data is not easily accessible to the public. The communication used is via a public MQTT platform provided by MQTTHQ.

TABLE 2. List of Publisher topic addresses on MQTT brokers

No	Reference node	Function	Topics
1	Reference 1	Publisher	esp32-ble-rssi-reference1
2	Reference 2	Publisher	esp32-ble-rssi-reference2
3	Reference 3	Publisher	esp32-ble-rssi-reference3

After the data is published, it will then be subscribed to by the server to calculate and estimate its coordinate points using the trilateration method. The data displayed on the Arduino IDE serial monitor of the server device matches what is shown on the MQTTHQ client broker platform. This indicates that the communication between the reference point device and the server device has successfully connected through MQTT communication. Figure 7 shows an example of the RSSI data communication test results displayed on the Arduino IDE serial monitor and on the MQTTHQ client broker platform.

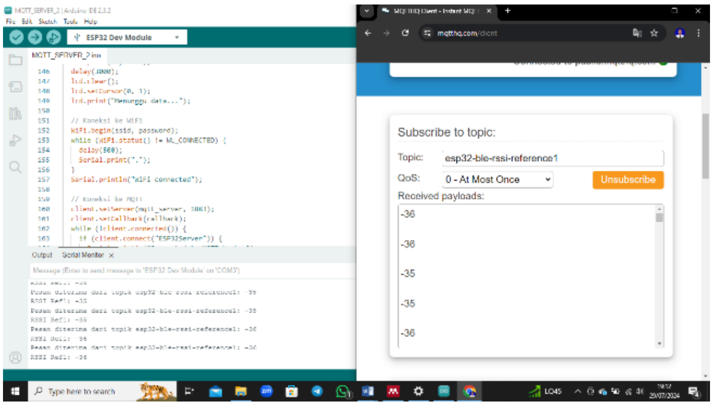

FIG 7. RSSI data communication test results

After the data is processed and obtained, the resulting data will be published back to the MQTT broker to be subscribed to by the localhost server and displayed on the prepared monitoring interface, making it easier for anyone to monitor

TABLE 3. The list of topic subscriber addresses on the localhost web program

No	Data	Function	Topic
1	Coordinate X	Subscriber	esp32/position/x
2	Coordinate Y	Subscriber	esp32/position/y
3	Room Position	Subscriber	esp32/position/room
4	Patient Condition	Subscriber	esp32/status/fall

3.3. Fallen detection test

The testing was conducted to determine the accuracy of fall detection from the gyroscope sensor with the following sensitivity set points.

Pitch: >= -40° and <= 40° = Safe
Pitch: < -40° and > 40° = Fallen
Roll: >= -40° and <= 40° = Safe
Roll: < -40° and > 40° = Fallen

TABLE 4. Fallen test result

No	Pitch	Roll	Conditions
1	0°	-3°	Safe
2	11°	-14°	Safe
3	22°	-18°	Safe
4	30°	-29°	Safe
5	39°	-37°	Safe
6	55°	-59°	Fallen
7	67°	-61°	Fallen
8	78°	-77°	Fallen
9	85°	-86°	Fallen
10	-1°	82°	Fallen
11	-15°	71°	Fallen
12	-22°	65°	Fallen
13	-30°	54°	Fallen
14	-38°	35°	Safe
15	-55°	29°	Fallen
16	-63°	20°	Fallen
17	-70°	13°	Fallen
18	-79°	5°	Fallen

3.4 Indoor localisation prediction test

Testing was carried out to determine the accuracy between the actual distance and the distance displayed by the device as shown in Figure 8.

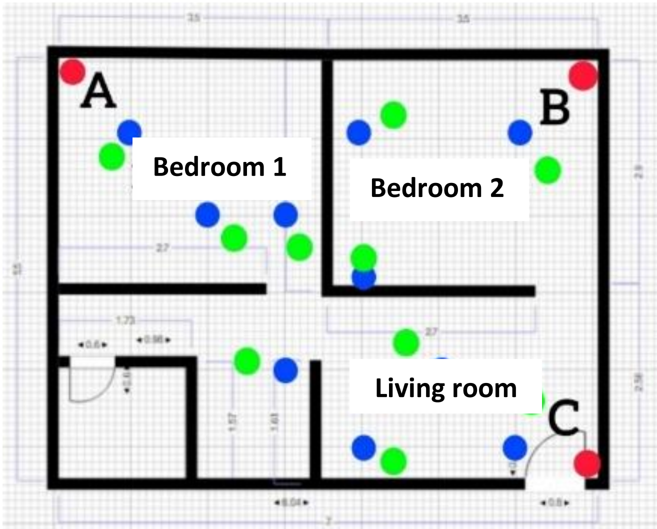

FIG 8. Accuracy of location reading

Point A is Reference Point 1 with coordinates (0, 0). Point B is Reference Point 2 with coordinates (0, 7). Point C is Reference Point 3 with coordinates (5.5,7). The X-axis reading line is between points B and C with a length of 5.5 meters. The Y-axis reading line is between points A and B with a length of 7 meters. The blue point indicates the actual measurement distance. The green point indicates the measurement distance calculated by the system.

TABLE 5. Comparison of actual location measurements with location measurements using the IPS

Actual measurement distance (Blue) (X, Y) (Meter)	Measurement distance (Green) (X, Y) (Meter)	Error (X, Y) (Meter)
4, 5	3.7, 4.5	0.3, 0.5
2, 3	2.7, 3.5	0.7, 0.5
3, 4	3.2, 4.0	0.2, 0.0
1, 6	1.3, 6.2	0.3, 0.2
5, 6	4.5, 6.1	0.5, 0.1
1, 1	1.1, 0.9	0.1, 0.1
4, 3	3.9, 2.5	0.1, 0.5
1, 4	0.8, 4.3	0.2, 0.3
5, 4	5.2, 4.3	0.2, 0.3
2, 2	2.2, 2.2	0.2, 0.2
Error Average		0.28, 0,27

FIG 9. Display on the local host: (a) patient is monitored as safe, (b) patient is in a fallen condition.

4. Conclusions

The test results, an average error value of X = 0.28 meters and Y = 0.2 meters was obtained. Communication testing showed that the RSSI data published by the reference point devices was successfully received by the server device and calculated using the trilateration method to determine the position. Receive Signal Strength (RSSI) received by the server device from each reference point device is not sequential, as the process of sending data to the MQTT broker is affected by the internet network being used.

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