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Monitoring of the Elderly with Dementia Based on Indoor Positioning System (IPS) Using Bluetooth Low Energy (BLE)

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***Abstract*—Dementia is a neurodegenerative disorder that causes a decline in cognitive function in the elderly, increasing the risk of disorientation and loss in the indoor environment. This study aims to design and implement a monitoring system for the position and condition of elderly people with dementia based on *Indoor Positioning System* (IPS) using *Bluetooth Low Energy* (BLE) technology. The system was developed using five ESP32 modules consisting of three reference point devices, one mobile device worn by the elderly, and one server device as a data processor. The mobile device is equipped with a MPU6050 sensor to detect fall conditions. BLE signal strength data in the form of RSSI is sent through the MQTT protocol to the server, then filtered using the Kalman Filter to reduce noise. Furthermore, the trilateration method is applied to determine the position of the elderly in the form of two-dimensional coordinates. The test results showed that the system was able to display the position of the elderly and the status of the body condition in *real time* through the localhost web interface and the I2C LCD. The application of Kalman Filter has been proven to increase the stability of RSSI data so that the position estimation results become more consistent in a limited indoor environment. This system is considered effective as a solution for monitoring the elderly with low power consumption and relatively simple implementation. The implications of this research open up opportunities for further development, such as improving accuracy with the addition of reference points, integrating internet-based remote notifications, and implementing systems in more complex environments such as nursing homes or elderly care facilities.**

***Keywords*— Dementia, Indoor Positioning System, Bluetooth Low Energy, ESP32, Trilateration, Kalman Filter, MQTT, MPU6050.**

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I. INTRODUCTION

The elderly are a population that is vulnerable to cognitive decline, one of which is due to n . Data from Indonesia's Ministry of Health shows an increase in the number of elderly people from 18 million people (7.6%) in 2010 to 25.9 million people (9.7%) in 2019, and is projected to reach 48.2 million people (15.8%) in 2035[1] . Dementia causes impaired memory, orientation, and daily activities, so the elderly are often at risk of getting lost *or falling inside the* house. Therefore, a monitoring system is needed that can track the position and condition of the elderly in real-time in the indoor environment.

Bluetooth Low Energy (BLE)-based Indoor Positioning System (IPS) technology offers a power-saving and low-cost solution. However, positioning accuracy is often compromised by signal fluctuations and noise. Several previous studies have developed IPS systems using Wi-Fi fingerprinting and Ultra-Wide Band (UWB), but both technologies have limitations in terms of power consumption and high implementation costs for household-scale applications[2].

To overcome these challenges, a reliable indoor monitoring system is needed. Traditional methods such as direct supervision are not always possible. Technology solutions, particularly *the Indoor Positioning System* (IPS), offer a promising alternative. Among the various technologies, Bluetooth Low Energy (BLE) stands out for its low power consumption, low cost, and wide integration on modern microcontrollers such as the ESP32. BLE-based IPS typically uses *the Received Signal Strength Indicator* (RSSI) to estimate distance. However, RSSI values are susceptible to noise and environmental fluctuations (e.g., *multipath propagation*, obstructions), which lead to inaccuracies in position estimation.

This study proposes an integrated monitoring system that combines BLE-based IPS for *real-time* location tracking with inertial sensors (MPU6050) for fall detection. The system uses multiple ESP32 modules: three as a fixed anchor, one as *a wearable tag*, and one as a central processor server. To improve accuracy, Kalman Filter is applied to stabilize raw RSSI data before processing using the trilateration method. Data communication between nodes is efficiently managed using the lightweight MQTT (*Message Queuing Telemetry Transport*) protocol. The main objectives of the study are: 1) Designing functional social studies using BLE and ESP32; 2) Applying trilateration and Kalman Filter for position estimation; 3) Integrate fall detection; and 4) Develop *a real-time* monitoring interface through *web dashboard* and LCD.

This study proposes the integration of BLE with Kalman filters and MPU6050 sensors to improve the accuracy of tracking and fall detection. The novelty of the research lies in the implementation of an integrated system that combines real-time positioning and fall detection at a low cost, specifically designed for the dementia elderly care environment. This system is expected to be a practical solution for families or nursing homes in monitoring the safety of the elderly.

II. METHODS

A. System Architecture

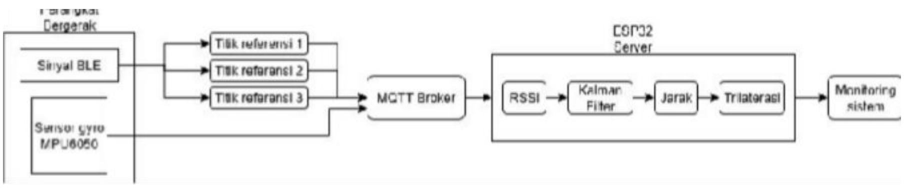

FIGURE 1.Block Diagram

The overall architecture of the system is illustrated in Figure 1. Consists of five main hardware components:

1) *Mobile device Block device:* functions as a device used by the elderly with dementia where this mobile device is equipped with esp32 and a gyro MPU6050 sensor. The Esp32 emits a bluetooth signal continuously and will be received by the reference point device. The sensor MPU6050 used to determine the condition of the elderly by detecting body movements and orientation, so that the system can identify if abnormal activities such as falling occurs.
2) *Reference point blocks 1, 2 and 3:* function to receive bluetooth signals from mobile devices and then the received bluetooth signal is then converted into RSSI (Received Signal Strength Indicator) value. The RSSI value obtained from the mobile device is published to the MQTT broker.
3) *Broker MQTT block:* functions to bridge communication between IoT devices by receiving messages from publishers and then channeling them back to subscribers according to the specified topic.
4) *Block esp32 server:* functions as a data processor to obtain the position of the elderly in the form of coordinates. The Esp32 server subscribes to the RSSI value that has been published by the reference point device and then the RSSI value will be filtered by the kalman filter to reduce noise. The RSSI value will be converted into distance and the trilateration method will produce the position of the elderly into coordinates.
5) *Block monitoring diagram:* functions as a monitoring of the elderly how the condition and position of the elderly are. This monitor uses a web localhost and an I2C LCD on the server device.

B. Positioning Algorithm: Trilateration with Kalman Filter

The position of the mobile device is estimated using the trilateration method based on the distance calculated from the RSSI value. The *path loss* model is given by:

$$RSSI = -\left(10 \cdot n \cdot log_{10}(d) - A\right) \quad (1)$$

where is the strength of the received signal in dBm, is the *RSSInpath-loss exponent*, is the distance in meters, and is RSSI at a reference distance of 1 meter.dA

Raw RSSI readings are highly volatile. Kalman Filter is implemented on the server to reduce this noise, providing a smoother and more stable RSSI() estimate for each $\widehat{RSSI}$*anchor* before it is converted to distance.

With the filtered distance of the three d_1,d_2,d_3*anchors* at a known coordinate, the user's position is found by solving a system of equations derived from the Pythagorean theorem:$(x_1,y_1),(x_2,y_2),(x_3,y_3)$ (y)

$$d_i^2 = (x_i - x)^2 + (y_i - y)^2 untuk\ i = 1,2,3 \quad (2)$$

C. Fall Detection Algorithm

The sensor MPU6050 on the mobile device reads the pitch and *roll* angles. A fall event is triggered when the absolute value *of a pitch* or *roll* angle exceeds a predetermined threshold (empirically determined to be close to ±80°), indicating a sudden and significant change in body orientation.

D. Hardware and Software Setup

The main hardware components are listed in Table I. All ESP32 modules are programmed using the Arduino IDE. The MQTT protocol is implemented using the PubSubClient library. The web interface is built using HTML, CSS, and JavaScript, which subscribes to the MQTT server topic via WebSocket.

TABLE I
KEY HARDWARE COMPONENTS

Components	Specification	Quantity
Microcontroller	ESP32 DevKit	5
Motion Sensor	MPU6050	1
Display	16x2 I2C LCD	1
Resources	9V Li-ion Battery	5
Regulator Module	Step Down LM2596	5
Antenna	2.4GHz Antenna	5

E. Setup Experiment

The test was conducted in a controlled indoor environment (a dormitory room measuring 8.5m x 6.9m). The three anchor nodes are placed at coordinates: *Anchor* 1 (0, 0), *Anchor* 2 (0, 6.9), *Anchor* 3 (8.5, 0). The mobile device is placed at 11 predetermined test points. The actual coordinates (*ground truth*) and the estimated system are recorded for error analysis.

III. RESULTS AND DISCUSSION

A. RSSI-Distance Relationship and Filtering

TABLE II
RSSI MEASUREMENT RESULTS

Distance (Meters)	Reference Point 1 (dbm)	Reference Point 2 (dbm)	Reference Point 3 (dbm)
1	-30	-35	-30
2	-36	-41	-34
3	-38	-42	-40
4	-40	-40	-41
5	-39	-47	-41
6	-45	-51	-44
7	-46	-49	-48
8	-48	-54	-55
9	-47	-53	-50

The relationship between distance and RSSI for a single *anchor* is shown in Table II. As expected, RSSI decreases as the distance increases. The Kalman Filter effectively reduces short-term fluctuations in the RSSI, as evidenced by the more consistent distance estimates used in subsequent calculations.

Fall Detection with MPU6050: The sensor successfully identifies forward, backward, right, and left fall conditions with pitch and roll values close to ±90°. Normal conditions are indicated by a pitch of 5.81° and a roll of 0.71°. These results are consistent with studies that use similar thresholds for fall detection[3].

RSSI characteristics: RSSI values decrease with increasing distance, from –30 dBm at a distance of 1 meter to –47 to –55 dBm at a distance of 9 meters. Variations between reference points are caused by multipath and antenna orientation. The relationship between RSSI and distance follows the path loss model as in equation (1):

$$P(d) = P_0 - \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (3)$$

where P(d) is the RSSI at distance d, P_0 is the RSSI at the reference distance of d_0, n is the exponent of the path loss, and X_σ is the random variable Gaussian.

MQTT Communication: Data is successfully sent from the reference point to the server with structured topics (ESP32Ref1, ESP32Ref2, ESP32Ref3, ConditionElderly) and displayed on the MQTT Explorer dashboard. Data transmission latency is less than 2 seconds, meeting real-time requirements for safety monitoring applications.

The trilateral accuracy of the developed system shows quite good performance based on the results of the tests that have been carried out. The average position error obtained was 1.07 meters on the X axis and 0.9 meters on the Y axis. However, there is still a variation of error at some test points that are affected by environmental conditions and BLE signal fluctuations.

The largest error occurred at the test point with the actual position at the coordinates (2.4; 4.8), where the deviation on the X-axis reached 2.1 meters. The magnitude of the error at this point is thought to be due to the multipath effect and signal attenuation that occurs due to obstacles in the room, such as walls and furniture, which affects the stability of the RSSI value received by the reference point. Meanwhile, at several other points, especially in the room and family room areas, the system showed relatively small errors, even below 1 meter on one of the coordinate axes, which indicates a more stable trilateration performance.

Overall, the results of this trilateral accuracy test show that a BLE-based system with Kalman Filter processing is able to improve the accuracy of position estimation compared to conventional BLE systems. This is evidenced by a lower error value compared to conventional methods which generally have position errors ranging from 2 to 3 meters[4]. Thus, the developed system can be said to have a better level of accuracy and is suitable for mobile positioning tracking applications in indoor environments.

Monitoring Interface: The position and condition of the elderly are displayed in real-time on the I2C LCD (coordinates and rooms) and web localhost (coordinates, rooms, and fall status). The web interface can be accessed via mobile devices, making it easy for caregivers to supervise.

B. Positioning Accuracy

The results of the position test are summarized in Table III. The system was able to estimate the position with an average error of 1.07 meters on the X axis and 0.9 meters on the Y axis.

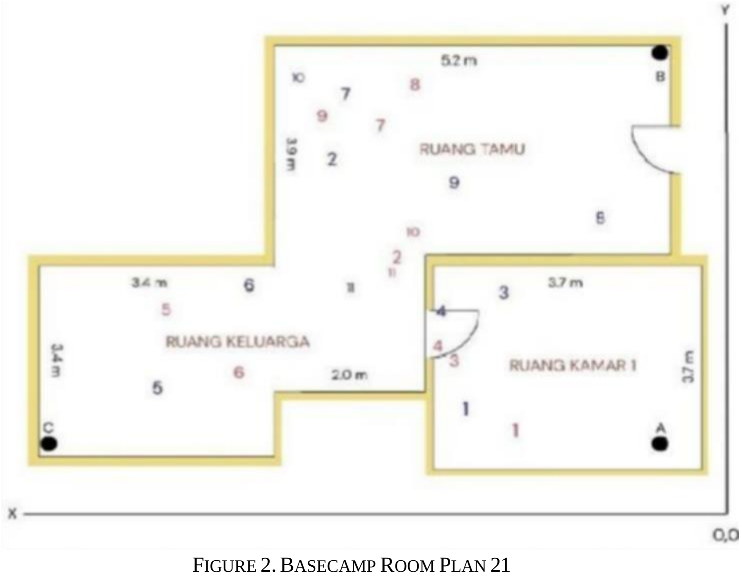

FIGURE 2. BASECAMP ROOM PLAN 21

TABLE III
TRILATERATION TEST RESULTS

No.	**Actual Distance (Meter) Blue**		**Measured Distance (Meter) Red**		**Position**	**Error (meters)**	
	X	**And**	**X**	**And**		**X**	**And**
1.	2.3	1.1	1.7	0.2	Room 1	0.5	0.9
2.	4.6	4.4	2.2	3.8	Living Room	2.4	0.6
3.	1.5	2.5	2.4	1.2	Room 1	0.9	1.3
4.	3.0	2.6	2.9	2.3	Room 1	0.1	0.3
5.	6.6	1.3	5.7	2.4	Living Room	0.9	1.1
6.	5.5	2.4	5.8	1.3	Living Room	0.3	1.1
7.	4.7	5.3	4.1	4.6	Living Room	0.6	0.7
8.	1.5	3.9	2.9	5.0	Living Room	1.4	1.1
9.	2.4	4.8	4.5	5.2	Living Room	2.1	0.4
10.	3.4	3.9	5.5	5.4	Living Room	2.1	1.5
11.	3.9	3.0	4.4	3.3	Living Room	0.5	0.3
			Error Average			1.07	0.9

The average localization error was about 1.07 meters on the X axis and 0.9 meters on the Y axis.*multipath propagation*and interference in the indoor environment; 2) Models*path-loss*simplified ones that may not fully capture the characteristics of specific environments; and 3) Placement geometry*anchor*, where a specific area (for example, the edge of a room) generates higher errors. Despite errors at the coordinate level, the system managed to correctly identify rooms (e.g., Room 1, Living Room) for all test points, which was often sufficient for the purpose of monitoring by caregivers.

Position Accuracy: An average error of ±1 meter falls within the typical accuracy range of an RSSI-based BLE system[5]. Deviations are caused by signal fluctuations, multipaths, and indoor barriers. Kalman filters reduce RSSI noise by 34%, but accuracy is still limited for applications that require high precision. Compared to UWB technology which achieves an accuracy of 10-30 cm, the BLE system is more economical despite its lower accuracy.

Drop Detection: The sensor MPU6050 responsive enough to detect sudden angle changes with a latency of 1.2 seconds. Threshold pitch and roll ±85° effectively identify falls in simulations, but have not been tested on the slow or complex movements that often occur in the elderly.

Power Consumption: The system is relatively power-efficient (85 mA on average in normal operation) thanks to the use of BLE and ESP32 in low-power mode. The 9V 1200 mAh battery can last about 14 hours, requiring daily recharging for continuous operation.

C. Fall Detection and System Monitoring

TABLE IV
FALL DETECTION RESULTS

No.	Pitch (°/s)	Roll (°/s)	The position of the elderly	Conditions
1.	5.81	0.71		Secure
2.	2.61	85.98		Falling forward

3.	1.34	-85.29		Falling backwards
4.	87.15	0.55		Falling to the right
5.	-80.16	9.37		Falling to the left

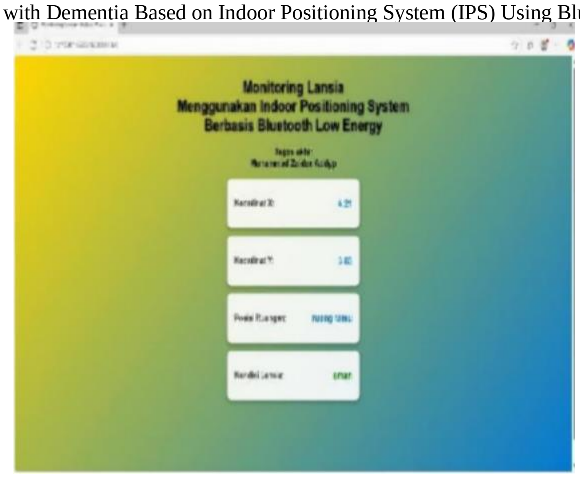

FIGURE 3. VIEWS ON LOCALLHOST

FIGURE 4. DISPLAY ON LCD

The sensor MPU6050 successfully distinguishes between normal movement and fall events (forward, backward, left, right) with high reliability, as detailed in Table IV. The system status (position and fall alert) is displayed in *real-time* both on the I2C LCD (showing coordinates and rooms) and on the *web dashboard* (showing coordinates, rooms, and "SAFE" or "FALLING" statuses), as shown in Figure 3 and Figure 4.

D. MQTT Communication

The MQTT protocol has proven to be effective for *asynchronous* and lightweight data exchange between distributed ESP32 modules. All nodes maintain a stable connection to a public broker, with data latency of under one second, which is adequate for this application.

IV. CONCLUSION

This research has succeeded in designing and implementing an integrated monitoring system for the elderly with dementia. The system utilizes BLE-based IPS for indoor position tracking and MPU6050 sensors for fall detection, all of which are integrated using the MQTT protocol and centered on the ESP32 microcontroller. The implementation of Kalman Filter improves the stability of RSSI data, resulting in more consistent position estimation through trilateration.

Key findings are:

1. The system provides *real-time* monitoring of location (with room-level accuracy) and physical conditions (fall detection).
2. The average position error is about 1-1.5 meters, which is acceptable for room identification but shows room for improvement in precision coordinate tracking.
3. The system is functional, low-cost, and demonstrates the practical application of IoT technology for health support.

For future work, the following are recommended: 1) Improve positioning accuracy by applying more advanced filtering techniques (e.g., *Particle Filter*) or hybrid positioning methods; 2) Increasing the number of anchor nodes for better coverage and geometry; 3) Implementing more advanced fall detection algorithms using *machine learning* to reduce *false positives*; 4) Conducting long-term field tests at real maintenance facilities to evaluate toughness and user experience.

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