ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

SMART HOME FOR SUPPORTING ELDERLY BASED ON ULTRAWIDEBAND POSITIONING SYSTEM

Muhtadin[1], Ahmad Ricky Nazarrudin[2], I Ketut Eddy Purnama[3], Chastine Fatichah[4], Mauridhi Hery Purnomo[5]

[1,5] Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember
[1,2,3,5] Department of Computer Engineering, Institut Teknologi Sepuluh Nopember
[4] Department of Informatics, Institut Teknologi Sepuluh Nopember

email: muhtadin@its.ac.id[1], rickynazarrudin@gmail.com[2], ketut@te.its.ac.id[3], chastine@if.its.ac.id[4], hary@ee.its.ac.id[5]

Abstract

In 2017, the rate of dependency among the elderly was reported to be at 13.28%, which was problematic, due to the limited number of caregivers to assist them at all times. To address this issue, a robotic service and vital sign-based system were developed, but it was found to be insufficient for monitoring the activities of the elderly. This study aimed to design an ultrawideband-based positioning system to address the high dependency rates of elderly individuals who require constant support and care. The system consists of five sub-systems, including an indoor positioning system, a database system, a data processing system, an actuator system, and an application user interface. The experiments showed highly promising results, with the system accurately tracking the elderly's position, showing only minor differences of 98.884 mm in Line of Sight and 279.94 mm in Non-Line of Sight conditions. Additionally, by applying the average filter method, we significantly reduced the initial error rate from 164.39% to just 1.096%, demonstrating the system's precision and reliability. The actuator system also demonstrated an impressive success rate of 98%, while the Android-based application user interface received a high user experience rate of 92.3%. Overall, these findings suggested that the ultrawideband-based positioning system had significant potential to support smart homes for the elderly and improve their quality of life.

Keywords : Positioning system, Elderly, Smart home, Actuator, Application

Received: 14-08-2024 | **Revised:** 18-10-2024 | **Accepted:** 21-10-2024
DOI: https://doi.org/10.23887/janapati.v13i3.84186

INTRODUCTION

Ministry of Health of Indonesia in 2017 released forecast data on the elderly population in Indonesia, revealing an estimated 33.69 million elderly residents in 2025, 40.95 million in the next five years and 48.19 million in 2035 [1]. While this growth presents several positive effects, it also brings negative impacts, including increasing number of elderly individuals who rely on others for care and support. This is a problem because not all of them have access to caregivers or smart home technology[2], leading to difficulties with daily activities such as opening and closing doors. The current dependency ratio for the elderly in Indonesia stands at 13.28%, meaning that 13 elderly individuals rely on every 100 productive people[3]. The increasing dependency ratio of the elderly, various efforts have been made to address this issue, such as self-medication, home-based treatments, or hospitalization. However, many elderly still prefer self-medication, with 54.06% choosing to avoid external treatment options [1].

The increasing elderly population and high dependency rates require effective indoor localization systems to improve the safety and comfort of their living environments. Indoor localization is essential for a variety of applications, especially in healthcare settings[4], where it helps in monitoring and assisting the elderly. Traditional GPS systems are inadequate for indoor environments as they rely on line-of-sight communication and have limited accuracy, which can be as low as 5 meters [6],[18],[19],[20]. While traditional GPS is limited indoors due to its reliance on satellite signals, it remains effective for outdoor tracking. Systems like SafeRoute[17] utilize multi-sensor tracking, including GPS, to monitor elderly people in environments such as parks or urban spaces[15][21].

Several studies have adopted indoor localization Wi-Fi fingerprinting, which uses Received Signal Strength Indicator (RSSI) data from Wi-Fi access points. Systems like [22][23] use machine learning models to analyze Wi-Fi signal patterns and pinpoint the location of elderly individuals within a building. Such systems[24] integrated Wi-Fi fingerprinting with health monitoring tools to provide real-time alerts in case of emergencies like falls or sudden inactivity, which are critical in elder care. Wi-Fi-based indoor localization systems have certain limitations that affect their effectiveness. One significant weakness is the susceptibility to environmental factors such as walls, furniture, and other obstacles, which can cause signal attenuation and multipath effects, reducing accuracy. This issue becomes especially problematic in Non-Line-of-Sight (NLoS) conditions, where the signal is obstructed, further reducing precision[16][25][26].

Many researchers implemented RFID-based localization systems for elderly monitoring, particularly to enhance safety and support independent living. System [31] uses passive RFID tags worn by elderly individuals and strategically placed RFID readers within the home to track movement and ensure timely interventions in case of dangerous behavior like aimless walking[32]. These systems have significant issues associated with the limited range of RFID tags[33]. Active RFID tags with battery power are required to extend the range beyond this, but this increases costs and complicates the system setup[34].

Bluetooth Low Energy (BLE) has emerged as a popular technology for indoor localization due to its low energy consumption and wide availability in mobile devices. One notable application [27] is tracking the wandering behavior of dementia patients utilizing BLE beacons to monitor and detect repetitive walking patterns, ensuring that caregivers can respond swiftly to wandering incidents, which pose significant safety risks. Another example [28] involves a hybrid UWB (Ultra Wide Band)/BLE tracking system designed for monitoring elderly individuals at home. However, BLE-based indoor localization systems face several notable limitations: First, the accuracy of BLE systems generally ranges from 1 to 3 meters, which may not be sufficient for applications that require high precision, such as monitoring the movements of elderly individuals within confined spaces[29]. Second, Similar to Wi-Fi, BLE-based localization often requires initial calibration, such as creating a signal map of the environment. This process is time-consuming and must be regularly updated as the environment changes, making the system less scalable and more challenging to maintain over time[30].

UWB technology[12] stands out as one of the most promising solutions for indoor localization due to its ability to provide high-resolution positioning and resilience to multipath interference [35][36]. UWB systems can achieve centimeter-level localization accuracy, making them particularly suitable for applications involving eldercare, where precise tracking is critical for fall detection and emergency response [37]. For example, UWB has been shown to significantly improve localization errors, achieving mean absolute errors as low as 0.0094 meters under line-of-sight conditions [38]. This level of precision is critical to ensuring the safety of the elderly, as it allows for timely intervention in the event of a fall or other emergency.

Additionally, UWB systems can be integrated with other sensors, such as IMU (*Inertial Measurement Unit*) and variety of smart technologies to create comprehensive monitoring solutions. For example, UWB can be combined with machine learning algorithms to improve the accuracy of indoor localization systems, thereby increasing the overall effectiveness of eldercare applications [39].

Several studies have tried to solve problems related to dementia and the elderly using other smart devices such as a robotic service that monitored the vital signs of the elderly and provided supervision [10]. However, this system unable to track the elderly daily activity levels, such as distance travelled and calories burned [7][14]. To address this, an ultrawideband-based positioning system was developed to support smart homes. The system includes an indoor positioning system to track the coordinates of the elderly, as well as an actuator system to simplify daily activities such as opening and closing doors. Others include an Android application for doctors or family members to monitor and provide assistance [11]. Before use, the data collected by the positioning system must be filtered using the average filter method [11].

Despite all its reliability, using UWB devices poses challenges related to interference with metal objects in households. In this study, we propose the development of a smart home to support the activities of the elderly by utilizing indoor localization using UWB devices. We implement UWB-based indoor localization by applying various filtering algorithms to reduce the measurement error of UWB devices. We use the results of the localization that has been repaired to track the position of the elderly who are active at home. To prove the functionality of a smart home as a support system for elderly' activities, we involve sensors and actuators that move home furnishings, such as doors that elderly will

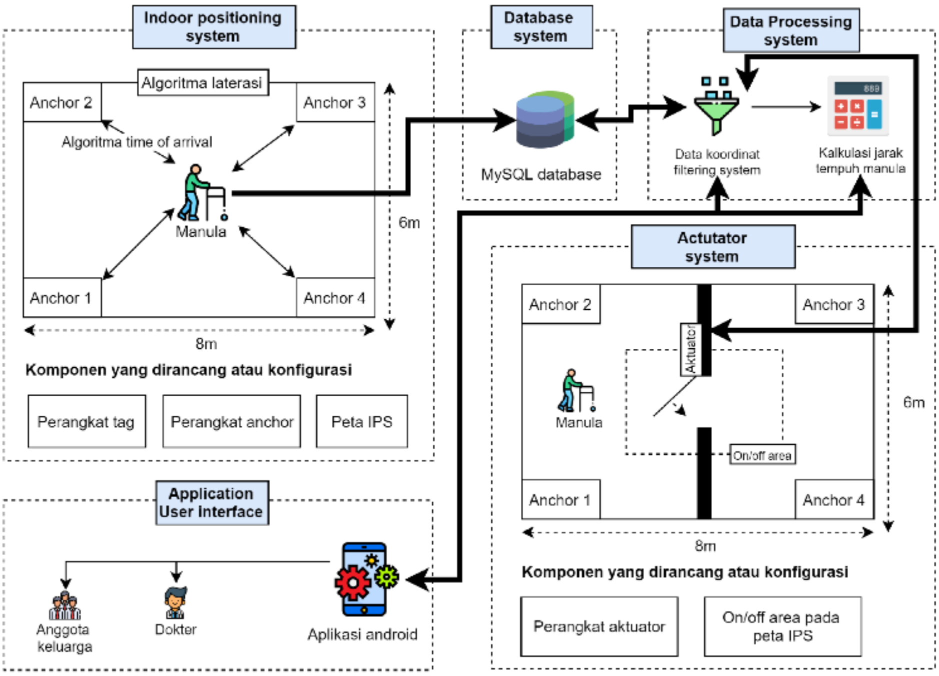

Figure 1. System design: Indoor positioning system using UWB Device

pass through. As a support and monitoring of the health of the elderly, we have also created an Android-based application that is used to monitor the daily movements of the elderly, which family members and nurses can access in places far from the elderly.

We developed a smart home system that is used to support daily activities for elderly. Elderly movement detection is implemented by trajectory tracking based on position data from UWB data that has been filtered. We have integrated the smart home prototype with an actuator that will work based on where the elderly are. The main contributions of this article can be summarized as follows:

1. The proposed system is a complete smart home system starting from physical devices to data in the cloud system which can be accessed again using applications on smart phones.
2. The proposed system was prototyped to be integrated with sensors and actuators installed in smart homes. One of them is in the form of an actuator connected to the door, to prove that the system is complete end-to-end detection system to the movement and position of the elderly.
3. An Android-based application that is used to monitor the daily movements of the elderly that can be accessed by families and nurses, so that they can find out the level of activity of the elderly compared from day to day.

METHOD

In this section, we will explain UWB design, followed by wearable devices, followed by door-opening actuator systems, and finally with android application designs.

The system has three main components: tags, anchors, and maps. Five Pozyx devices were utilized to implement this indoor positioning system, with four configured to act as anchors and one used as a tag. A visual representation of the entire system used in this study is shown in Figure 1.

Wearable Device

This study utilized the Pozyx system, a low-cost commercial indoor localization solution. Pozyx is a hardware that uses the DWM1000[8] designed for high-precision real-time positioning. We use four anchors strategically placed on the edge of the room, equipped with one tag whose location point will be calculated using the Time of Arrival (ToA)[5]. The distance between the tag and the anchor is calculated, and then the tag position is determined using a multilateration algorithm based on the four anchor references. We use UWB Channel 5, a preamble length of 1024, and a data rate of 110 kbps. An IMU (Inertial Measurement Unit) can be used on the tag and anchor devices to obtain the orientation angle, gyroscope, accelerator, and magnetometer. However, in this work, we only take the position from the tag.

The tag device, used to continuously monitor the elderly's position, is designed to be

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

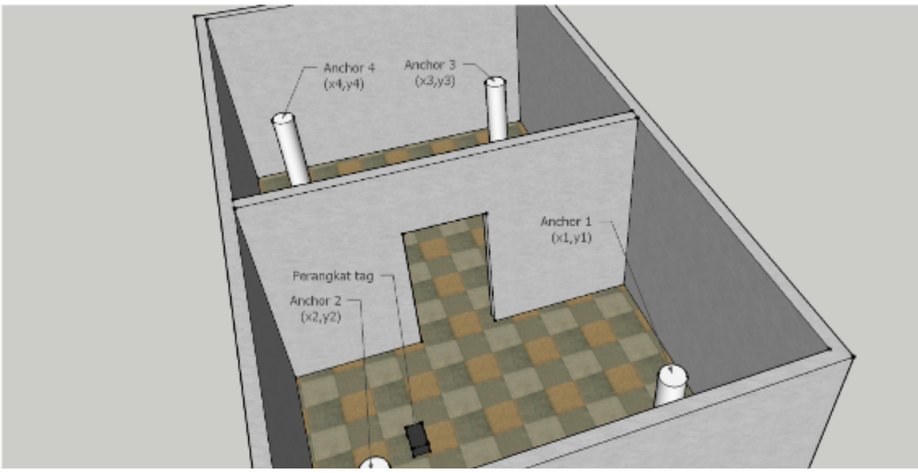

Figure 3. Illustration of indoor positioning system map implementation


Figure 2. Tag device installation to the elderly

as small as possible. This is to ensure that it does not impede their comfort during daily activities while still fulfilling its primary function. As shown in Figure II-A1, the tagging devices are attached to a belt worn by the elderly. This ensures that the ultrawideband DWM1000 antenna is always kept in a vertical position.

The tag device is made up of several components, including the Pozyx, the Wemos[9] D1, wifi modules, and a 12VDC power source which serves as the communication medium with the anchor, functions as the microcontroller, enables the tag device to transmit data to the database server, and supply power, respectively. The software for the tag was successfully developed using libraries provided by Pozyx and ESP8266. The program occupies 27% of the storage quota owned by Wemos D1, which is 286,992KB. Once the program is successfully embedded into the tagging device, the tags are activated and ready for use, as shown in Figure 2.

Map and anchor

The anchor device is a Pozyx devices that serves as a reference point for the tag device in the indoor positioning system. This device is placed in the corners of the map used for the implementation of the system. To configure a Pozyx device to become an anchor, the jumper on the T/A pin must be removed. After Pozyx is configured to be an anchor, the next step is to place it in the appropriate position specified in the map. It is crucial to ensure that the anchor is placed correctly, as any errors in the placement will result in less accurate position readings. Figure 3 provides an illustration of the map implementation used in the indoor positioning system.

Time Of Arrival Algorithm

In this system, the Time of Arrival (ToA) algorithm is used to obtain the distance value between the tag and each anchor. This distance value is necessary for the system to perform the lateration algorithm in the subsequent stage. The ToA algorithm works by utilizing the speed formula, as shown in equation (1), to calculate the difference in time between the transmission and reception of signals.

$$V = S/t \qquad ...(1)$$

S is the value of the distance sought, with the unit being metered, while *v* denotes the speed of the signal being sent. The speed is 299,729,458 m/s, and *t* is time in seconds. The time can be determined by the ToA method, where the difference between the time of sending and receiving signals is conducted.

Lateration Algorithm

This system use of the lateration algorithm [3] to determine the position of the coordinate (x, y) of the tag device carried by the elderly. The value depends on the distance between the tag devices with each reference point and their associated coordinates. The lateration algorithm was implemented after the system has determined the formation.

In this study, the lateration algorithm was implemented using four reference points, commonly referred to as multilateration. The implementation process is shown in Equation (2).

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

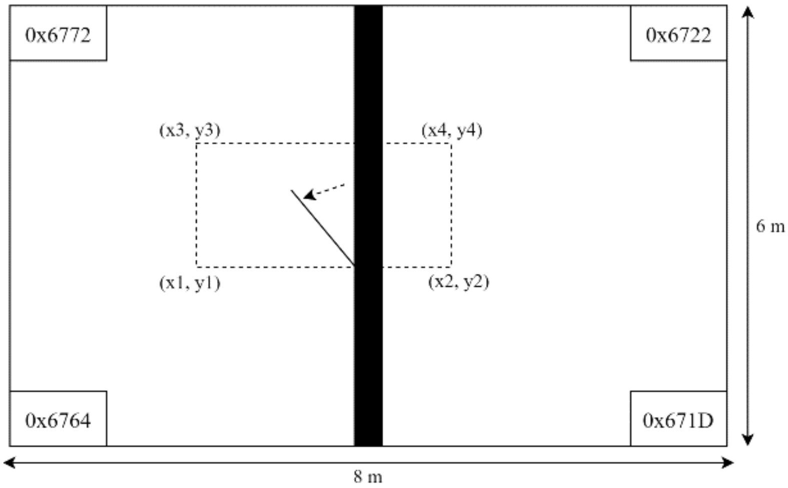

Figure 4. Indoor positioning system map with on/off area

$$2\begin{bmatrix}(x_1-x_n) & (y_1-y_n)\\ \vdots & \vdots \\ (x_m-x_n) & (y_m-y_n)\end{bmatrix}\begin{bmatrix}x\\ y\end{bmatrix}= \begin{bmatrix}x_1^2-x_n^2+y_1^2-y_n^2+d_n^2-d_1^2\\ \vdots \\ x_m^2-x_n^2+y_m^2-y_n^2+d_n^2-d_m^2\end{bmatrix} \quad ...(2)$$

Where n is the number of reference points used, d is the distance between the reference point and the position of the coordinate sought, and m is the result of n_1. Meanwhile, x and y are the position coordinates to be determined.

Data Processing Using Average Filter

For further processing, we take the tag location data then we save the raw data into a MySQL database. The coordinate data stored on the database server is considered raw data since it is obtained directly from a process that uses radio waves as the communication medium. As a result, this data may be affected by noise and the tolerance limits of the DWM1000 module. When this raw data is used directly to monitor elderly, the information of the distance between the tags and each anchor of the algorithm process associated with the ToA.

The elderly position is expected to be noise-free. Therefore, we need to remove noise from the raw data of the tag position. Since noise is generally at high frequencies, we decided to can be executed directly using SQL commands. In every second, ideally, at least the tag device can produce 15-20 coordinate data stored in the database. The average of the data in each time unit is calculated to ensure accurate coordinate data. The calculation process is possible because the coordinate data includes a time attribute indicating time-stamp. The calculations were performed using query statements in the MySQL database.

Calculation Using Euclidean Distance

After utilizing the average filter, the system calculates the distance travelled by the tag device using the Euclidean distance. The input for this process is an array of data that contains the x and y coordinates of the tag device after filtering. The input is then used to calculate the distance travelled by the tag device using the Euclidean distance algorithm. The results are stored in the database server, where they can be used by the user interface and other systems that require information on the distance travelled. The Euclidean distance algorithm is implemented using equation (3) [13].

$$d(p,q) = \sqrt{(q_1-p_1)^2+(q_2-p_2)^2+\cdots+(q_n-p_n)^2} \quad ...(3)$$

Actuator System

The system we designed is expected to help the elderly with their daily activities, especially in terms of their mobility. Therefore, we combine an indoor localization system with an actuator that can open and close doors automatically based on the position of the elderly in relation to the door. To achieve this goal, the map used for indoor positioning systems is customized by creating an on/off area. When the elderly are detected inside this area, the actuator assumes that the elderly want to open the door in the map area. Figure 4 shows the customized map with the on/off area. obtained may be inaccurate or even invalid. Additional processing steps are required to ensure that the data can be utilized effectively for purposes such as extracting distance and calorie information. We utilized a linear motor actuator with a stroke of 100 mm which has a maximum strength of 1500N

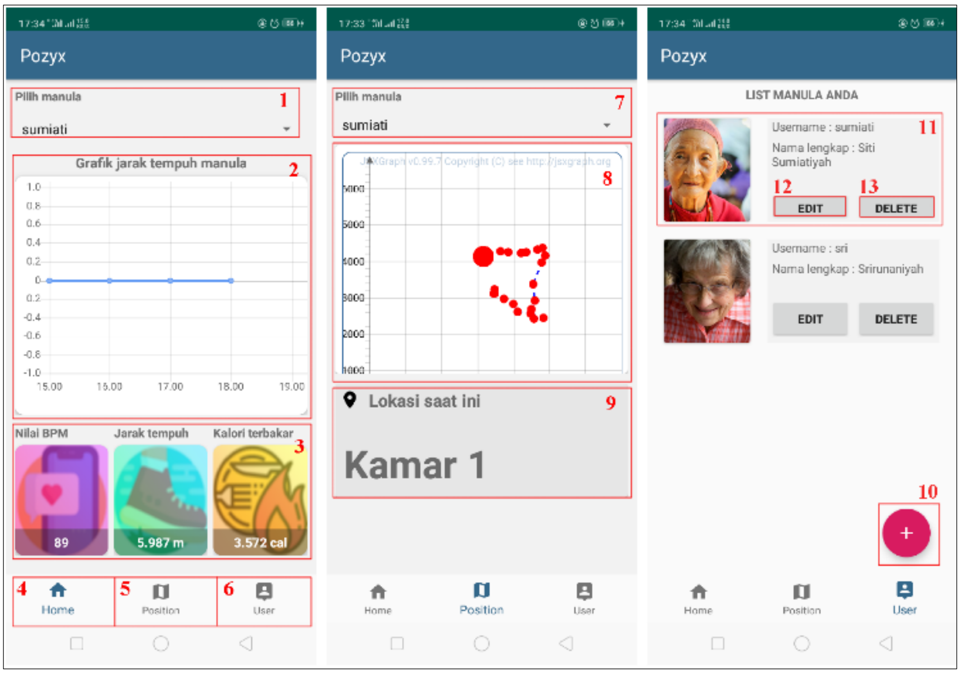

Figure 5. Application user interface screenshots

(150KG) with a speed of up to 6mm/second. The motor is controlled using a relay that supplies 12V DC electricity, both ends of the motor are attached to the wall and door.

Displaying Data Using the Application User Interface

Pozyxapp, an android based application enable doctors or family members to monitor the activities carried out by elderly, as shown in, Figure 5. This application enable used to monitor the bpm and mileage values of the elderly hourly, estimates their calories level, and track their trips as well as current positions of elderly. This application is designed to be used by users to monitor more than one elderly person, which enables a doctor or family member to monitor the activity of more than one elderly person simultaneously. Users are required to log in the first in order to have access to the monitoring process.

Using the mobile application, family members, nurses, and doctors can see the movement of the elderly and reports of mileage that elderly pass in a day. The application also estimates the number of calories the elderly use when walking for a day due to the current activity. Therefore, family members, nurses, and doctors can quickly determine whether or not elderly are in trouble. If the elderly do not do mobility as usual, there is the possibility of the elderly being in a state of illness or other things that cause them not to move. Conversely, if the elderly are actively moving, it can be concluded that they are in good condition. This feature demonstrates how the system improves the daily lives of elderly users.

SYSTEM IMPLEMENTATION AND TESTING

This section describes the test results of the system implementation that has been designed. Testing determines whether the developed system has been running according to the design. Therefore, to obtain comprehensive and in-depth test results, this test was carried out with the following details:

1. Indoor positioning system testing
2. Testing the average filter method on the data filtering system
3. Actuator system testing
4. Application user interface testing

Testing was conducted in a controlled laboratory setting with an indoor scenario, where the Pozyx device was used to determine the coordinates of the elderly. The system relied on Line of Sight (LoS) and Non-Line of Sight (NLoS) settings to measure the difference in accuracy in unobstructed and obstructed conditions. Line of Sight (LoS) conditions have no physical obstacles between the tag and the anchor, allowing the signal to travel directly. In Non-Line of Sight (NLoS) conditions, physical obstacles, such as walls, separate the tags and the anchor, causing the signal and accuracy to degrade and accuracy to decrease compared to LoS. This testing focused on a more controlled indoor environment, such as using scenarios with pre-set maps and placing anchors in specific positions to minimize unwanted variations.

Table 2. LOS Time of Arrival Testing Result

Test number	Pozyx ToA (mm)	Actual distance (mm)	Error (%)
1	1.031	1.000	3,1%
2	3.050	3.000	1,6%
3	4.965	5.000	0,7%
4	6.920	7.000	1,1%
5	8.986	9.000	0,1%
6	10.948	11.000	0,1%
Average			1,1%

Table 1. NLOS Time of Arrival Testing Result

Test number	Pozyx ToA (mm)	Actual distance (mm)	Error (%)
1	1.105	1.000	10,4%
2	3.264	3.000	8,8%
3	5.006	5.000	0,1%
4	7.018	7.000	0,2%
Average			4,9%

UWB positioning systems are sensitive to other microwave signals, such as digital TV and 3G wireless systems. UWB devices are also sensitive to metal materials in furniture and building structures in walls[15,16]. In this experiment, we only control the placement of the UWB device without controlling external microwave signals and interference from metal materials that cause noise in the UWB signal.

Indoor Positioning System Testing

Indoor positioning system testing is conducted to determine the accuracy of obtaining the elderly's positions. The testing process involves two conditions, Line of Sight (LOS) and Non-Line of Sight (NLOS). We configured the LOS condition by placing both the UWB tag and anchor in the same room without any obstacles. For the NLOS condition, we positioned the UWB tag and anchor in separate rooms, with a wall serving as the obstruction. Afterward, we measured the distance and compared it to the actual distance for accuracy.

The accuracy of this algorithm was tested by comparing its results with manual measurements using a meter. The maximum range of the Pozyx module was also determined through testing. These tests were conducted under two conditions, namely Line of Sight (LOS) and Non-Line of Sight (NLOS), with the results shown in Table 1 and Table 2, respectively. Based on Table 1 and Table 2, it can be seen that the maximum distance between the tag and the anchor in LOS conditions is 11 meters, while in NLOS conditions, the maximum distance is 7 meters. There is a difference between the measured and actual distances, with an average of 1.1% and 4.9% for LOS and NLOS, respectively. This is because the distance measurements are influenced by various equipment and furniture containing metal materials that affect the signal received by the tag, so the TOA calculation is not entirely accurate, obstructed by the presence of walls that block the tag from the anchor in NLOS conditions. This error can still be considered reasonable according to Pozyx's claim that the measurement accuracy is between 10-30 cm.

Table 3. Tag and Anchor Configuration for Lateration Algorithm

No	ID Pozyx	Coordinate (mm)		
		x	y	z
1	0x671d	0	0	150
2	0x6764	0	5200	600
3	0x6722	6000	5200	900
4	0x6772	6000	0	1500

Lateration Algorithm Testing

After knowing the maximum distance between the tag and the anchor in LOS and NLOS conditions, we tested the accuracy of the tag position measurement using the multilateration algorithm. This experiment was conducted to test the accuracy of the lateration algorithm used to calculate the position of wearable devices carried by elderly. The testing process involved calculating the difference between the coordinate positions generated by the Pozyx module and the predetermined coordinates. This was carried out to evaluate the accuracy of the Pozyx module before any filtering process. In order to test the lateration algorithm, a system map with both LOS and NLOS conditions was required. However, before localizing using the lateration algorithm, both the tag and anchor devices need to be configured. The configuration of the tag and anchor devices is shown in Table 3, while the position of the anchor in this system with LOS condition is described in Figure 6, indicating 5 coordinates used for testing, while figure 7 illustrates the multilateration test setting for NLOS conditions with 7 test coordinates.

As seen in Table 3, the anchor configuration has three-dimensional coordinates (x, y, z). The z coordinates that are not level indicate that the height of the anchor from the floor is different. This configuration adapts the installation instructions for the Pozyx system, which requires the anchor level to have a difference between the lowest level and the highest level so that the anchor can cover the tag work area so that the 3-dimensional measurement results can produce accurate values.

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

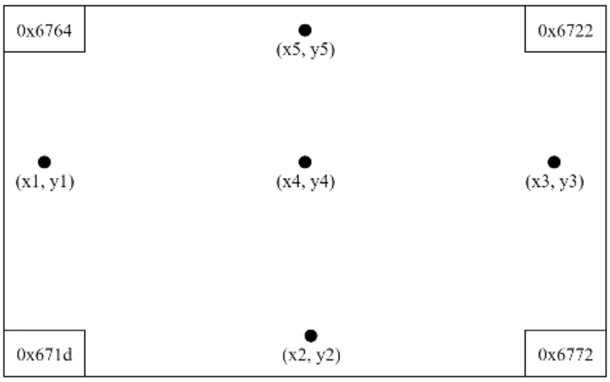

Figure 6. Configuration map for laterration algorithm with LOS setting

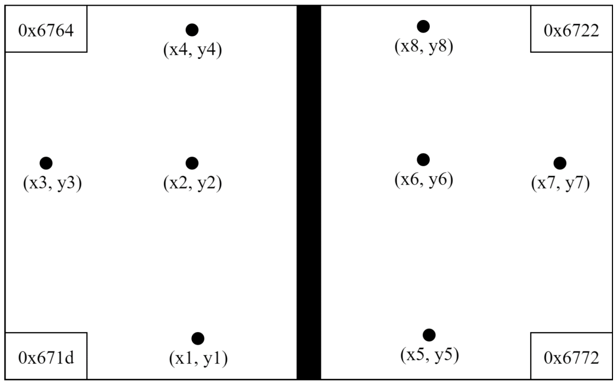

Figure 7. Configuration map for laterration algorithm with NLOS

Table 4. Test Result of Lateration Algorithm on LOS Condition

ID	Actual coordinate (mm)		Lateration result (mm)		Error (mm)
	x	y	x	y	
1	180	2.800	123	2.733	89,49
2	3.200	250	3.027	259	173,23
3	5.900	2.800	5.842	2.681	132,38
4	3.200	2.800	3.191	2.845	45,89
5	3.200	5.000	3.167	4.958	53,41
Average					98,80

Table 5. Test Result of Lateration Algorithm on NLOS Condition

ID	Actual coordinate (mm)		Lateration result (mm)		Error (mm)
	x	*y*	*x*	*y*	
1	1.450	150	1.220	157	230,1
2	1.450	2.800	1.264	2.797	186,0
3	250	2.800	235	2.613	187,6
4	1.450	5.100	1.304	4.904	244,4
5	4.570	400	4.414	266	205,6
6	3.370	2.400	3.377	1.762	638,0
7	5.770	2.400	5.735	2.277	127,8
8	4.570	5.100	4.988	5.061	419,8
Average					279,9

These positions were determined based on both ideal and possible error cases. The ideal case is when the tag is located exactly in the middle between anchors, while error cases may occur in the border area of the map. The test results on the use of the lateration algorithm with LOS conditions are shown in Table 4.

Meanwhile, to test the lateration algorithm under NLOS conditions, a different number of test coordinate points were used compared to the LOS condition, as shown in Figure 7. The reason for this is to divide the testing into two separate rooms: room one and room two. This was carried out to determine whether there are any differences in the accuracy of the lateration algorithm results between the two rooms. Even though the testing principles for both conditions are the same, i.e., testing for both the ideal case and possible error cases. The test results of the lateration algorithm under NLOS conditions can be found in Table 5.

Based on the test results presented in Table 4 and Table 5, there are position measurement errors in both LOS and NLOS conditions of 98.8 millimeters and 279.9 millimeters, respectively. However, to obtain these measurement results, the tag must be placed statically for at least 10 seconds until there is no oscillation of the measurement results. This is due to some interference to the UWB signal caused by furniture and devices containing metal. The error becomes greater when the presence of a wall obstacle in the NLOS condition.

Performance Of Moving Average Filter

The data filtering was implemented using the average filter to obtain position coordinate data from tag devices similar to the original conditions compared to the coordinates of the position of tag devices received from the sensor directly, which are still mixed with noise.

Testing of the data filtering system using the average filter method aims to determine the most appropriate time interval for the filter process. The test was conducted by creating an indoor positioning system implementation scenario with a map in which ten coordinate points have been determined.

The performance of the moving average filter is tested by positioning the tags randomly in the room and taking measurements to obtain their actual position. Several different time window lengths are applied to obtain optimal filtering performance. The results are then

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

Figure 8. Moving average filter performance

compared, and the smallest calculated error compared to the actual position is marked.

According to the experimental results shown in Figure 8, the moving average filter with a window length of 3 seconds produces the smallest error value. Selecting a shorter window length makes the measurement results vulnerable to changes in position and susceptible to noise. The process of selecting a longer time makes the measurement results insensitive to changes and incapable of effectively eliminating noise, resulting in larger measurement errors.

Functional System Testing

The actuator system was tested to evaluate its accuracy in the successful detection of when the elderly are on or off the area. The system's success was evaluated based on its performance in automatically opening the door when the elderly was in the on/off area and not opening it when they were outside the area. The test was carried out using an indoor positioning system implementation scenario with an on/off area, and 10 coordinate points were predetermined for the elderly to occupy. The true positive condition included coordinates (x_3 x_7, y_3 y_7) where the elderly were in the on/off area, and the actuator system opened the door automatically.

As seen in Figure 9, we picked specific points to test where the user's tag is located. Imagine a square shape outlined by points 1, 2, 3, and 4; this square marks the space where the system uses sensors to make the door open and close autonomously. Inside this virtual square, the sensor's position tells the system when to open or close the door. Now, if the user's sensor tag is in the region between point 1, point 3, and the wall, the door will swing open to the left automatically. However, if the sensor tag is between walls 2 and 4, it means the user has passed through the door, and the door will close

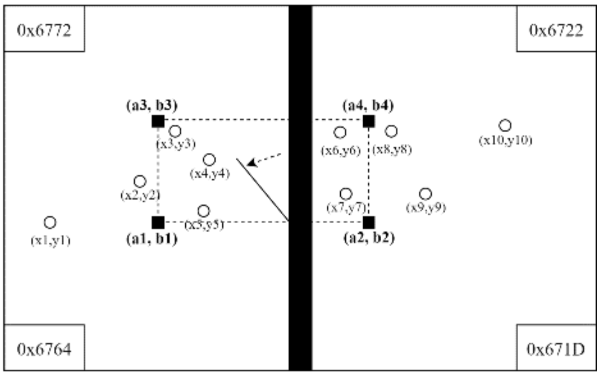

Figure 9. Configuration of functional testing. Elderly wearing the device randomly walking in and out through the door to another room

on its own. This smart system ensures the door opens and closes just when needed, making things easy for the user.

Notice that the imaginary boundary box is not precisely centered but leaning towards the left wall. We did this on purpose because the door swings open to the left. We wanted to ensure the user stays safe, so we shifted the boundary slightly to the left. This way, when the door opens, there is no risk of it accidentally hitting the user.

The indoor positioning system used in this test is shown in Figure 9. The test was conducted five times on each of the 10 predetermined coordinate points, and the accuracy of the system success was evaluated using a confusion matrix. Based on the test results, it was concluded that the actuator system performed well with an accuracy of 98%.

Application User Interface Testing

The user interface application was tested for two aspects : user functionality and experiences. Five volunteers were involved in using the application to provide feedback. The application user interface was tested in terms of functionality involved by running the features in the application five times and evaluating the success rate. The tested features required interaction with users, while features that only display were tested in terms of user experience. Table 7 describes the results of testing the user interface application from its functional aspects. It can be concluded that all features provided by the application user interface work optimally according to the system design made, with a success rate of 100% for each feature.

Based on the results, it can be concluded that the user interface application features work optimally as per the system design, with a success rate of 100% for each feature tested. Additionally, to evaluate the user experience, a

Table 3. User interface application testing results in terms of user experience

Question of the block	Right answer	Wrong answer	Doubt	UX rate
1	20	2	0	90.91%
2	21	0	1	95,45%
3	21	1	0	95,45%
4	21	1	0	95,45%
5	22	0	0	100%
6	18	0	4	81,82%
7	19	3	0	86,36%
8	17	3	2	77,27%
9	20	2	0	90,91%
10	21	1	0	95,45%
11	22	0	0	100%
12	21	1	0	95,45%
13	21	1	0	95,45%
Average				92,31%

survey was conducted by asking prospective users questions about the function of the components or features in the application. Table 6 shows the results of the user experience testing on the user interface application, indicating a fairly high user experience rate of 92.31%.

CONCLUSIONS AND FUTURE WORK

In this article, a novel solution was proposed to perform gesture recognition by using a low-cost UWB communication system.

In this article, a smart home solution system was proposed to support daily manual activities using a low-cost UWB system. Based on the conducted experiments, the smart home system has proven effective, covering the detection of the position of the elderly, to actuators in the form of automatic doors that work autonomously based on the position and movement of the elderly.

The following conclusions are drawn from the tests conducted on the system implemented in this study.

1. The ToA algorithm used to measure the distance between tags and anchors in LOS conditions provided better accuracy with an error rate of 1.158% and a range of 11 meters. However, in NLOS conditions, the error rate increased to 4.914%, and the range was reduced to 7 meters. For indoor positioning of elderly, the lateration algorithm used by the system in LOS conditions had an average reading difference of 98.88 mm, whereas, in NLOS conditions, the average difference in coordinates was larger at 279.94 mm. This errors are caused by the presence of walls that block the signal between the anchor and the tag and the presence of other metal equipment and furniture. Of course, this condition will be worse if implemented in a house with many rooms, because several walls that block will cause more significant errors. Therefore, implementation in a home with many rooms requires more anchors placed in each room.
2. Applying the average filter method in the data processing system significantly reduced the error from an initial 164.39% to just 1.096%. This simple filter has proven to be suitable for application to raw elderly position data because it is easy to implement into simple SQL syntax.
3. This work has succeeded in combining UWB localization with an actuator system. The actuator system ran smoothly, with a success rate of 98%. However, it should be noted that the implementation of the actuator system forces the system to work in NLOS conditions; therefore, to minimize NLOS condition errors, additional anchors need to be placed around the door.
4. The application user interface was evaluated in terms of functionality and user experience. The user interface functionality had an optimal success rate of 100%, with a 92.31% rating.

Future Work

Probing deeper, the results of this study also provide a strong foundation for future work in monitoring and assisting the elderly in their daily activities. The application can be broader if combined with other smart devices, such as robot service or smart sensors, to build a comprehensive smart home.

This section discusses future work that can be developed from the results of this study.

1. Integration with Wearable Health Monitoring Devices: The system could be expanded by integrating health monitoring features, such as tracking heart rate, blood pressure, or oxygen levels. This integration would provide a more comprehensive health monitoring solution for elderly users, enabling real-time alerts for localization and potential health emergencies.
2. User-Friendly Mobile Applications for Caregivers and family members: The application has been developed and tested on adult users. However, real testing is needed on family members and caregivers to get input for further development. The application also needs to be tested on the elderly so that they understand how they are monitored and can provide suggestions regarding what needs to be developed so that they can use similar applications for other purposes, such as asking to be reminded for medication and physical therapy.
3. Machine Learning for Behavioral Analysis: Implementing machine learning algorithms could enhance the system's ability to predict

and detect abnormal behaviors. For example, analyzing movement patterns over time could help the system identify deviations from normal behavior, which could indicate early signs of health problems or cognitive decline, allowing for prevention.
4. Integration with service robots: We have robots that can assist the elderly. By integrating the elderly's position data with the service robot, the robot can provide appropriate service by considering the distance to the elderly and is able to understand the context of the elderly's activities based on their position.

ACKNOWLEDGMENT

This work was supported in part by the Indonesian Government through the 2019–2023 Lembaga Pengelola Dana Pendidikan (LPDP) scholarship and in part of the Penelitian Keilmuan ITS Research Grant.

REFERENCES

[1] Badan Pusat Statistik Indonesia, ''Analisis lansia di indonesia 2017,'' in Statistic Report 1964, 2018.
[2] R. J. Robles and T.-h. Kim, ''Applications, systems and methods in smart home technology: A Review,'' Int. Journal of Advanced Science And Technology,vol. 15, 2010.
[3] B. P. Statistik, ''Statistik indonesia 2016,'' 2016.
[4] M. Kessel, M. Werner, F. Gschwandtner, and C. Linnhoff Popien, ''Tracking and navigation for goods and people,'' Encyclopedia of automotive engineering, pp. 1-12, 2014.
[5] B. OKeefe, ''Finding location with time of arrival and time difference of arrival techniques,'' 2017.
[6] J. Reed, Introduction to ultra wideband communication systems, an. Prentice Hall Press, 2005.
[7] ''Datasheet dwm1000 module.'' last accessed on May 3, 2019.
[8] H. Lee, J.W. Park, and A. S. Helal, ''Estimation of indoor physical activity level based on footstep vibration signal measured by mems accelerometer in smart home environments,'' in International Workshop on Mobile Entity Localization and Tracking in GPS-less Environments, pp. 148-162, Springer, 2009.
[9] ''Development board wemos d1.'' last accessed on 3 may 2019.
[10] A. A. N. S. Laksmana, ''Internet of things untuk memantau kondisi serta aktivitas manula menggunakan turtlebot sebagai gateway,'' 2018.
[11] S. Dengler, A. Awad, and F. Dressler, ''Sensor/actuator networks in smart homes for supporting elderly and handicapped people,'' in 21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07), vol. 2, pp. 863-868, IEEE, 2007
[12] J. Foerster, E. Green, S. Somayazulu, D. Leeper, et al., ''Ultrawideband technology for short-or medium-range wireless communications,'' in Intel technology journal, Citeseer, 2001.
[13] M. Malkauthekar, ''Analysis of euclidean distance and manhattan distance measure in face recognition,'' 2013.
[14] N. Komiya, M. Tokuoka, R. Egusa, S. Inagaki, H. Mizoguchi, M. Namatame, and F. Kusunoki, ''Novel application of 3d range image sensorto caloric expenditure estimation based on human body measurement,''in 2018 12th International Conference on Sensing Technology (ICST), pp.371-374, IEEE, 2018.
[15] Cheng Tu, Jiabin Zhang, Zhi Quan, Yingqiang Ding,"UWB indoor localization method based on neural network multi-classification for NLOS distance correction", Sensors and Actuators A: Physical, Volume 379, 2024.
[16] Khodjaev, J., Park, Y. & Saeed Malik, A. Survey of NLOS identification and error mitigation problems in UWB-based positioning algorithms for dense environments. Ann. Telecommun. 65, 301–311, 2010.
[17] Alemán, J.J., Sanchez-Pi, N., Garcia, A.C.B. SafeRoute: An Example of Multi-sensoring Tracking for the Elderly Using Mobiles on Ambient Intelligence. In: Bajo, J., et al. Highlights of Practical Applications of Agents, Multi-Agent Systems, and Sustainability - The PAAMS Collection. PAAMS 2015. Communications in Computer and Information Science, vol 524. Springer, Cham, 2015.
[18] Guo, Q. Design of a Smart Elderly Positioning Management System Based on GPS Technology. In: J. Jansen, B., Liang, H., Ye, J. (eds) International Conference on Cognitive based Information Processing and Applications (CIPA 2021). Lecture Notes on Data Engineering and Communications Technologies, vol 84. Springer, 2022.
[19] Thakur, Nirmalya, and Chia Y. Han, "Indoor Localization for Personalized Ambient Assisted Living of Multiple Users in Multi-Floor Smart Environments" Big Data and Cognitive Computing 5, no. 3: 42. 2021.

ISSN 2089-8673 (Print) | ISSN 2548-4265 (Online)
Volume 13, Issue 3, December 2024

[20] Thakur, Nirmalya and Han, Chia Y., “A Simplistic and Cost-Effective Design for Real-World Development of an Ambient Assisted Living System for Fall Detection and Indoor Localization: Proof of Concept”, 2022.
[21] Jane Chung, Lana Sargent, Roy Brown, “Use of GPS Tracking Technology to Measure Mobility in Older Adults: A Systematic Review, Innovation in Aging”, Volume 4, Issue Supplement_1, 2020
[22] Lin, Xuxin, Jianwen Gan, Chaohao Jiang, Shuai Xue, and Yanyan Liang. "Wi-Fi-Based Indoor Localization and Navigation: A Robot-Aided Hybrid Deep Learning Approach" Sensors 23, no. 14: 6320. 2023.
[23] Martins, H., Gupta, N., Reis, M.J.C.S. ”A Non-intrusive IoT-Based Real-Time Alert System for Elderly People Monitoring”. In: Science and Technologies for Smart Cities. SmartCity360°. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 372. Springer. .2021.
[24] Bibbò, Luigi, Riccardo Carotenuto, and Francesco Della Corte. "An Overview of Indoor Localization System for Human Activity Recognition (HAR) in Healthcare" Sensors 22, no. 21: 8119,2022.
[25] Roy, P., Chowdhury, C. “A survey on ubiquitous WiFi-based indoor localization system for smartphone users from implementation perspectives”. CCF Trans. Pervasive Comp. Interact. 4, 298–318, 2022.
[26] Obeidat, H., Shuaieb, W., Obeidat, O. et al. “A Review of Indoor Localization Techniques and Wireless Technologies”. Wireless Pers Commun 119, 289–327, 2021.
[27] M. Kolakowski and B. Blachucki, "Monitoring Wandering Behavior of Persons Suffering from Dementia Using BLE Based Localization System," 2019 27th Telecommunications Forum (TELFOR), Belgrade, Serbia, 2019, pp. 1-4
[28] Kolakowski, Jerzy, Vitomir Djaja-Josko, Marcin Kolakowski, and Katarzyna Broczek. 2020. "UWB/BLE Tracking System for Elderly People Monitoring" Sensors 20, no. 6: 1574
[29] Röbesaat, Jenny, Peilin Zhang, Mohamed Abdelaal, and Oliver Theel. 2017. "An Improved BLE Indoor Localization with Kalman-Based Fusion: An Experimental Study" Sensors 17, no. 5: 951
[30] Leitch, Samuel G., Qasim Zeeshan Ahmed, Waqas Bin Abbas, Maryam Hafeez, Pavlos I. Laziridis, Pradorn Sureephong, and Temitope Alade. 2023. "On Indoor Localization Using WiFi, BLE, UWB, and IMU Technologies" Sensors 23, no. 20: 8598.
[31] Raad, M.W., Sheltami, T., Soliman, M.A., Alrashed, M. (2018). An RFID Based Activity of Daily Living for Elderly with Alzheimer’s. In: Ahmed, M., Begum, S., Fasquel, JB. (eds) Internet of Things (IoT) Technologies for HealthCare. HealthyIoT 2017. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 225. Springer, Cham.
[32] Kim, SC., Jeong, YS. & Park, SO. RFID-based indoor location tracking to ensure the safety of the elderly in smart home environments. Pers Ubiquit Comput 17, 1699–1707 (2013)
[33] Shen, J., Jin, C., Liu, D. (2016). A Survey on the Research of Indoor RFID Positioning System. In: Sun, X., Liu, A., Chao, HC., Bertino, E. (eds) Cloud Computing and Security. ICCCS 2016. Lecture Notes in Computer Science(), vol 10040. Springer.
[34] Obeidat, H., Shuaieb, W., Obeidat, O. et al. A Review of Indoor Localization Techniques and Wireless Technologies. Wireless Pers Commun 119, 289–327 (2021).
[35] Wang, D., Yin, J., Chen, X., et al. (2019). On the use of calibration emitters for TDOA source localization in the presence of synchronization clock bias and sensor location errors. EURASIP Journal on Advances in Signal Processing, Vol.2019 (1), 1-34.
[36] AMJAD I, OMAR A S, ARBAB W A, et al. Mutual coupling reduction using F-shaped stubs in UWB-MIMO antenna[J]. IEEE Access, 2018, 6:2755-2759.
[37] S. Campaña-Bastidas, M. Espinilla-Estévez, and J. MedinaQuero, Review of Ultra Wide Band (UWB) for Indoor Positioning with application to the elderly. [Online]. Available: https://hdl.handle.net/10125/79601
[38] S. K. Gharghan, R. Nordin, A. M. Jawad, H. M. Jawad and M. Ismail, "Adaptive Neural Fuzzy Inference System for Accurate Localization of Wireless Sensor Network in Outdoor and Indoor Cycling Applications," in IEEE Access, vol. 6, pp. 38475-38489, 2018, doi: 10.1109/ACCESS.2018
[39] Geng Chen, Lili Cheng, Rui Shao, Qingbin Wang, Shuihua Wang, A Review of Device-Free Indoor Positioning for Home-Based Care of the Aged: Techniques and Technologies, CMES - Computer Modeling in Engineering and Sciences, Volume 135, Issue 3, 2022,