Jurnal Teknologi Elekterika, 2024, Volume 21 (1): 1-8 **e- ISSN 2656-0143**

Simulation Model Design of VHF Omni-Directional Range (VOR) Based on Microcontroller

Roby Tristiantoro [1,a] Usman Umar [2,b] Risnawaty Alyah [3]
[1] Rekayasa Elektro-medis, Politeknik Muhammadiyah Makassar, Makassar, Indonesia
[2] Teknologi Elektro-medis, Politeknik Muhammadiyah Makassar, Makassar, Indonesia
[3] Teknik Elektro, Universitas Sawerigading Makassar, Makassar, Indonesia
[a] robytrist@gmail.com
[b] usmanmr4@gmail.com

***Abstract*— The process of giving directional information to assist airplanes in making an accurate landing at the airport of destination is known as aviation navigation. The VHF Omnidirectional Range is a crucial navigation tool for guiding planes to the airport (VOR). Since it costs a lot of money to learn how to fly an airplane, a VOR simulator was developed that can mimic the movement of an aircraft passing through the VOR. The simulation that was produced is a prototype that sends and receives signals to the aircraft utilizing an antenna and microcontroller as supporting hardware. The VOR/DME flight navigation system is constructed in this study using mathematical modeling; a formulation representing the essential features of the system is expressed as a set of connected variables. The ESP32 module that powers the system serves as a DME by sending out Bluetooth radio signals. where one ESP32 module serves as a DME object (moving DME) and three ESP32 modules serve as DME stations (ground DME). Information on the distance between the DME station and the DME object will be communicated using the MQTT protocol, and this data will be processed using the trilateration method to predict the location and movement of the DME object. The measurement accuracy at DME station 1, DME station 2, and DME station 3 are 99.52%, 99.92%, and 99.98% respectively. The enhanced capabilities to estimate the position of objects observed from different directions or omni-directionally on a two-dimensional scale are made possible by the performance results of combining the performance of three ESP32 devices as Distance Measurement Equipment (DME).**

Keywords—VOR Simulator; DME; Bluetooth; Microcontroller

I. Introduction

Aviation navigation is a method of guiding or providing directional information to help aircraft land correctly at the destination airport. Initially, navigation to guide the plane to the destination airport was only done with human vision, but extreme weather conditions such as rain and fog apparently limited human vision.

In aviation navigation services there must be equipment capable of directing aircraft to the destination airport, which requires the navigation equipment to operate continuously. And has unlimited capabilities, so it can guide the plane to the destination airport [1].

In flight operations, the knowledge and navigation skills of everyone involved in the flight operation are very important in determining the success of a flight mission. As in the Republic of Indonesia Aviation Law No. 1 of 2009, it is stated that: "Air traffic control is the process of controlling the movement of aircraft safely and smoothly from one location to another to avoid dangers and/or flight obstacles [2].

An aviation navigation system consists of a collection of various aviation navigation devices (navigation aids) which are useful in providing indications such as direction, distance, speed to the airport, height above ground level, as well as equipment which functions to provide instructions for landing in bad weather conditions intended to aviation safety and security. Flight plans can follow existing airways, where these airways connect waypoints, waypoints can be predetermined points, which can be airports, VORs, NDBs or agreed waypoints [3]. To carry out flights according to the flight plant that has been determined, the pilot can fly using visual flight or using flight instruments. To fly using instrument flight, you must use navigation equipment to guide the flight direction, one of the devices used is the VHF Omni-Directional Range (VOR). This VOR equipment uses very high radio frequencies. The plane can aim at its destination by utilizing the VOR station without being affected by weather conditions by using the auto-pilot instrument [4].

VOR works on very high frequencies (VHF) from 108 MHz to 117.95 MHz. VOR is an air navigation tool whose function is to provide distance information to aircraft, the tilt angle between the aircraft and the transmitter from Distance measurement equipment (DME). The working principle of VOR/DME is that the pilot tunes the frequency on the VOR/DME that is the target. Then the aircraft instruments will provide information on the bearing, slant range (slant distance) between the aircraft and the VOR, so that with this information the pilot will go straight to the destination VOR/DME [5].

An important navigation device that has unlimited potential to direct aircraft to the airport is the VHF Omni-directional Range (VOR). VHF Omni-directional Range (VOR) is an aviation navigation device to guide aircraft to land perfectly at the destination airport by providing information in the form of azimuth or artificial azimuth, not the correct flight direction. True direction (north, east, south, west). on the plane) but information about the VOR ground station at the airport.

According to Ref. [7] studied the analysis of speed parameters and the Doppler effect, and changes in frequency on each of the 48 sides of the antenna are changes in frequency caused by the Doppler effect, namely the effect that causes changes in frequency. as a result of a change in the speed of the source towards the observer, but within the DVOR. The speed of the observer itself can be ignored because changes in the frequency of the sideband antennas result in changes in the frequencies of each antenna that are continuously generated. The research was carried out by studying the performance of radio navigation aids such as ILS and VOR/DVOR systems, which are sensitive to their operating environment. Multipathing from buildings and other structures in the vicinity of the ILS/CVOR/DVOR ground station is combined with the direct signal to form a composite signal with different amplitude and phase characteristics than the direct signal. Airborne receivers (ILS/CVOR/DVOR) that pick up "contaminated" signals and process them in various ways will send incorrect position or course indications. (Yellu, 2013)

Study Ref. [8] that in DVOR using the Doppler effect, the data sent to the aircraft experiences signal loss due to distance. Analysis of link budget calculations using path loss and Doppler loss parameters with the recipient target (aircraft) produces insignificant changes in path loss and attenuation values when the aircraft approaches.

According to Ref. [3] that in the world of aviation, detecting the direction and distance of an aircraft is one way to achieve good flight. VOR/DME is an aviation navigation tool/device. The FAA invented this parallel component device capable of transmitting combined radio signals, including Morse code and data, to enable aircraft receiving equipment to obtain magnetic direction from the station to the aircraft. VOR usually works together with DME to provide information/guidance to pilots about the flight path/azimuth (VOR) and distance (DME) to the ground station. Modeling and simulation of VOR/DME devices is the study of the behavior of aviation navigation devices, which are created using software that is able to imitate the behavior of certain real systems (reality) in interesting aspects that are easily understood by users. The resulting output is in the form of numerical data, which is then converted into an animated form that matches the actual appearance of the device.

II. Literature Study

A. Simulation Method and Prototype

Simulation means imitation or action that is only an appearance. As a teaching method, simulation can be interpreted as an activity that depicts actual situations. The simulation learning method is a learning method that imitates something real, the environment (situation), or the process. corresponds to the actual appearance of the device [9].

Prototyping is a systematic development method that allows the creation of programs quickly and gradually, so that users can immediately evaluate them. A prototype represents a model of the product to be built or simulates the structure, functionality and operation of a system. The prototype dimension consists of (1) representation, namely how is the model explained or presented? These can be text descriptions or visual images and diagrams. (2) Scope, is it just an interface or does it contain computer components? (3) Executable (potentially executable). Once the prototype is running, will there be a period when the prototype doesn't work? (4) maturation, in the form of product development stages. There are two phases, namely (a) Revolutionary: replacing the old. If you feel that the old system can no longer keep up with technological developments. (b) Development: continuing to make changes to the previous model [10].

A simulation model is a model that describes cause-and-effect relationships in a system using a computer model that is able to describe behavior that may occur in a real system. Simulation models are used to find out what happens when one or more variables or components are changed [11].

B. *Aerial Navigation System*

Navigation is broadly defined as "the science and art of moving ships according to a plan from one place to another on the face of the earth" (summarized from several encyclopedias). It is clear from the above definition that navigation is the science and art that deals with the movement of ships (with the various angles involved) from one port to another on earth.

The mathematical model of the VOR/DME air navigation system is listed in the Navigation Form on page 8, a reference source in international aviation.

1. The distance between the aircraft position and the VOR/DME can be calculated using the following formulation

$$distance = a\cos(\sin(lat_1)\cdot\sin(lat_2) + \cos(lat_1)\cdot\cos(lat_2)\cdot\cos(lon_1 - lon_2)) \quad (1)$$

$$bearing = mod(a\tan^2(\sin(lon_1 - lon_2)\cdot\cos(lat_2), \cos(lat_1)\cdot\sin(lat_2) - \sin(lat_1)\cdot\cos(lat_2)\cdot\cos(lon_1 - lon_2)), 2\pi) \quad (2)$$

2. Calculating the position of the aircraft at the next time can be calculated using

$$SWC = \left(\frac{WS}{TAS}\right)\cdot\sin(WD - CRS) \quad (3)$$

$$lat_{new} = a\sin(\sin(lat_1)\cdot\cos(distance) + \cos(lat_1)\cdot\sin(distance)\cdot\cos(bearing)) \quad (4)$$

Where,

lat_1 = latitude 1, airplane latitude
lat_2 = latitude 2, VOR latitude
lon_1 = longitude 1, airplane longitude
lon_2 = longitude 2, VOR bearing longitude within radius distance in mile
SWC = Speed, Wind and Course.

C. *VHF Omni- Directional Range (VOR)*

VOR stands for VHF (Very High Frequency) Omni-Directional Range and is the oldest and most widely used navigation device. It consists of thousands of ground transmitting stations that communicate with aircraft receivers. VOR is a radio navigation system for aircraft. The VOR broadcasts a composite radio signal containing Morse code and data that allows the aircraft's receiving equipment to obtain a magnetic bearing from the station to the aircraft. VOR operates on the UHF frequency 108 - 117.95 MHz. Because VORs operate on UHF frequencies, ground-to-air communication distances are limited in terms of "line of sight"

D. *Distance Measuring Equipment (DME)*

DME or Rangefinder is a radio navigation aid used by pilots to determine the level of inclination of the aircraft from the position of the DME ground station. The ship's avionics DME sends a pulse signal to the land-based DME, which responds with a feedback pulse signal. The on-board receiver measures the delay between sending and receiving pulses and calculates the tilt distance. There is no azimuth information, only distance.

The simple operation of DME is that when the plane approaches the runway, the DME will automatically operate and receive signals emitted from the ground station, the closer the plane is to the runway, the lower the distance. When the antenna receives a signal from the ground station then sends it to the transceiver, the signal is processed in the transceiver and produces output in the form of digital data which is displayed on the indicator.

The DME function is often used in conjunction with VOR to complement each other and is useful for providing distance information to ground stations DME or VOR (VOR provides angle or direction information in degrees, while DME provides distance information in nautical miles or NM), DME can be used independently of Instrument Landing System (ILS) navigation function, which is useful for providing continuous distance information to aircraft when approaching or landing at an airport.

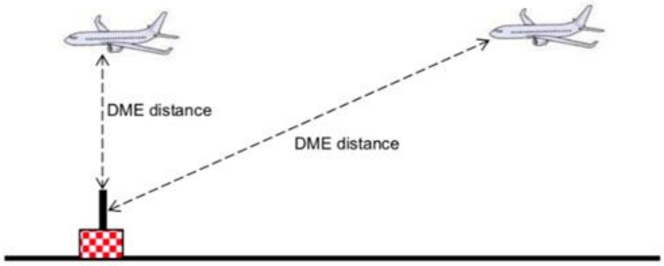

Figure 1. DME work principle

III. Research Method

E. VOR Model Design

In this research, a system design was carried out, both hardware and software. First, a model design is created as a reference. VOR design with a microcontroller as in the following image.

Design of a microcontroller-based VOR model, including input, process and output. Where input is a signal from a sensor or antenna which is sent and received by the antenna of the aircraft which is the size of the Received Signal Stregth Indicator (RSSI) and Power TX. The signal received is processed based on a mathematical equation model that has been entered into the Arduino IDE software or program. So that the three distance and coordinate outputs can be obtained accurately. The output data can be seen in the Graphical User Interface (GUI).

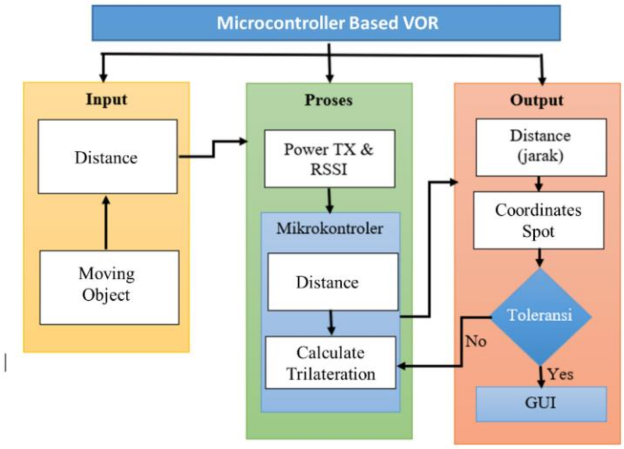

Figure 2. VOR microcontroller-based model design

F. VOR system design

In this research, the VOR/DME flight navigation system is implemented through mathematical modeling, where a set of related variables express the fundamental characteristics of the system in the form of a formulation for operating the system or model.

This system uses an ESP32 module which acts as a DME by transmitting Bluetooth radio signals. Where there are three ESP32 modules which act as DME stations (ground DME) and one ESP32 which acts as a DME object (moving DME). The DME station will be programmed into Bluetooth signal scanning mode. Meanwhile, the DME object will be programmed into Bluetooth advertising/broadcasting mode. This DME object will later be scanned for signal strength (RSSI and Power TX) by the DME station and will be calculated in distance units. To convert RSSI and TX Power values to distance units, the following equation is used

$$Distance = 10^{\left(\frac{TX\ Power\ -\ RSSI}{10 \cdot \alpha}\right)} \quad (5)$$

Where α is the path loss exponent value of the ESP32 module antenna, which in this measurement uses α with a value of 3.5 for indoor conditions.

Next, to determine the location of the DME object, the following equation is used

$$x = \frac{(C \times E) - (F \times B)}{(E \times A) - (B \times D)} \quad (6)$$

$$y = \frac{(C \times D) - (A \times F)}{(B \times D) - (A \times E)} \quad (7)$$

Where,

$A = 2(x_2 - x_1)$
$B = 2(y_2 - y_1)$
$C = d_1^2 - d_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2$
$D = 2(x_3 - x_2)$
$E = 2(y_3 - y_2)$
$F = d_2^2 - d_3^2 - x_2^2 + x_3^2 - y_2^2 + y_3^2$

Declaration,

x = object coordinates in x-axis
y = object coordinates in y-axis
x_n = DME station n coordinates (n = 1, 2, 3) in x-axis
y_n = DME station n coordinates (n = 1, 2, 3) in y-axis
d_n = distance between object to DME station n (n = 1, 2, 3)

IV. Results and Discussion

The location determination program is based on distance measurements from three DME stations using the trilateration method. This program will display the location coordinates of objects detected by the system which will then be displayed on the Graphical User Interface (GUI). Apart from that, there is also a feature for setting the coordinate position of each DME station. So, the use of this tool can be adjusted to the size of the place or room when the tool demonstration process is carried out. Distance measurement testing using Bluetooth Low Energy (BLE) from the ESP32 module. This distance measurement is carried out by converting the Received Signal Strength Indication (RSSI) and TX Power values from the ESP32 module using equation (5). Where α is the path loss exponent value of the ESP32 module antenna, which in this measurement uses α with a value of 3.5 for indoor conditions.

Measurements are carried out on each ESP32 module which acts as a DME station. Each DME station will be tested for the distance measurement results from the DME station to the ESP32 which acts as a moving object. Each measurement was repeated 5 times each. Thus, the average measurement results obtained are as follows

Table 1. Distance measurement data

d **(m)**	$\overline{d_1}$ **(m)**	$\overline{d_2}$**(m)**	$\overline{d_3}$ **(m)**
0,2	0,25	0,24	0,22
0,4	0,42	0,41	0,41
0,6	0,56	0,60	0,61
0,8	0,80	0,81	0,82
1,0	0,95	0,99	1,00
1,2	1,22	1,20	1,22
1,4	1,43	1,41	1,41
1,6	1,62	1,62	1,61

Where:

d = distance between object and DME station measured by tape measure

$\overline{d_1}$ = average measurement between object and DME station 1

$\overline{d_2}$ = average measurement between object and DME station 2

$\overline{d_3}$ = average measurement between object and DME station 3

The location detection process is carried out using the trilateration method. Where each DME station will be placed in its position according to its respective coordinates. Then the measurement results from the three DME stations that detect the presence of the observed object are substituted together with the coordinates of each station into equation 6 & 7. With this method, the position of the object being observed can be known and then it can be displayed on the following Graphical User Interface (GUI).

Figure 3 shows the coordinates of the object's location are displayed which are the results of observations from the ESP32 module which acts as a DME station. Each DME station is connected to the same WiFi network to allow communication via the MQTT protocol. Where each object distance information is sent to the MQTT broker running on a PC/laptop and will be read by the program created and display the GUI.

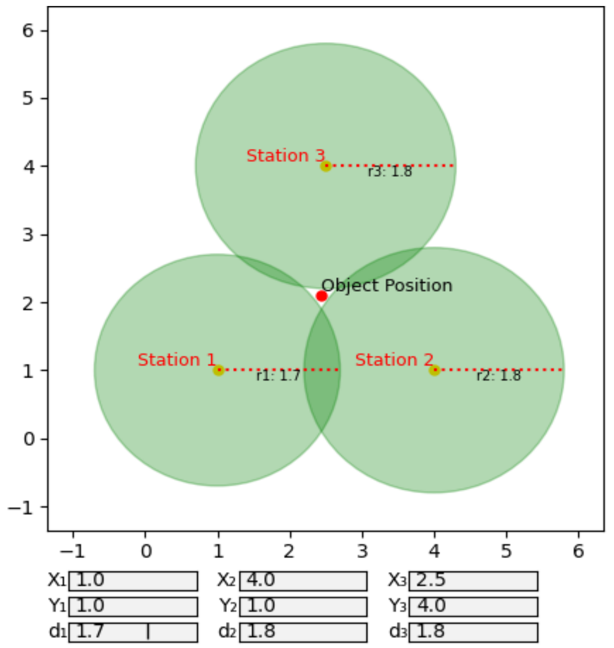

Figure 3. object positioning system GUI

Measurements using the ESP32 as Device Measurement Equipment (DME) are carried out by programming the distance measurement equation using Bluetooth into a code function as follows

```
DoublecalculateDistance(int txPower, int rssi) {
```

```
double n = 3.5;
int rssiAtOneMeter = -55;
return pow(10.0, (txPower - rssi) / (10.0 * n));
 }
```

This code will produce values from distance measurements using Bluetooth. The correlation between distance measurements with a meter and distance measurements with ESP32 as a DME station is shown in the following graph

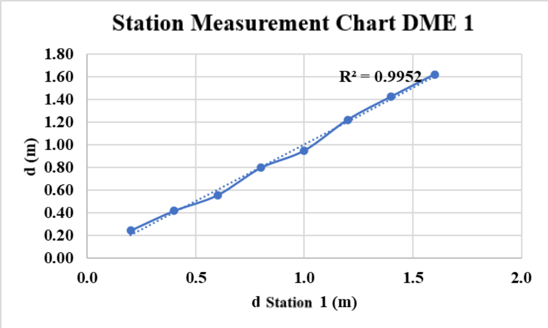

Figure 4. Correlation graph of DME station 1

Figure 4 shows the relationship between measuring object distances from DME stations using a tape measurement (y-axis) and measurements using Bluetooth pads at DME stations (x-axis). The image above shows a high correlation between measurements using a tape measurement and measurements at DME 1 station. This is proven by the closeness of the data line to the linear trend line shown in the graph. The high level of correlation is indicated by the coefficient of determination R^2 = 0.9952. Where, the closer the R^2 value is to 1, the higher the level of linearity between the two data. This means that the correlation coefficient for measurements with DME 1 station has a value of 99.52%.

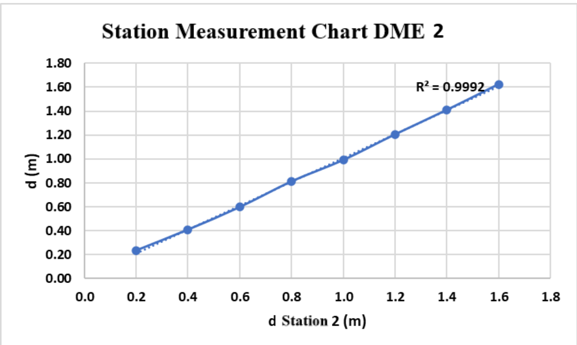

Figure 5. Correlation graph of DME station 2

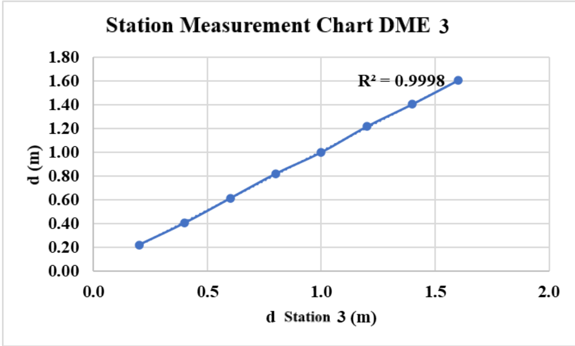

Figure 6. Correlation graph of DME station 3

Figures 5 and 6 measurements with DME 2 station and DME 3 station also show a high level of correlation with respective coefficient of determination R^2 values of 0.9992 and 0.9998. That means the correlation coefficient between the two is 99.92% and 99.98% respectively. The three stations have slightly different coefficient of determination and correlation coefficient values, because even though they are the same type and come from the same manufacturer. However, there are other factors that can influence wireless measurements using radio waves, in this case Bluetooth, including the antenna used and the location where the data is collected.

In determining the location, each station is placed in a position which, if connected with a straight line, will form a triangle. This is done to minimize the occurrence of errors in determining the location. Once the location is determined, the active DME station will be connected to the same Wi-Fi connection as the MQTT broker on the laptop/PC. Once connected, each DME station will send the distance value of the observed object to the MQTT broker on the laptop/PC. Then on the laptop/PC run a program that has been created to display the location of the object being observed. However, the coordinates of each DME station are first determined as part of the calibration process before this system is used, which can be entered in the column that has been created as in the following image

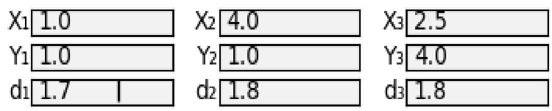

Figure 7. Textbox of DMS station coordinates

After entering the coordinates of each DME station, these variables will be calculated using the following trilateration function

```
def trilaterate (p1, p2, p3, r1, r2, r3):
    x1, y1 = p1
    x2, y2 = p2
    x3, y3 = p3
    A = 2 * (x2 - x1)
    B = 2 * (y2 - y1)
    C = r1**2 - r2**2 - x1**2 + x2**2 - y1**2 + y2**2
    D = 2 * (x3 - x2)
    E = 2 * (y3 - y2)
    F = r2**2 - r3**2 - x2**2 + x3**2 - y2**2 + y3**2
    x = (C*E - F*B) / (E*A - B*D)
    y = (C*D - A*F) / (B*D - A*E)
return x, y
```

That function will produce the position coordinates of the object being observed, and then the position or movement of the object can be observed via the GUI that has been created as follows.

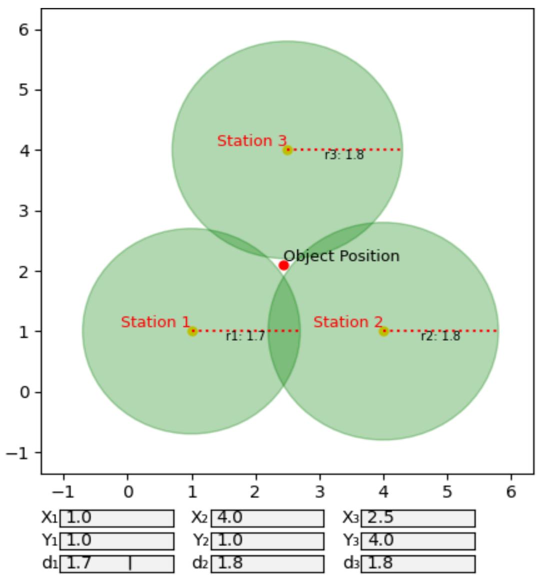

Figure 8. object position before moving

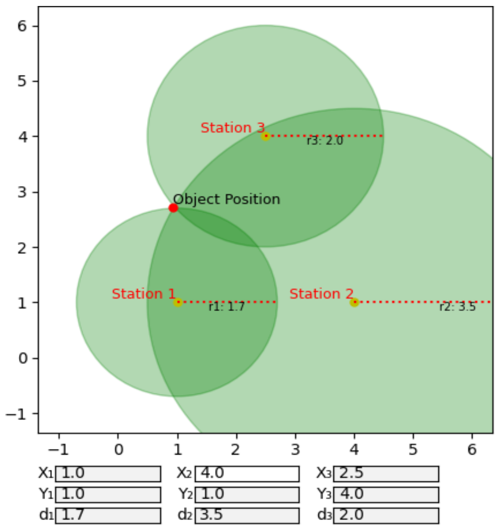

Figure 9. object position after moved

From figures 8 and 9 you can see the movement indicated by changes in the position of the object in the form of red dots on the GUI. This shows the ability of this system to estimate the position of an object using radio signals in the form of Bluetooth from all directions.

V. Conclusion

In research that creates a VOR/DME simulator model, it can be concluded that,

1. Measurements using Bluetooth Low Energy (BLE) on the ESP32 can represent Distance Measurement Equipment (DME).
2. Measurements using ESP32 as Distance Measurement Equipment (DME) has the same working principle by sending signals to each other to obtain measurement distance values using Bluetooth Low Energy (BLE) has good accuracy on a scale of 0.1 m.
3. Combining the performance of three ESP32 devices as Distance Measurement Equipment (DME) allows increased functionality to estimate the position of objects observed from various directions or omni-directional on a two-dimensional scale.

Acknowledgement

The author would like to express his sincere thanks to the Director of Politeknik Penerbangan (Poltekbang) Makassar, Head of the Center for Research and

Community Service, Poltekbang for their contribution in providing funding for the implementation of this research.

References

[1] A. Sahputra *et al.*, "Implementasi monitoring parameter localizer berbasis internet of things," vol. VII, no. 3, 2021.

[2] K. RI, *UU No.1 Tahun 2009.pdf*. Indonesia, 2009, pp. 1–66.

[3] W. Ariyanti, "PEMODELAN DAN SIMULASI INSTRUMEN PESAWAT VOR / DME (VHF OMNI-DIRECTIONAL RANGE / DISTANCE MEASURING EQUIPMENT) SEBAGAI PERALATAN NAVIGASI UDARA (NAVAIDS) PADA PESAWAT TERBANG," |*Jurnal Teknologi Informasi dan Komunikasi*, vol. 9, no. 1, pp. 25–35, 2019.

[4] A. D. Rachmanto, "SIMULATOR PESAWAT MELEWATI VHF OMNIDIRECTIONAL RADIO RANGE (VOR)," *Jurnal Teknologi Kedirgantaraan*, vol. 5, no. 1, pp. 36–49, 2020.

[5] N. W. Sari and B. Yulianti, "Analisa Fungsi T-DME Sebagai Pengganti Fungsi Outer Marker Runway O7 L Bandara Soekarno Hatta," vol. 7, pp. 49–54, 2018.

[6] C. Utomo, "Doppler Very High Frequency Omni-directional Range 3 (DVOR) AWAV RB51D Sebagai Salah Satu Alat Navigasi Udara Di Bandara Ahmad Yani Semarang," *Jurnal, Universitas Diponegoro, Semarang*, 2013.

[7] F. Haryadi, "Analisis Perangkat Navigasi Model 1150 Doppler Very High Omni-Directional Range (DVOR) Untuk Memandu Pesawat Menuju Bandara Tujuan"," *Jurnal, Akademi Teknik Telekomunikasi Sandhy Putra Puwokerto, Purwokerto*, 2013.

[8] E. Wahyudi, W. Pamungkas, B. Saputra, P. Studi, and T. Telekomunikasi, "ANALISIS LINK BUDGET ANTENA SIDEBAND DOPPLER VERY HIGH OMNI-DIRECTIONAL RANGE (DVOR)," *Jurnal Infotel*, vol. 5, no. 1, pp. 1–9, 2013.

[9] Ahmad Daili, "PENERAPAN METODEPEMBELAJARAN SIMULASI UNTUK MENINGKATKAN PERCAYA DIRI DAN PRESTASI BELAJARNo Title," *Jurnal Ilmiah Teknologi Pendidikan*, vol. 12, no. 1, pp. 68–74, 2022.

[10] R. C. N. Santi, "Perancangan Interaksi Pengguna (User Interaction Design) Menggunakan Metode Prototyping," *Jurnal Teknik Informatika*, vol. 9, no. 2, 2016.

[11] M. Arif, *Pemodelan Sistem*. Deepublish, 2017.

[12] E. Lolang, "HIPOTESIS NOL DAN HIPOTESIS ALTERNATIF," *JURNAL KIP*, vol. 3, no. 3, pp. 685–695, 2015.

[13] F. J. Gravetter, L. B. Wallnau, L.-A. B. Forzano, and J. E. Witnauer, *Essentials of statistics for the behavioral sciences*. Cengage Learning, 2020.