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A Fuzzy Logic Approach to Enhance GPS Accuracy for Blood Cooler Box Tracking

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ABSTRACT An innovative technological development, the position tracking system uses latitude and longitude coordinates to determine the GPS's location. The covid-19 pandemic has caused the demand for cool box delivery for convalescent blood plasma to increase significantly. The obstacle in the field is the hospital's position and patient rooms far from the reach convalescent donors, so they require a cool box for delivery. The problem is tracking the cool box accurately and precisely so that it can be monitored by the hospital properly. For this reason, it is necessary to increase the accuracy of the GPS position in the cool box by using fuzzy logic algorithms The Ublox NEO-6M is one GPS module that can be utilized for navigation. This module uses UART connection using the NMEA 0183 protocol and has an accuracy level of around 2.5 meters to 10 meters. In this research, validation of the accuracy of the GPS coordinate position was carried out on a Blood Cool Box device which was designed using the fuzzy logic method. The Sugeno method fuzzy logic algorithm is used to validate the accuracy of GPS coordinate positions based on latitude and longitude obtained from the GPS sensor module. The test results show a Mean Absolute Percent Error (MAPE) value of 21.66% which can be concluded that the Sugeno fuzzy logic method algorithm has forecasting model capabilities that are suitable for use as a validation method for testing GPS position coordinates.

INDEX TERMS GPS, Fuzzy Logic, Blood Cool Box, Tracking

I. INTRODUCTION

GPS (Global Positioning System) is a satellite-based navigation system that can display location and time information in all weather conditions anywhere on Earth's surface as long as it is covered by at least four GPS satellites [1] [2]. This GPS application can also be implemented using the Internet of Things (IoT) concept by leveraging internet connectivity development [3] [4].

The position tracking system is a technological breakthrough that serves as a tool for determining where the GPS is based on Latitude and Longitude coordinates. Users can view the environmental conditions in which object is moving using GPS Tracker. However, due to the various functions of each of these objects, not every object can function as a carrier; thus, the selection of a self-moving object as a carrier for the GPS Tracker device must have a wide and minimal viewing angle. Vehicles, animals, and humans are three examples [5] [6].

Accuracy instability issues are frequently encountered as a result of GPS sensor readings with various types of reading constraints. The GPS components are chosen based on the accuracy and precision with which the coordinates are read [7] [8] [9]. The GPS system will connect to satellites faster if it is outside the room, and it can even reach the maximum satellite limit of 12 satellites, but when it is inside, the GPS data system is connected to satellites for a longer period of time [10] [11].

The Ublox NEO 6MV2 GPS module is one of the GPS modules that can be used for navigation. The GPS module with the NEO-6MV2 type is a GPS module manufactured by Ublox AG that uses UART communication with the NMEA 0183 protocol and comes in a variety of baud rate values, including 4800, 9600, and 38400 bps [12]. This module has a fast Time to First Fix (TIFF) of 27 seconds. This module accepts input voltages ranging from 3.3 to 5 volts. This module has an accuracy range of 2.5 – 10 meters [13] .

The Blood Cool Box available in Indonesia is simple without a temperature measurement application. The issue is that a thermometer is used to measure the temperature in the Blood Cool Box, which is placed adjacent to the blood bag, making it impractical to use a thermometer as a display of the measured temperature value. Because the thermometer is in contact with the outside environment's temperature, it must be removed from the Blood Cool Box to determine the temperature value, resulting in inaccurate temperature readings.

This has the potential to lead to human error in terms of blood temperature reading accuracy and precision. Another disadvantage of using a thermometer in the Blood Cool Box is the lack of temperature recording data during the cold chain distribution system [14]. The cold chain distribution system is for storing and distributing blood and blood products at the appropriate temperature and conditions from when the donor's blood is collected until the blood is transfused to the patient.

Fuzzy logic is a control method that can convert a large number of inputs from the surrounding environment into a single input that is adjusted to the current state. This method is considered appropriate because numerous reference points will be responded to by a controller such as an Arduino with all equipment including sensors to determine the direction, speed, and action to be taken to reach the target GPS coordinates end point that humans desire as a user. Fuzzy logic is commonly used to solve problems involving uncertainty, imprecision, and interference. Fuzzy logic was created based on the human way of thinking, which has numerous applications. Fuzzification, inference system, and defuzzification are the three main processes in implementing fuzzy logic [15] [16].

In this study, GPS coordinate position accuracy was validated on the device Blood Cool Box, which was designed using the fuzzy logic method. Fuzzy logic will validate the accuracy of GPS coordinate position based on latitude and longitude positions obtained from GPS. The final result obtained is a prototype Blood Cool Box with a GPS tracking system. The following contributions are expected in this research, namely:

a. Provide research references for monitoring and tracking systems using Internet of Things (IoT) technology.
b. Provide an alternative solution for validating GPS position in a GPS-based tracking system using a fuzzy logic algorithm.

II. MATERIAL AND METHODS

A. BLOOD COOL BOX DESIGN

Blood Cool Box will be prototype-scaled with a tracking system based on the Internet of Things (IoT) protocol. According to the model system description in FIGURE 1, the DHT11 temperature sensor will read the temperature of the blood bag on the Blood Cool Box. Furthermore, a GPS module is used to track the vehicle's location carrying the Blood Cool Box, which receives data in the form of coordinates from GPS satellites. The ESP32 serves as the overall system controller. The input dataNeo-6M GPS Module is processed using a program function (software) embedded in the ESP32 microcontroller chip. SIM800L module is used to send data from sensor to webserver via internet connection by utilizing cellular operator GPRS (General Packet Radio Service) connection service, which allows for web-based data transfer. sing the IP-based bearer feature on a GPRS connection, SIM800L module communicates with the internet. The AT-Command command is used to connect SIM800L module to the internet. Using the fuzzy logic method, the IDE Arduino application will be used to program the controller, and MATLAB software for validating the GPS position tracking system. Webserver that displays monitoring and tracking data of Blood Cool Box using Blynk Server. Blynk is an iOS and Android application platform that allows you to control Arduino, Raspberry Pi, and other similar devices over the internet.

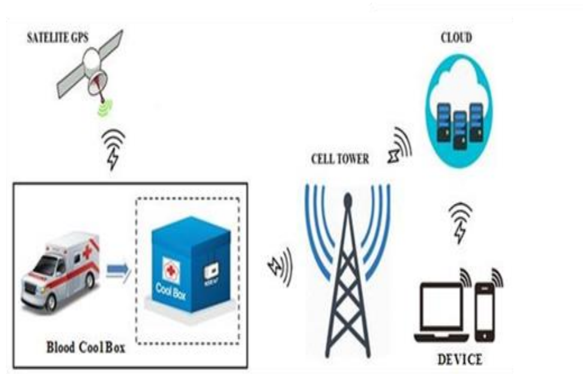

FIGURE 1. Blood Cool Box Monitoring and Tracking System Architecture

B. VALIDATION GPS POSITION TRACKING SYSTEM USING FUZZY LOGIC

To get the GPS position of the object in real time, the GPS sensor is used to generate position coordinate readings in the form of latitude and longitude. Data form of latitude and longitude obtained from reading the position coordinates in the form of latitude and longitude by the NEO-6M GPS module are used as a marker of the object's position to determine distance and angle value of the object to intended location. Input data in the form of changes in the value angle and object distances are used as input variables for Sugeno algorithm fuzzy logic. Flow diagram of validation GPS position is shown in FIGURE 2. Eq (1) can be used to convert latitude and longitude coordinate values to decimal coordinates [7].

$$\text{Decimal} = \text{degrees} + \frac{\text{minutes}}{50} + \frac{\text{seconds}}{3600} \quad (1)$$

The Euclidean Distance method is a calculation between two points in the Euclidean space. Euclidean space was introduced

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by Euclid, a mathematician from Greece around 300 B.C which focus on a relationship study between angles and

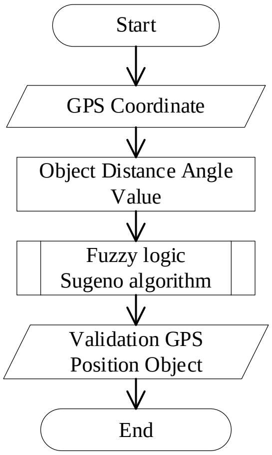

FIGURE 2. Flow Diagram of Validation GPS Position

FIGURE 3. Distance Coordinates [18]

According to the distance coordinates in FIGURE 3, the first location has coordinates (1,2) and the second location has coordinates (5,5). Eq. (2) can be used to calculate the distance between two coordinate points [7].

$$d = \sqrt{(Lat_1 - Lat_2)^2 + (Long_1 - Long_2)^2} \qquad (2)$$

The results of Formula 2 calculations will be in the form of coordinates or decimal degrees (according to the format latitude longitude used). The real distance between the two coordinate points can be calculated by multiplying this value by 111,319 km (1degree earth = 111,319) [19].

Input variable from fuzzy logic tracking GPS position consists of distance and angle variables. The distance variable is the difference between the dynamic (moving) and static object distance. Dynamic object distance is the distance between objects based on data from the GPS sensor. While static object distance is the distance between objects based on data from the Google Maps API. Calculation of the distance between dynamic and static objects using Formula 2.

TABLE , there are three membership functions with a maximum distance of 10 meters between the two objects. The maximum distance value of 10 meters was chosen because the distances [17]. Figure 3 depicts a distance measurement using Euclidian's method.

NEO-6M GPS module has an accuracy rate of about 2.5 meters – 10 meters under normal conditions [20]. FIGURE 4 depicts the membership function of the distance's input variable (input), which is represented by a triangular curve.

TABLE 1
Input variable distance

Variable Distance	Membership
Near	0 – 4 meters
Medium	3 – 7 meters
Far	6 – 10 meters

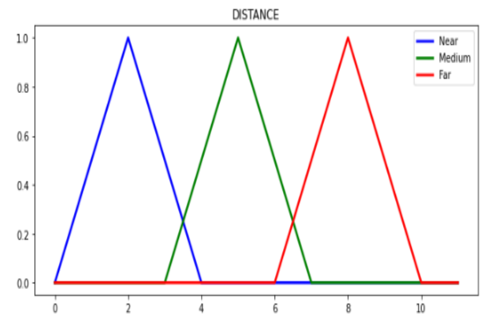

FIGURE 4. Membership Function Variable Distance

The angle input variable represents the Blood Cool Box prototype's final position in terms of movement direction. TABLE 2 and FIGURE 5 depict the membership function of the angle input variable, which is represented by a triangular curve.

TABLE 2
Input Variable Angle (Cosine θ)

Variable Angle (Cosine **θ**)	Membership
Left	-1 – -0.2
Straight	-0.4 - 0.4
Right	0.2 – 1

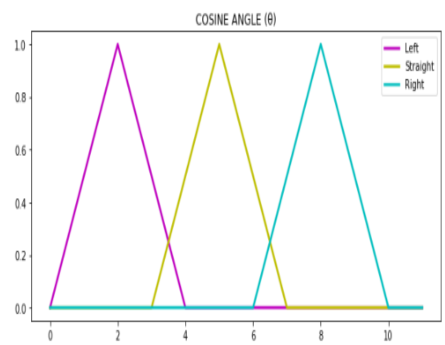

FIGURE 5. **Membership Function Cosine Angle**

Eq. (3) can be used to calculate the value of the triangular curve's membership function [21].

$$\mu(x;a,b,c) = \begin{cases} 0; & x \le a \text{ atau } x \ge c \\ (x-a)/(b-a); & a \le x \le b \\ (c-x)/(c-b); & b \le x \le c \end{cases} \quad (3)$$

GPS position output variable has two memberships, namely "Accurate (A)" and "Not Accurate (NA)" which is described in TABLE . The variable is the result of the sum of the value of the distance variable with the cosine function of the value of the angle variable. The determination of the membership value of the GPS Position Output Variable is based on the WAAS/EGNOS (Wide Area Augmentation System / Euro Geostationary Navigation Overlay Service) standard, namely the accuracy provided by GPS is 15 meters [22] [23]. FIGURE 6 shows the membership function of the GPS position validation output variable which, represented a shoulder curve.

TABLE 3
Output variables GPS position

Variable GPS Position	Membership
Accurate (A)	0- 15 meters
Not Accurate (NA)	≥ 15 meters

Value of membership function output variables GPS position as follows.

$$[Accurate]\ (z;0,15) = \begin{cases} 1; & z \le 15 \\ 0 & z \ge 15 \end{cases} \quad (4)$$

$$\mu[Not\ Accurate]\ (z;15,30) = \begin{cases} 0; & z \le 15 \\ 1 & z \ge 15 \end{cases} \quad (5)$$

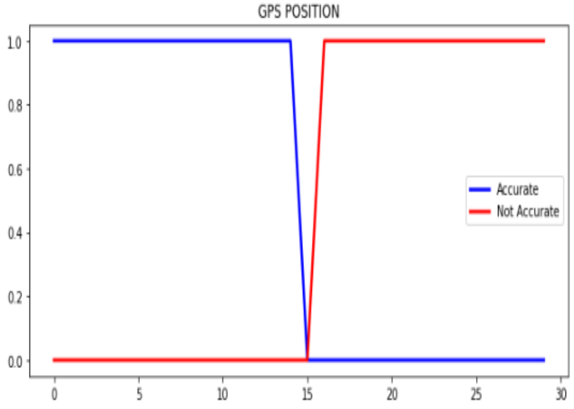

FIGURE 6. Membership Functions GPS Position

The establishment of bases Fuzzy knowledge is represented by a collection of rules in the form of an IF – THEN statement. The rules of the fuzzy GPS position tracking system are as follows:

IF Near And Left Angle Then GPS Position = Distance + Cos θ (Rules 1)
IF Near And Straight Angle Then GPS Position = Distance + Cos θ (Rules 2)
IF Near And Right Angle Then GPS Position = Distance + Cos θ (Rules 3)
IF Medium And Left Angle Then GPS Position = Distance + Cos θ (Rules 4)
IF Medium And Straight Angle Then GPS Position = Distance + Cos θ (Rules 5)
IF Medium And Right Angle Then GPS Position = Distance + Cos θ (Rules 6)
IF Long And Left Angle Then GPS Position = Distance + Cos θ (Rules 7)
IF Long And Straight Angle Then GPS Position = Distance + Cos θ (Rules 8)
IF Long And Right Angle Then GPS Position = Distance + Cos θ (Rules 9)

The implication function of rule composition employs the MIN function, which is used to determine the predicate value of each rule (α_1, α_2, α_3, α_n) [24]. Then each predicate value is used to calculate the output of the inference results explicitly (crisp) for each rule (z_1, z_2, z_3, z_n) [21] .

The results of the defuzzification are used as a reference to determine whether or not valid system tracking GPS position of device is Blood Cool Box designed. Assertions (defuzzification) using the mean (average) can be computed as in Eq. (6) [21].

$$z^* = \frac{\Sigma\, \alpha_1 z_1 + \alpha_2 z_2 + \alpha_3 z_3 + \dots\dots + \alpha_n z_n}{\Sigma\, \alpha_1 + \alpha_2 + \alpha_3 + \dots\dots + \alpha_n} \quad (6)$$

III. RESULT AND DISCUSSION

A. VARIABLE DISTANCE AND ANGLE TESTING

The coordinate data from the NEO-6M GPS module is then compared to coordinate from Google Maps live satellite. This test employs a static testing method. TABLE displays data coordinates test results from the NEO-6M GPS module.

TABLE 4
Testing Data for Variable Distance NEO-6M GPS Module

Location	Euclidean Distance (m)
Bank BTN Tembalang	8.38
Diponegoro University Monument	2.34
Diponegoro University Hospital	6.36
FPIK Building Diponegoro University	7.09
FKM Building Diponegoro University	4.26
Department of Industrial Engineering Diponegoro University	5.01
FEB Building Diponegoro University	8.12
Department of Electrical Engineering Diponegoro University	7.68
FSM Building Diponegoro University	6.57
Department of Statistics Diponegoro University	6.78

The data generated by NEO-6M GPS sensor module in the form of latitude and longitude coordinate data is compared to Google Maps coordinate value data. The data is then used with Formula 7 [22] to calculate the value error in the NEO-6M GPS sensor module, Eq. (7) :

$$Error = \frac{module\ value - comparison\ value}{Comparison\ Value}\ x\ 100\% \qquad (7)$$

Based on the results of Formula 5, the level of accuracy of The NEO-6M GPS sensor module is 99.99 percent, with an average error reading of the coordinate values of 0.000034 percent. The angle test is then performed by comparing the value generated by the NEO-6M GPS sensor with the value generated by the compass application on an Android smartphone. TABLE displays the data from the angle test results. The static testing method revealed a relative error of 1.64 degrees in the average angle reading of the readings of the angle variable values generated by the GPS sensor module at 10 locations.

TABLE 5
NEO-6M GPS module angle variable testing data

Location	Error	Cosine Angle (θ)
Bank BTN Tembalang	2.74	-0.74
Diponegoro University Monument	1.68	0.90
Diponegoro University Hospital	2.09	0.71
FPIK Building Diponegoro University	2.34	-0.74
FKM Building Diponegoro University	1.82	0.85
Department of Industrial Engineering Diponegoro University	1.59	0.82
FEB Building Diponegoro University	0.78	0.45
Department of Electrical Engineering Diponegoro University	2.49	0.78
FSM Building Diponegoro University	0.42	-0.91
Department of Statistics Diponegoro University	1.46	0.82

FIGURE 7. Route coordinates of GPS tracking system testing

B. GPS TRACKING SYSTEM TESTING

After the Blood Cool Box is turned on, data on temperature, humidity and GPS coordinate position will be sent to a web server using the internet network with an interval of 5 seconds. The web server used is Blynk. Blynk server is a facility Backend Service -based cloud that is responsible for managing communication. Blynk allows to create project interfaces with various components input and output that support sending and receiving data and representing data according to the selected components. The display of the monitoring and tracking page Blood Cool Box on Blynk is shown in FIGURE 8 As a reference for analyzing the sending of GPS data to the Blynk server, testing was carried out at an average speed of 30 km/h and an average speed of 60 km/h on the route shown in FIGURE 7 with a test time of 5 minutes. FIGURE 9 represents the results analysis of measuring data transmission.

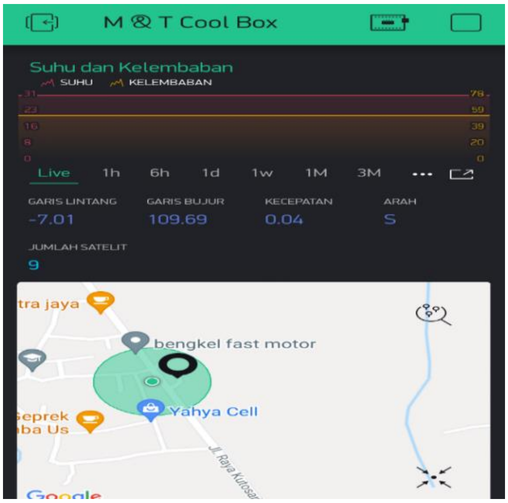

FIGURE 8. Graphical User Interface (GUI) Monitoring and Tracking Blood Cool Box.

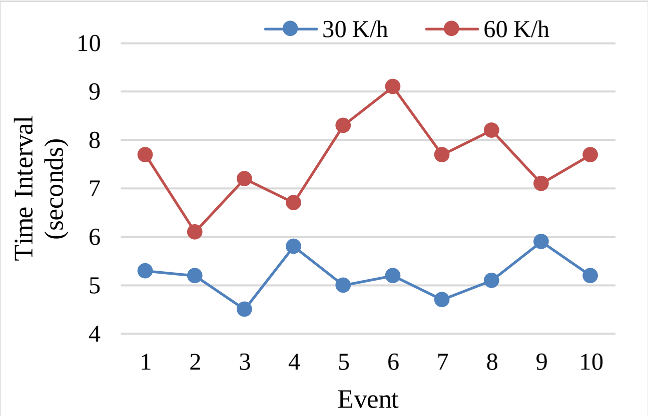

FIGURE 9. Data transmission trend line

Based on FIGURE 9 which represents the data delivery to the web server, most of the tracking results are quite good. When the speed is 30 km / h the module is still stable in sending data with an average delay value of 5.19 seconds. But at a speed of 60 km / h, the delivery time interval is more volatile compared to a speed of 30 km/h with an average delay value of 7.58 seconds. This is because the module is less stable in obtaining an internet signal for sending data to the server. In general, based on the evaluation results of the overall system testing that has been done, it is known that the system is capable of monitoring temperature and humidity and tracking the position of the Blood Cool Box at a speed of 30 – 60 km/h.

IV. DISCUSSION

Fuzzy logic tracking position validation GPS is accomplished by comparing the output value of testing the value of fuzzy logic tracking GPS position with the output value of fuzzy logic calculation using Matlab software.

FIGURE 10 depicts Graphical User Interface (GUI) MATLAB FIS for testing fuzzy logic tracking GPS positions.

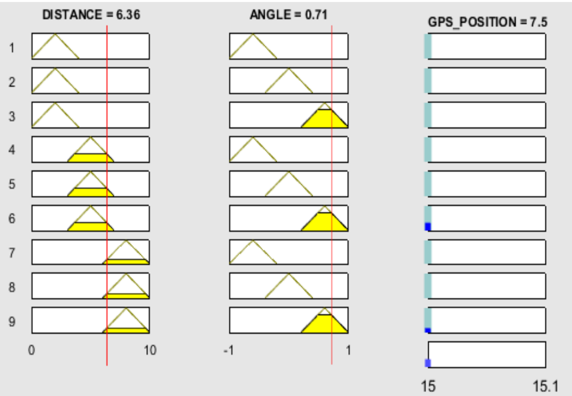

FIGURE 10. Graphical User Interface (GUI) Matlab FIS GPS Position

Overall, the comparison of the output values for testing the GPS position using Sugeno algorithm fuzzy logic with MATLAB and the results of calculating the value Euclidean Distance can be seen in TABLE 6.

TABLE 6
Comparison Value Output GPS Position

Location	Output: Euclidean Distance (m)	Output: MATLAB (m)
Bank BTN Tembalang	8.38	9.75
Diponegoro University Monument	2.34	3.75
Diponegoro University Hospital	6.36	7.50
FPIK Building Diponegoro University	7.09	8.17
FKM Building Diponegoro University	4.26	5.63
Department of Industrial Engineering Diponegoro University	5.01	6.75
FEB Building Diponegoro University	8.12	9.38
Department of Electrical Engineering Diponegoro University	7.68	8.25
FSM Building Diponegoro University	6.57	6.60
Department of Statistics Diponegoro University	6.78	6.75

Calculation Mean Absolute Percent Error (MAPE) is the average of the overall error (difference) between actual data (actual values) and forecasting results (projected values). The Mean Absolute Percent Error (MAPE) has a range of values that can be used as measurement material for the ability of a forecasting model [25], as shown in TABLE 7.

TABLE 7
MAPE Value Range [25]

MAPE Range	Meaning
< 10 %	Highly Accurate Forecasting Model Ability
10 -20 %	Good Forecasting Model Ability
20 -50 %	Reasonable Forecasting Model Ability
> 50 %	Inaccurate Forecasting Model Ability

According to the calculations in TABLE 8, the value Mean Absolute Percent Error (MAPE) is 21.66 %. As a result, the Sugeno method's fuzzy logic algorithm can be concluded to be reasonable forecasting model ability as a validation method for testing GPS position coordinates.

TABLE 8
Calculation of Mean Absolute Percent Error (MAPE)

Index Time	Euclidean Distance	Fuzzy Logic	Error	Absolute Error
1	8.39	9.75	1.76	0.162097735
2	2.34	3.75	1.41	0.602564103
3	6.36	7.50	1.14	0.179245283
4	7.09	8.75	1.09	0.152327221
5	4.26	5.63	1.37	0.321596244
6	5.01	6.75	1.74	0.347305389
7	8.12	9.38	1.26	0.155172414
8	7.68	8.25	0.57	0.07421875
9	6.57	6.60	0.03	0.00456621
10	6.78	6.75	0.97	0.167820069
			Count	2.166913419
			MAPE	21.66

Difference in output values for GPS position testing using the Sugeno method fuzzy logic algorithm with MATLAB software and the results of calculating the Euclidean Distance value from the GPS position coordinate values between the GPS sensor and Google Maps. The difference in values produced by fuzzy logic calculations is caused by the value of the angle input variable produced by NEO-6M GPS module, which based on test results shows an average relative error in the angle reading value of 1.64 degrees. Based on the Sugeno fuzzy logic algorithm calculation approach, the GPS position output value is still less than 15 meters, indicating that the resultant GPS position output value falls inside the Valid category. In addition, a direct validation system that is integrated with the tracking system for GPS position coordinates must be added in order for users to know the accuracy value of the coordinates in real time. If angle values are to be read with more accuracy, NEO-6M GPS sensor's function should be replaced with HMC5883L compass sensor

V. CONCLUSION

The prototype for monitoring and tracking the *Blood Cool Box* has been designed and implemented. The test results show that the accuracy of the NEO-6M GPS sensor module is 99.99% with an average error reading of the coordinate values of 0.000034%. The designed prototype can also monitor and track the *Blood Cool Box* properly at a speed of 30 km/h with an average delay value of 5.19 seconds of data transmission and 7.58 seconds at a speed of 60 km/h. The validation results of testing the GPS position coordinates using the Sugeno method fuzzy logic algorithm show that the accuracy value given by GPS is still in the valid category, which is below the accuracy threshold value of 15 meters.
Based on calculations using the *Mean Absolute Percent Error* (MAPE), a value of 21.66% is generated which can be concluded that the Sugeno algorithm fuzzy logic method has

the ability to forecast a reasonable model to be used as a validation method for testing GPS position coordinates. In the context of further development, it is necessary to add a GPS position coordinate validation system directly integrated into the tracking system so that the user can immediately find out the accuracy value of the GPS position coordinates in real time and use the HMC5883L compass sensor to increase the accuracy of the resulting angle value.

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