

Design Heading Control for Steering AUV with fuzzy logic

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ABSTRACT

Autonomous underwater vehicles (AUV) are a type of unmanned submarine robot that has many uses. The navigation system in an autonomous robot becomes an important point to guide the movement of submarine robots from one position to another through determining the position and direction of movement. Due to several interference factors such as currents and ocean waves, the movement of the AUV robot becomes unstable. Therefore we need a control system for robot movement so that the robot always faces the coordinates of the location so that AUV can move forward until it reaches the destination location. In this paper, the post control system will be designed using the Takagi Sugeno fuzzy method to determine the direction of movement of the robot by controlling the rotation angle (yaw).

Keywords: *autonomous underwater vehicles (AUV), fuzzy logic controller, navigation system*

INTRODUCTION

The rapid development of technology, especially in the field of robots can facilitate a lot of human work. Many robot models are developed by researchers. Auv is one of the underwater vehicles or robots that attract many researchers interest in the last few years [1]. The navigation system becomes the most important part in autonomous underwater robots so that the robot is able to work independently. The navigation system on an autonomous robot can be interpreted as an ability to guide movement from one position to another through the determination of its position and direction of movement [2].

Development of the navigation system on the auv is on making the control system of the auv so that it can always face the coordinates of the intended location so that the auv can move forward going to the destination location. The parameter that must be controlled so that the direction of the AUV is stable facing the coordinates of the intended location is to set the angle of rotation of the vertical axis (yaw) or referred to as the heading control. But the disturbance of the currents and waves of the sea makes the robot's movements less stable when the robot moves to the desired location. In this problem, Fuzzy Logic is the most effective technique for precision control in non-linear dynamic systems[3]. Therefore the control system will be built using the Fuzzy Takagi Sugeno method to control the direction of the robot. In this paper, the GPS sensor is used to determine the position of the robot and the compass sensor to increase the direction of the robot's movement against the rotational angle of motion (yaw)[4].

MODELING AND CONTROL AUV

Underwater Robot. UUV (Unmanned Underwater Vehicle) is an underwater vehicle created to help humans in the exploration of the underwater environment, this vehicle is included in unmanned vehicles[5]. In general, underwater robots are grouped into two types namely AUV (Autonomous Underwater Vehicle) and ROV (Remotely Operated Vehicle). AUV is a type of underwater robot that is autonomous/automatic where the robot can move independently based on the program that has been planted to the robot. While ROV is an underwater robot that is controlled by the operator in its operation, usually equipped with a remote control device in operation[6].

In this paper the robot is designed using a gps sensor and compass sensor as a robot navigation system. The motors used are two motors that are placed parallel to the right and left of the robot that functions to control the robot's motion to remain stable on a predetermined path.

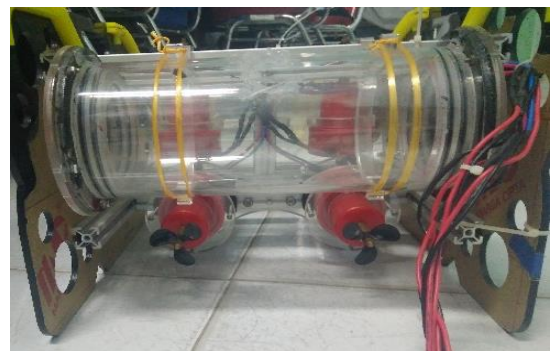


Figure 1. Underwater Robot

Navigation System. An underwater robot has input and output. The input in this system is the distance and angle error that is affected by the sensor used, while for the output that is the motor speed. The navigation system is designed using GPS sensors and compass sensors. GPS sensors function to determine the position and distance of the robot, while the compass sensor serves to improve the direction of the movement of the robot.

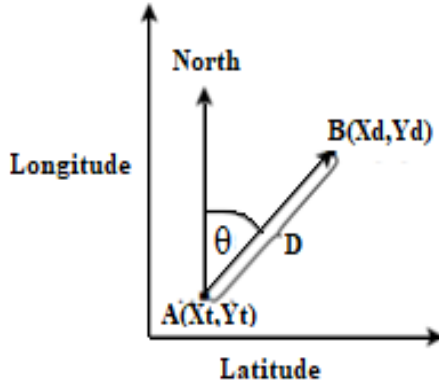


Figure 2. Illustration of movement from the starting point towards the destination point

In Figure 2, the angle θ is the angle formed between the starting point and the destination point. The angle value θ can be calculated using equation 1. In the calculation to find the angle value θ must be considered in determining the right quadrant.

$$\text{Angle } \theta = \tan^{-1} \frac{xd-xt}{yd-yt}$$

(1)

From the latitude and longitude data at the starting point and destination point, the distance and angle can be calculated from the current robot position to the destination position. From the compass sensor we will get angular data that will be compared with the angle from the initial coordinate point to the destination coordinate point so that the angular error is obtained by equation 2. Then to calculate the distance from the current robot position to the destination position, equation 3 can be used.

$$\text{Angle error} = \text{Angle } \theta - \text{Compass Angle}$$

(2)

$$\text{Distance} = \sqrt{(xd - xt)^2 + (yd - yt)^2}$$

(3)

FUZZY LOGIC CONTROL DESIGN

Fuzzy logic is the knowledge that can mimic human intelligence like expert operators who work based on linguistic rules[7]. Fuzzy logic can translate a quantity into linguistic language, for example, the magnitude of the speed of a vehicle that is expressed becomes slow, rather slow, medium, rather fast and fast[8]. This paper uses the Sugeno fuzzy logic method as the heading control system. The main structure of fuzzy logic control can be seen in Figure 3.

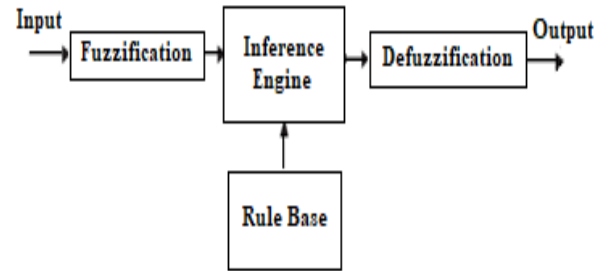


Figure 3. Fuzzy Logic Structure

There are several stages in fuzzy logic control, namely fuzzification, Inference Engine, rule base, and defuzzification. The fuzzification stage aims to process crisp input into Fuzzy input in the form of linguistic values in fuzzy sets. Fuzzy Set is a collection of linguistic values that encompasses the universe of speech from Linguistic Variables. Linguistic value is a membership function that can be in the form of trapezoidal, triangular or gaussian functions. the fuzzification process aims to map the universe of speech x into intervals 0 and 1.

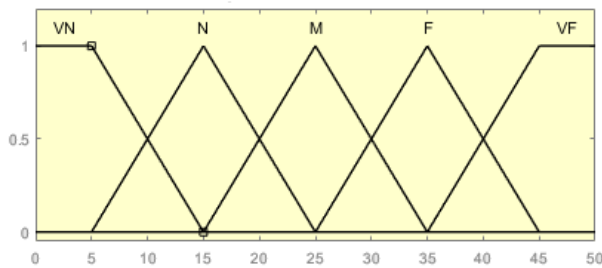
Fuzzification. The fuzzification process in this system consists of 2 inputs, namely distance and angular error. At distance input has five linguistic variables, namely very close, near, medium, far and very far, while at the angle of error the input has five linguistic variables, namely large negative, small negative, zero, small positive and large positive. At this stage, the input values (crisp) of distance and angle errors will be categorized based on predetermined linguistic variables and then converted to membership degrees between 0 and 1 for each linguistic variable that satisfies the distance and angle of error input. The following is the membership function of the distance that can be seen in Figure 4 and the angular error that can be seen in Figure 5

Table 1. Membership Function and Symbol from Distance

linguistic Variabel	Simbol	Distance (m)
Very Near	VN	0 -15
Near	N	5 – 25
Medium	M	15-35
Far	F	25 – 45
Very Far	VF	35 – 50

Table 2. Membership Function and symbol dari Error Sudut

Linguistic Variabel	Symbol	Angle Error (°)
Negative Large	NL	-90 - (-22,5)
Negative Small	NS	-45 – 0
Zero	Z	-22,5 - 22,5
Positive Small	PS	0-45
Positive Large	PL	22,5-90



Rule Base. At this stage, the basic rules (Rule Base) will be designed for the movement of the robot using IF-THEN rules. Rule base is made using language that is easy to understand with all the possibilities that occur. To determine the number of rule bases that will be created by multiplying the number of linguistic variables in each membership function. Thus, there are a total of 25 rules produced as shown in Table 3. In this paper we use the implication function min (AND) for the rule base created

Figure 4. Membership Function from Distance

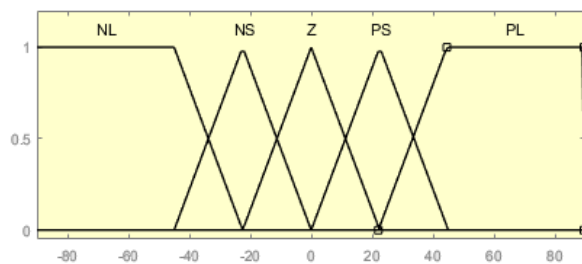


Figure 5. Membership Function from Error Angle

Table 3. Rule Base

Distance Error Angle	VN	N	M	F	VF
	NL	F	F	VF	VF
	NS	M	M	F	F
	Z	VS	M	F	VF
	PS	M	M	F	F
	PL	F	F	VF	VF

Defuzzification. The value generated in the inference phase (ground rules) will be passed on to the final stage of fuzzy logic is defuzzification. At this stage, the results of inference will be converted back into crisp values. In the Sugeno fuzzy method, the technique used is Weighted Average (WA) which is stated in equation (4). To change the value needed, it can be adjusted to what is needed by the motor. The shape of this output function uses the singleton form in Figure 6

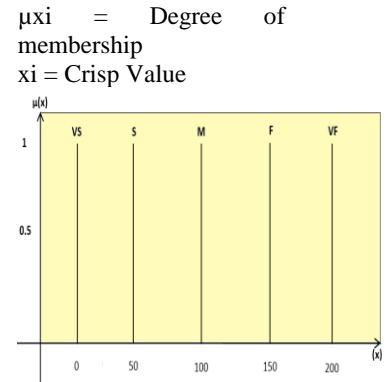


Figure 6. Singleton function

$$WA = \frac{\sum_{i=1}^n \mu_{xi} \cdot xi}{\sum_{i=1}^n \mu_{xi}}$$

(4)

Table 4. Singleton value and symbol

Linguistic Variabel	Symbol	Value
Very Slow	VS	0
Slow	S	50
Medium	M	100
Fast	F	150
Very Fast	VF	200

RESULTS AND ANALYSIS

Compass Sensor Testing. Compass Sensor testing is done by comparing the angle value produced by the compass sensor with the angle value on an analog compass. The angle value in the testing is the angle value that adjusts to the angle value in the cardinal direction. The sensor testing results can be seen in the table 5.

Table 5. Compass Sensor Testing Results

No	Points Of the Compass	Code	Analog Compass(°)	Compass Sensor(°)	Error(%)
1	North	N	0	358.38	0.45
2	Northeast	NE	45	42.32	5.95
3	East	E	90	91.4	1.5
4	Southeast	SE	135	133.63	1.01
5	South	S	180	183.72	2.06
6	Southwest	SW	225	227.86	1.27
7	West	W	270	268.4	0.6
8	Northwest	NW	315	312.42	0.81
Average					1.71

GPS Sensor Testing. GPS sensor testing is done to find out how accurate the latitude and longitude are generated on the GPS sensor. Testing is done by comparing the results of latitude and longitude from the M8N GPS sensor with latitude and longitude on google

maps at several locations that have been determined. The value generated from the GPS sensor will determine the value of the distance and angle formed from two different locations. The test results of the GPSM8N sensor can be seen in table 6.

Table 6. GPS M8N Sensor Testing Results

No	Location		Google Maps	Sensor GPS	Distance Error(m)
1	KPA Unsri	Latitude	-2.985547	-2.985526	2.38
		Longitude	104.731876	104.73188	
2	Fasilkom Unsri	Latitude	-2.985250	-2.985248	2.23
		Longitude	104.731924	104.731944	
3	Lembaga Bahasa Unsri	Latitude	-2.985334	-2.985323	3.03
		Longitude	104.732550	104.732575	
4	Fakultas Kedokteran Unsri	Latitude	-2.984134	-2.984113	2.81
		Longitude	104.732049	104.732063	

FuzzyTesting. Fuzzy logic testing is done by using Arduino as a sensor data processor and fuzzy logic. Fuzzy results from Arduino will then be validated with fuzzy results in Matlab. Testing is done by conducting 10 experiments with different input and rule bases.

From these results, it can be seen that the value of the resulting error is not much different from the biggest error of 0.29%. Fuzzy logic test results get an average error value of 0.126% which can be seen in table 7

Table 7. The output from Fuzzy Arduino and Matlab

No	Distance(m)	Angle Error(°)	Arduino	Matlab	Error (%)
1	8	-30	119.8	120	0.17
2	17	-18	107.1	107	0.09
3	28	5	152.7	153	0.2
4	25	0	150	150	0
5	10	20	90.9	90.9	0
6	18	35	136.1	136	0.07
7	30	-25	138.6	139	0.29
8	40	-40	184.6	185	0.22
9	45	38	184.4	184	0.22
10	10	18	85.7	85.7	0
Average					0.126

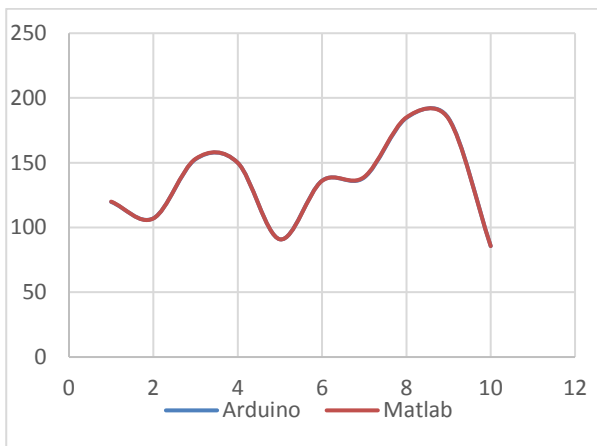


Figure 7. Comparative graph of the Arduino and Matlab fuzzy outputs

CONCLUSION

Compass sensor test results produce an average error value of 1.71% and the GPS sensor test produces the largest distance error value of 3.03 meters. In this case, the two sensors produce a good enough value to produce the distance and angle error values in the fuzzy input. In the fuzzy test, it is produced a value that is not much different in the output of Arduino and MATLAB with the largest error of 0.29% and an average error of 0.126%. Overall it can be concluded that the system works well.

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