Intelligent Control System of Fire-Extinguishing and Obstacle-Avoiding Hexapod Robot

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Abstract

This hexapod fire extinguisher robot is constructed based on technological developments evolving very rapidly, especially in the field of robotics technology. The hexapod robot has become a big concern in the development of robotics technology with many existing contests of hexapod robot. This hexapod fire extinguisher robot is designed based on Fuzzy Mamdani Logic. The navigation of fire extinguisher hexapod robot is based on distance detection with ultrasonic sensor determining the movement of robot's legs utilizing Fuzzy Logic. A fire extinguisher hexapod robot will explore a tunnel arena having several rooms created for the robot to explore. This hexapod robot uses Arduino as a microcontroller and uses 18 servo motors in which each foot requires 3 servo motors. Moreover, good navigation will be aimed by utilizing Fuzzy Logic in the hexapod robot design. The application of many rules on Fuzzy Logic makes the better navigation; furthermore, the results present the ultrasonic sensor having an average error of 1.256%, the Fuzzy Logic applied showing 0% error, and the overall success rate presenting approximately 80%.

Keywords: *Control System, Hexapod Robot, Fuzzy Logic, Arduino, Ultrasonic Sensor, Flame Sensor*

1. Introduction

Nowadays, people have become familiar with robots. There are many existing categories of robot contest, started from normal difficulty levels such as non-program lineflower robots up to robot art competitions with complex difficulty levels; moreover, the robot creation employing special features is closely related to modern industrial requirement reqquiring an advanced ability tool that can help human to accomplish either normal work or difficult work not being able to be accomplished by humans.

Robot is an instrument being imperatively necessary in the industry for particular conditions that can not be handled by humans exemplified by the requirement for high accuracy, enormous energy, high speed, high risk, and so forth. These circumstances can be overcome by assigning robots to take over these challenging tasks.

Hence, research for improving the robot ability should be continuously developed. In order robot can provide a high economic value, it should be designed for a specific purpose [1]. One of robot types with a special ability that have recently attracted many experts to be developed is a mobile robot. Mobile robot is a robot construction having wheels or leg actuators as its movement characteristic, so that the robot can move from its initial position to another [2].

In robotics technology, there are generally two types of robots, namely manual robots and automatic robots. Manual robot is a robot that still requires human intervention to operate; conversely, automatic robot is a robot carrying out its duties in the absence of any human interventions. In an automated mobile robot, the ability to detect objects and independently and swiftly move without crashing to any barriers or objects becomes vital. This capability can be achieved if supported by an adequate series of sensors; thus, the robot is able to detect the surrounding environment well being able to respond the existing changes in the surrounding environment. Like humans, robots also have "brains" acting as controllers as the robots' overall system, generally utilizing a microcontroller [3].

A hexapod robot is a robot that moves utilizing six legs. Statistically, robots remain stable by using 3 legs or more; hence, a hexapod robot has high stability and flexibility. In the case of faulty leg(s), the possibility of the robot to move remains.

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In this study, the hexapod robot prototype serving as a fire source point seeker and extinguisher has been developed. The fire source point seeking process is performed by scanning the robot's surrounding environment to locate any existing fire source point. The process of seeking the fire source point is performed by detecting the ultraviolet rays emitted by fire by using ultraviolet light detection sensors. Furthermore, the ultrasonic sensors are utilized to guide the robot navigation in determining the distance between the fire source point and the robot using Fuzzy Logic method for intelligent control system.

2. Relevant Research

The development of fire extinguisjer robots has shown a rapidly growing popularity in modern robotics technology. Some researchs related to fire-extinguisher robot are as follows:

1. Implementation of Wall Following Navigation System Using PID Controller with Tunning Method on Senior Wheeler Division of KRCI Robot. The researchers used PID controls on fire extinguisher robots having four wheels. The result of this research is the automatic robot system using PID method as a navigation system in tracing rooms to identify fire source points [4].
2. Fire Extinguisher Wheeled Robot Using Fire Sensor Processing Based on Fuzzy Logic. The researchers used Fuzzy Logic method in the wheel system to drive the robot. The result of this researcher is controlling the robot's navigation system utilizing Sugeno model in Fuzzy Logic method. The robot can navigate by calculating the distance from the wall employing membership function; consecutively, the speed on the right and the left motor can be determined [5].

From the literature review previously mentioned about the research on fire extinguisher robota, it can be seen the utilized navigation system employ wheels. However, fire extinguisher robot prototype that will be developed in this research is a hexapod robot using legs as the navigating mechanism and utilizing Fuzzy Logic as the control algorithm.

3. Research Methods

The research was started by conducting a literature review of theoretical concepts and relevant research results. The study of literature review became the basic idea for solving the problems found on fire extinguisher robots. To explore the problem, the observation on previous methods used was done. The error value on ultrasonic sensor was continuously evaluated. It was used as data in Fuzzy Logic. The results in this stage are optimized models of intelligent system for fire extinguisher legged robots. The analysis and system design were performed based on the method previously obtained. Subsequently, the development process of system prototype and Fuzzy Logic method was executed, followed by series of trials. After the system prototype attained the desired results and overcoming the research problems, an intelligent control system of fire extinguisher robot was obtained.

3.1 Fuzzy Logic

Fuzzy Logic is one of the artificial intelligence systems in reasoning type. Among the fastest growing intelligent control systems, Fuzzy control system becomes one of the most popular intelligent control systems. Controlling method using Fuzzy Logic offers some advantages compared with other controlling types, such as having unnecessary explicit mathematical model from the controlled system and providing very simple control algorithm [6].

Fuzzy Logic was first introduced by Lotfi Zadeh in 1965, a professor at the University of California in Berkeley. Fuzzy Logic has degrees of membership ranging from "0" to "1", being different from classical/Boolean Logic having only two values of "1" and "0" [7]. Fuzzy Logic is used to translate a quantity expressed to language (linguistic), for example expressing the speed of vehicle from slow, faster, fast, and very fast. To model and control non linier hydraulic system, fuzzy logic has been used by [8] in recent year. In the application of power and drive system, Irfan et al [9] has been successfully studied about the comparison of fuzzy logic controller and proportional-integral for electronic load control system.

3.2 Robot Navigation System

Before the program had been built, robot workflow was initially created in order to make the program becoming more organized and easy to understand. The flowchart of the robot navigation system can be seen in Figure 1. An application of intelligent controller using fuzzy logic has explored by the researchers for solving many uncertainty problems, as in [10] to optimize the navigation of underwater robot. Furthermore, [11] using multi-objective also to optimize the navigation of underwater robotic.

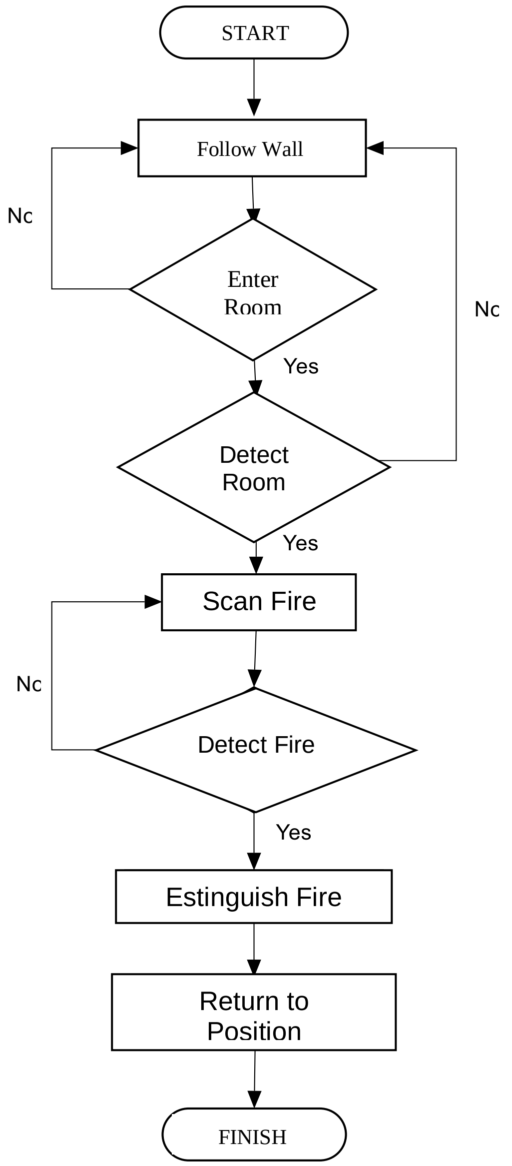

Figure 1. Flowchart of Robot Navigation System

From the flowchart in Figure 1, the stages can be explained as follows:

1. The whole process is started by turning the robot switch ON.
2. The robot goes along in a path bounded by a wall.
3. When fire is detected, the robot will stop and start to extinguish the fire until completely extinguished.
4. After the fire source point is extinguished, the robot returns to its previous location.

3.3 Controlling Process of Fuzzy Logic

In Fuzzy Logic, there are three processes, namely: Fuzzyfication, rule evaluation, and Defuzzyfication. Figure 2 depicts the Fuzzy Logic process from input, sensor data, to output. The quantity value is used to control the servo motor in the hexapod robot for either turning or going forward.

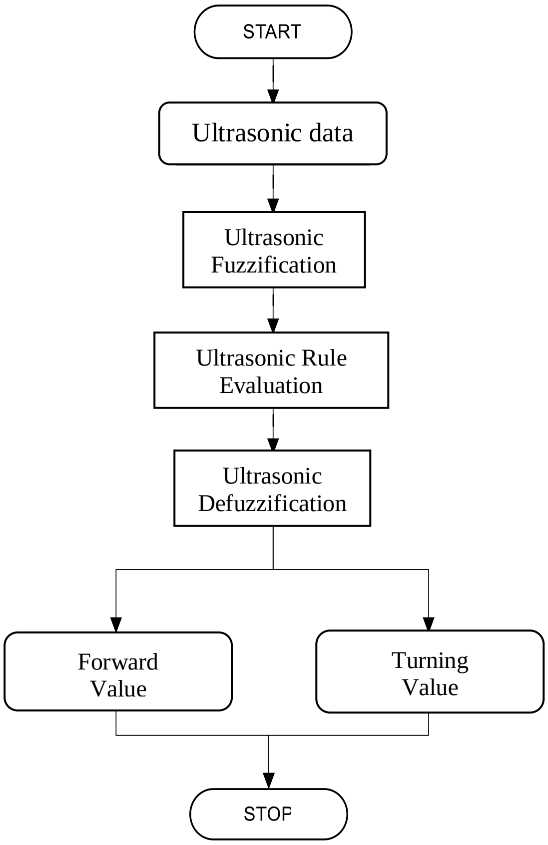

Figure 2. Fuzzy Logic Process in Robot

3.4 Fuzzyfication

Fuzzyfication stage is a stage to form membership functions. Fuzzyfication is divided into 6 groups, Fuzzyfication on each ultrasonic sensor, US1, US2, US3, US4, US5, and US6. The Fuzzyfication in US1 and US4 sensors will have two membership functions while Fuzzyfication in US2, US3, US5, and US6 will have three membership functions. The number of membership functions determination is based on the configuration of ultrasonic sensor location and data acquisition in different robot position while the robot is in the arena. The configuration of ultrasonic sensor locations can be seen in Figure 3.

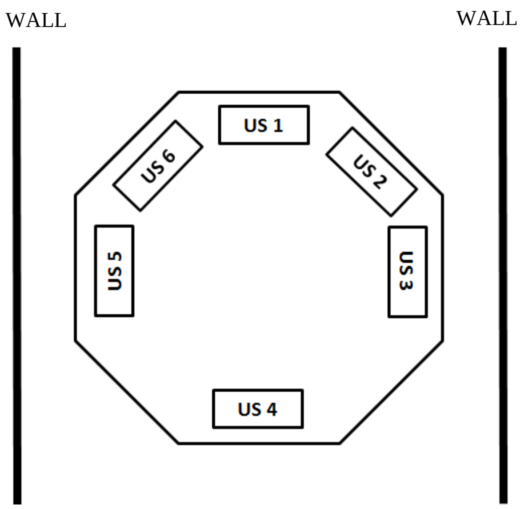

Figure 3. The Configuration of Ultrasonic Sensor Locations

The robot is expected to keep moving by always maintaining a distance of 20 cm from the wall. From these criteria domain values of the membership functions, either for Fuzzyfication error or direction will be obtained. The membership functions of US1, US2, US3, US4, US5, and US6 ultrasonic sensors can be seen in Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9 respectively.

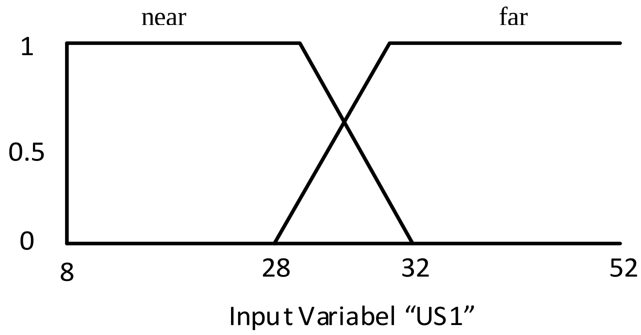

Figure 4. The Membership Functions of US1 Sensor

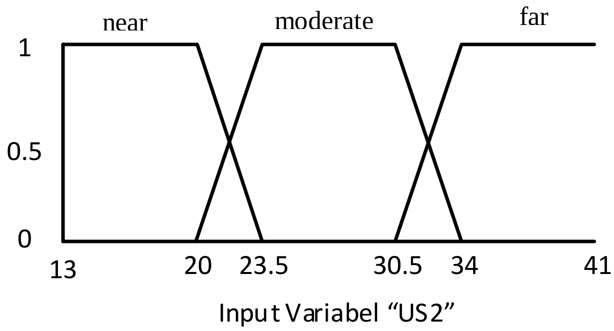

Figure 5. The Membership Functions of US2 Sensor

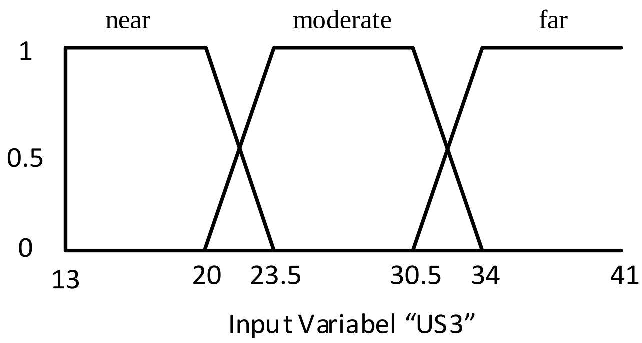

Figure 6. The Membership Functions of US3 Sensor

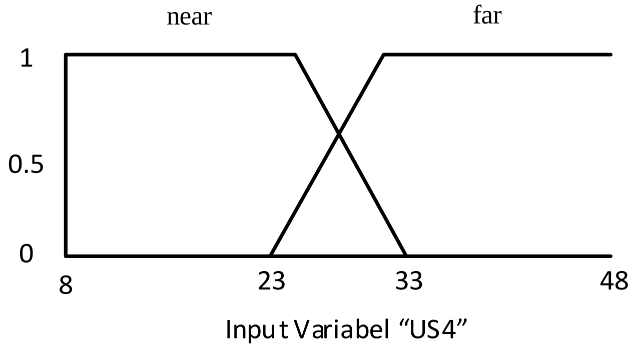

Figure 7. The Membership Functions of US4 Sensor

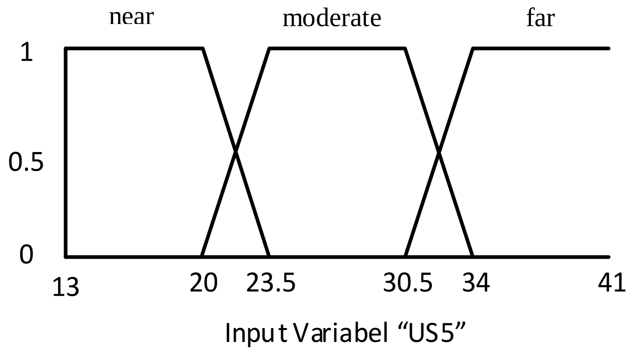

Figure 8. The Membership Functions of US5 Sensor

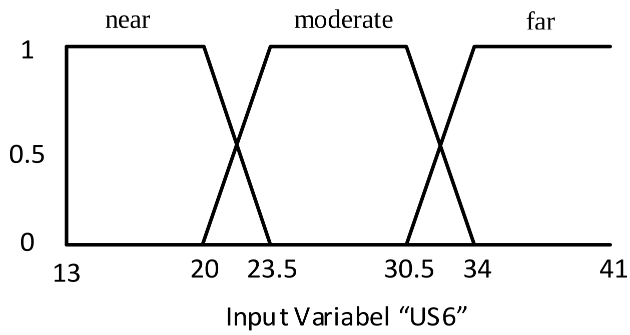

Figure 9. The Membership Functions of US6 Sensor

3.5 Evaluation Rule

At this stage, each output of the Fuzzyfication stage which is in the form of membership degree and linguistic variables will be combined using the evaluation rule. Afterwards, the variations of turning and going forward values of the robot will be recognized.

In the evaluation rule, there is a linguistic rule for determining the control action against the input value of Fuzzyfication. Evaluating the relationship or antecedent degree of each rule becomes the first phase; subsequently, the truth degree for each rule is searched, using the "AND" logical operation. Table 1 depicts the evaluation rule.

Tabel 1. Table of Evaluaion Rule

No	US1	US2	US3	US4	US5	US6	Output
1	Far	Far	Moderate	Near	Moderate	Far	Forward
2	Far	Far	Moderate	Far	Moderate	Far	Forward
3	Far	Far	Moderate	Far	Near	Far	Slant Right
4	Far	Far	Far	Far	Near	Far	Right
5	Far	Far	Near	Far	Moderate	Far	Slant Left
6	Far	Far	Near	Far	Far	Far	Left
7	Near	Far	Moderate	Far	Moderate	Far	Right
8	Near	Far	Far	Far	Near	Far	Right
9	Near	Far	Moderate	Far	Far	Far	Left
10	Near	Far	Near	Far	Far	Far	Left

3.6 Defuzzyfication

The inference result is a set of Fuzzy Logic or Fuzzy Logic membership functions. The information of Fuzzy Logic membership should be converted into numerical values in order to be used to control a process. Those numerical values should represent the information contained in the Fuzzy Logic set. The process used to convert the results of Fuzzy inference into numerical value as the output is called Defuzzification. Defuzzyfication used in this studi is the Mean of Maximum (MoM) method, illustrated by Figure 10.

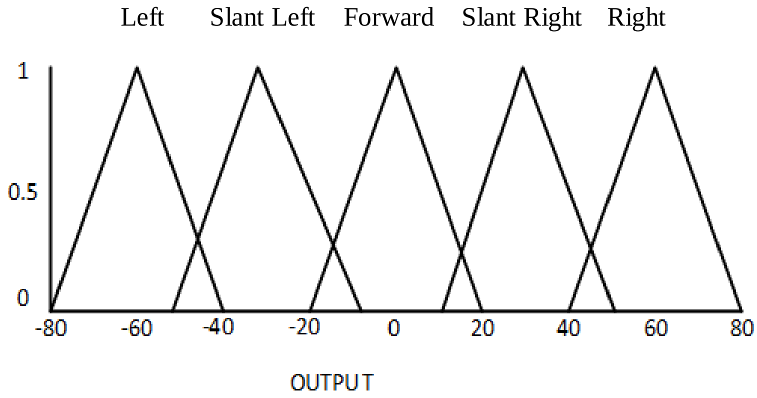

Figure 10. Defuzzyfication

4. Results and Discussion

4.1 HC-SR04, Ultrasonic Sensor Experiment

The experiment of ultrasonic sensor, HC-SR04, is finished using Arduino microcontroller; moreover, the reading results of the ultrasonic sensor are displayed on the monitor series in the Arduino sketch. In this experiment, the ultrasonic sensor, HC-SR04, is faced perpendicular to an obstruction, wall made of wood with a smooth surface, at a certain distance. The reading results of the ultrasonic sensor will be matched with the actual measurements using a measuring instrument. The reading results of the ultrasonic sensor can be seen in Table 2.

Table 2. The Reading Results of the Ultrasonic Sensor, HC-SR04

Testing	Object Distance (cm)	US 1	US 2	US 3	US 4	US 5	US 6
1	6	6.04	6.14	6.12	6.02	6.12	6.12
2	10	10.13	10.14	10.13	10.18	10.02	10.08
3	14	14.11	14.15	14.23	14.22	14.06	14.08
4	18	18.04	18.12	18.24	18.14	18.02	18.08
5	22	22.26	22.22	22.06	22.13	22.26	22.24
Average error		0.72%	1.26%	1.28%	0.96%	1.12%	0.94

From ulltrasonic sensor experiment, it is found that there are differences between actual measured distances and measured distances using ulltrasonic sensor. The different results between these readings can be caused by more detail readings from the ultrasonic sensor. However, the difference is insignificant accounted by merely 1.256%, presenting good quality in each sensor.

4.2 Fuzzy Logic Experiment

Fuzzy Logic is examined by comparing the output values generated on Matlab to output values generated on hardwere. In this experiment, a fuzzy rule that has been determined is created, obtained from the ultrasonic sensor reading results. The ultrasonic sensor values will be displayed on the monitor series in the Arduino sketch. The input values that will be entered in the rule viewer in Matlab will be adjusted to the ultrasonic sensor readings. The display of rule viewer and serial monitor can be seen in Figure 11.

The experiment results of Fuzzy Logic can be seen in Table 3. The inputs read from hardware and the inputs for Matlab must have the same values in order to get accurate results. The Matlab input values will be adjusted to the ultrasonic sensor value. Figure 3 shows US1 far, US2 far, US3 normal, US4 far, US5 normal, and US6 far conditions are considered following the rule number 2 having output going forward.

From the Fuzzy Logic experiment results, the output values that aregenerated by hardware are in accordance with the values generated in the rule viewer on Matlab. It can be said that the logic on the hardware has been in accordance with the desired values.

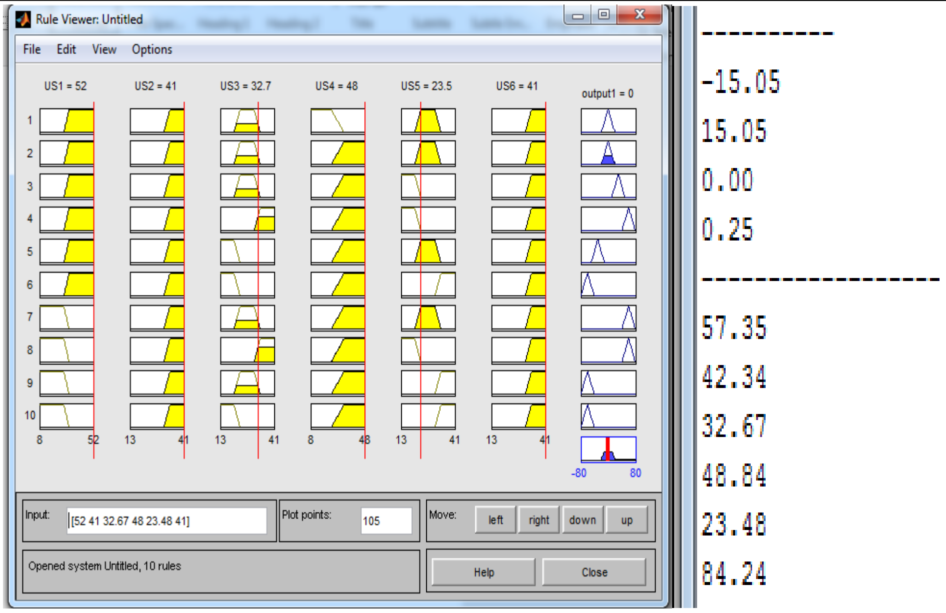

Figure 11. Display of Rule Viewer and Serial Monitor

Table 3. The Experiment Results of Fuzzy Logic

No	Input						Output		Error %
	US1	US2	US3	US4	US5	US6	Matlab	Hardware	
1	57.35	42.34	32.67	48.84	32.48	84.24	0	0	0%
2	63.52	45.81	36.86	47.81	17.10	81.03	60	60	0%
3	55.43	57.35	15.21	47.06	38.24	90.17	-60	-60	0%
4	60.42	53.04	21.69	46.91	32.10	90.02	-30	-30	0%
5	52.22	70.83	32.05	51.69	20.94	85.63	30	30	0%

4.3 Flame Sensor Circuit Experiment

Flame sensor circuit experiment was executed to recognize the flame sensor characteristics and to compare the output voltage among left, left-middle, middle, right-middle, and right position of the flame sensor circuits. The experiment was performed utilizing a candle whose position was altered and then the output voltage of the flame sensor circuit was measured. Afterwards, the flame sensor reading was conducted when the candle in left-middle position. Moreover, a protractor was utilized to measure the sensor reading limit. The sensor reading limit of S5 sensor ranged from 10˚ to 40˚, more than that of S5 sensor being unable to read. When the candle position was altered having the same position with the flame sensor, the led of the flame sensor turned on. This experiment result is illustrated in Table 4.

Table 4. The Experiment Results of the Flame Sensors

No	S1	S2	S3	S4	S5	Flame Position	Protractor Measurement
1	1	0	0	0	0	Left	135°
2	0	1	0	0	0	Slant Left	110° - 135°
3	0	0	1	0	0	Middle	65° - 110°
4	0	0	0	1	0	Slant Right	40° - 65°
5	0	0	0	0	1	Right	10° - 40°

A flame sensor is a sensor serving to detect a flame around the room. The sensitivity of a flame sensor can be adjusted by changing its resistance. Flame sensors can detect flame before the flame reaches and damages the flame sensor. The data that were detected from flame sensor would be processed utilizing a microcontroller.

1. When a candle flame was in S1 position or in left position, the led on the flame sensor was set to 1, and the other will set to 0. The measurement was performed using a protractor to recognize S1 sensor reading limit. Moreover, a protractor was utilized to measure S1 sensor reading limit, ranging from 135˚ to 170˚, more than that of the S1 sensor being able to read.
2. When the candle flame was in S2 position or in left-middle position, the led on the flame sensor was set to 1, and the other was set to 0. Moreover, a protractor was utilized to measure S2 sensor reading limit, ranging from 110˚ to 135˚, more than that of the S2 sensor being able to read.
3. When the candle flame was in S3 position or in the middle position, the led on the flame sensor was set to 1, and the other will set to 0. Moreover, a protractor was utilized to measure S3 sensor reading limit, ranging from 65˚ to 110˚, more than that of the S3 sensor being able to read.
4. When the candle flame was in S4 position or in the right-middle position, the led on the flame sensor was set to 1, and the other was set to 0. Moreover, a protractor was utilized to measure S4 sensor reading limit, ranging from 40˚ to 65˚, more than that of the S4 sensor being able to read.
5. When the candle flame was in S5 position or in the right position, the led on the flame sensor was be set to 1, and the other was set to 0. Moreover, a protractor was utilized to measure S5 sensor reading limit, ranging from 10˚ to 45˚, more than that of the S5 sensor being able to read.

4.4 Overall System Testing

Overall system testing was conducted to recognize whether the robot succeeded or not in performing proper movement. When the robot went along in a path bounded by a wall, the robot could turn left, turn left-middle, turn left-right, turn right, and went forward flawlessly. The arena utilized to find out how well the algorithm implemented in the robot system has the configuration presented in Figure 12.

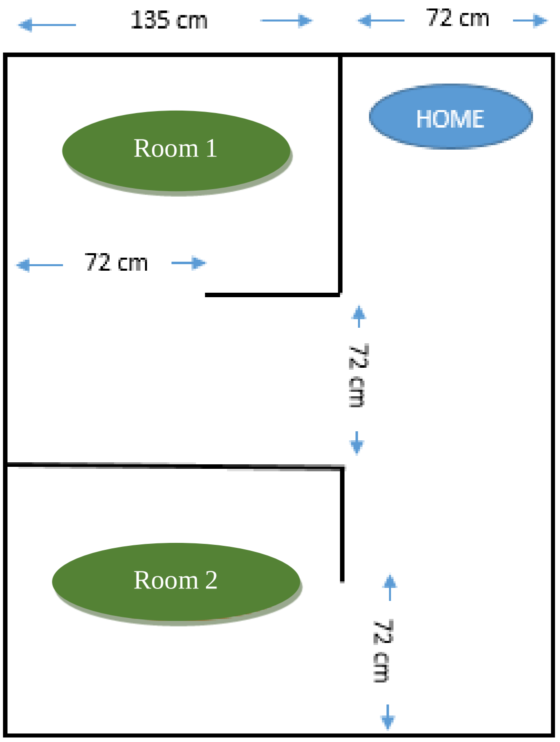

Figure 12. The Arena Configuration of the Hexapod Robot

As present in Table 5, the overall test results indicate the robot is able to properly move. However, this system still has some drawbacks leading to one failure in testing due to the robot's legs trapped on the wall.

Table 5. The Result of Overall System Testing

No	Input						Robot Movement	Info
	US1	US2	US3	US4	US5	US6		
1	57.35	42.34	32.67	48.84	23.48	84.24	Forward	Success
2	63.52	45.81	36.86	47.81	17.10	81.03	Right	Fail
3	55.43	57.35	15.21	47.06	38.24	90.17	Left	Success
4	60.42	53.04	21.69	46.91	32.10	90.02	Slant Left	Success
5	52.22	70.83	32.05	51.69	20.94	85.63	Slant Right	Success

5. Conclusion

Based on the results of design, testing, and discussion of intelligent control system, some points that can be concluded are as follows:

1. Hexapod robot navigation based on distance detection using ultrasonic sensor can determine the robot leg movement using Fuzzy Logic.
2. Fuzzy Logic used in this study is Mamdani method.
3. Fuzzification is divided into six groups based on the number of ultrasonic sensors used.
4. Defuzzification used in this study is MoM (Mean of Maximum) method.
5. The experiment results show that the average error of ultrasonic sensor and Fuzzy Logic is 1.256% and 0% respectively.
6. The average overall success is around 80%.
7. The limit range of flame sensor can be determined and detected well for left, left-middle, middle, right-middle, and right position in 135˚-170˚, 110˚-135˚, 65˚-110˚, 40˚-65˚, and 10˚-40˚ respectively.
8. Hexapod robot can identify, move to candle flame dan extinguish it in 10 cm distance.
9. After the fire source point is extinguished, the robot returns to its previous location.

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