LINE AND WALL FOLLOWER HEXAPOD ROBOT

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ABSTRACT

Robot widely use to help human to do something, especially for difficult or danger task. To fulfil the robot requirements, some techniques, sensors and controller have been applied. Due to kind of robot is a hexapod robot, which it develops in this research. Hexapod robot is a mechanical vehicle that's walk on 6 legs. A hexapod robot movement are guided with guidance, they are line and wall. Fuzzy logic control as intelligent control is applied to govern the robot follow line and wall. Fuzzy logic controller is used to create a smooth response of robot behaviour rather than logic programming**.** Infrared sensors are used to sense line and distance to the wall as the input variable for the controller. Based on these signals, the controller control the turning angle of forward movement thus making robot to move forward and turning in same time.

ABSTRAK

Robot banyak digunakan untuk membantu manusia untuk melakukan sesuatu, terutama untuk tugas yang sukar atau bahaya. Untuk memenuhi keperluan pada robot, beberapa teknik, sensor dan kawalan telah dilaksanakan. Dalam kajian ini robot Hexapod telah digunakan. Robot Hexapod adalah struktur mekanikal yang berjalan menggunakan 6 kaki. Gerakan robot hexapod dikawal dengan panduan garisan dan dinding. Kawalan Fuzzy Logik diterapkan untuk menetapkan robot mengikuti garis dan dinding. Fuzzy logic digunakan untuk mendapatkan respon robot yang lebih lancar berbanding pengaturcaraan logik. Sensor inframerah yang digunakan untuk membaca garis dan jarak dari dinding adalah sebagai pembolehubah masukkan untuk controller. Berdasarkan bacaan sensor, robot akan mengawal pergerakan ke depan dan juga pusingan pada masa yang sama.

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LIST OF SYMBOLS AND ABBREVIATIONS

cm -	Centimetre
LCD -	Liquid Crystal Display
RC-	Radio Control
ms -	Millisecond
IR -	Infrared
KHz -	Kilohertz
Hz -	Hertz
HIGH -	Logic for true or binary value of 1
LOW -	Logic for false or binary value of 0
" -	Inches
V*cm -	Voltage multiply with centimetre
LED -	Light Emitting Diode
PIC -	Harvard architecture microcontrollers made by Microchip Technology

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CHAPTER I

INTRODUCTION

1.1 Project Background

Line and wall following method are always popular as robot guidance in moving. Here in this project, this technique is combined together into one robot of 6 legs which called a hexapod robot. Although there are many configurations in 6 legs robot, in this project only use a simple 3 servo hexapod robot. This project only considers a line and wall following using a forward movement of robot. So a simple robot is sufficient to use in this project.

For the control method, fuzzy logic control with Sugeno style infrerence method is used. Wall following method and line following method is done in separate rules but they share a same output. Only one method is trigger in one time. When the line is present on wall, line following method is takes place. But when the line is not present, the wall following method will takes place. There is also simple obstacle avoidance at front of robot to ensure no collision happen at the front of robot. Simulation using Matlab is done to get a good expected output.

For line detection, Auto-Calibrating Line Sensor LSS05 sensors is use. For wall detection, two Sharp GP2Y0A21 distance sensors are use to measure front right and rear right distance from wall at right. PIC16F877A microcontroller is use as main controller for robot. Then the program will be written into this microcontroller for robot operation.

1.2 Problem Statements

Single guidance of autonomous robot tends to have its limits when there are conditions which can limit robot movement. Using line navigation, not all surface of floor suitable can be planted a line as guidance. If using colour line on a high traffic area makes the line more to become dirty or damaged. Using wall navigation, not all paths for movement is along walls. If some space is located at walls, when robot crossing at the front of the space, sensor will detect a far distance. This condition makes false reading of wall. According to these two problems, in this project these two kinds of guidance are applied. Line navigation will takes place if wall navigation cannot be used in certain condition. Fuzzy logic controller is used to create a smooth response of robot behaviour rather than logic programming.

1.3 Project Objectives

Objectives for this project are:

1. To design a hexapod robot with wall and line following behaviour.
2. To design fuzzy logic controller for hexapod robot.
3. To simulate the robot system for design analysis.
4. To test the robot performance at real time.

1.4 Project Scopes

This project is primarily concerned the use of fuzzy in wall and line following into a simple hexapod robot. The scopes of this project are:

a) A wall distance is set on 40 cm and cannot be adjusted to other distance value because of the suitability of the sensor range.
b) Turning movement with fuzzy rules is done in a forward movement of the robot only. Others movement is done in an open loop programming.
c) The wall is considered for the right side of robot only because to lower the cost of sensor needed.
d) Walking surface is on even surface because of the limitation on leg degree of freedom. Also no leg slipping is assumed when the robot is moving.

CHAPTER II

LITERATURE REVIEW

2.1 Technology Developments

There are many researchers who implement fuzzy rules on robot. An adaptive fuzzy line path tracking and obstacle avoidance control method is presented by Baoguo Li and Chunxi Zhang. The mobile robot moves toward the target point by tracking the virtual line path between the start point and the target point. An adaptive fuzzy controller is designed to minimize the tracking error caused by the uncertainty of the mobile robot velocity due to wheels radius error, assembly and gearing errors.

Sakr and Petriu presents a fuzzy logic controller for a hexapod robot that is able to move freely on an uneven surface environment without tipping over. The robot has the feel of the surface it's on through touch sensors located at the bottom of each of the six legs.

Azlan *et al.* describe the development of two miniature LEGO robots, which are the line following and the light searching mobile robots to provide a better understanding of fuzzy logic control theory and real life application for an undergraduate training system.

Yousef Moh. Abueejela Mosbah presented the modeling and development of an autonomous wall following robot which use fuzzy logic as controller. In his method, the sensor reading of distance different at front and rear makes the angular velocity of left and right wheel will be different thus making a turning movement.

2.2 Fuzzy Logic control

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. The fuzzy controller block diagram is given in Figure 2.1, where a fuzzy controller embedded in a closed-loop control system. The plant outputs is denoted by $y(t)$, and inputs is denoted by $u(t)$,while the reference input to the fuzzy controller is denoted by $r(t)$ [3].

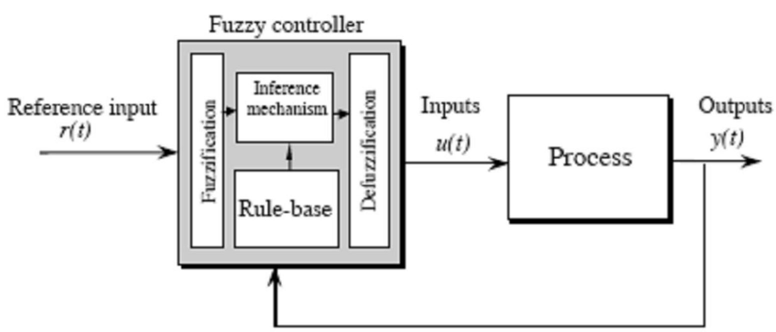

Figure 2.1: Fuzzy Controller Architecture

The fuzzy controller has four main components as below:

1. The "rule-base" holds the knowledge, in the form of a set of rules, of how best to control the system.
2. The inference mechanism evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.
3. The fuzzification interface simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base.

4. The defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant.

2.3 Wall detection

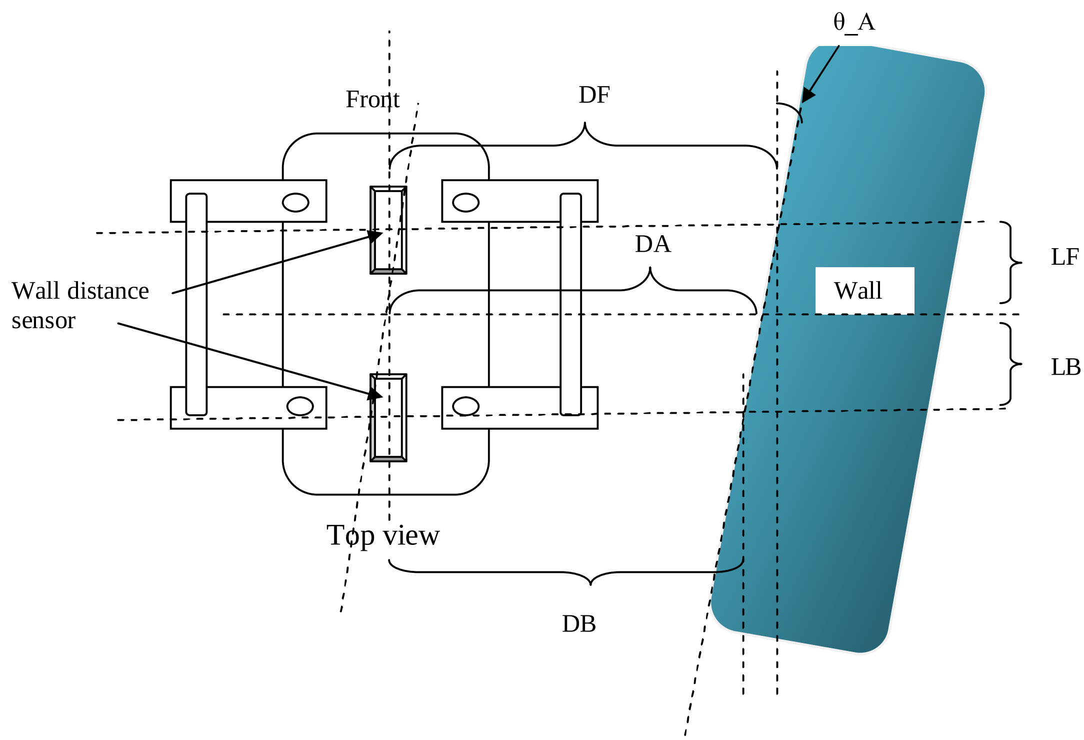

Figure 2.2: Connection between robot position and wall

Based on figure 2.2, DF is distance between front distance sensor and wall. DB is distance between rear distance sensor and wall. DA is distance between wall and the centre of robot. LF is distance between centre of front sensor and centre of robot. LB is distance between centre of rear sensor and centre of robot. θ_A is a angle between robot and wall. The connection of variable above can be described in figure 2.3 as follows:

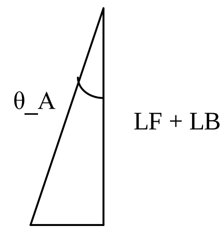

Figure 2.3: variable connection between wall angle and distance

From figure 2.3, equation below is formulated:

$$DFB = DF - DB \quad (1)$$

Where DFB is sensor different value

$$\theta\_A = atan\left(\frac{(DFB)}{(LF+LB)}\right) \quad (2)$$

Where θ_A is angle between robot and wall

Assuming LB is same value with LF then:

$$, DA = (DF+DB)/\ 2 \quad (3)$$

Where;

DA is distance between robot and wall

LF and LB is a fixed by distance between centre of two sensor

DF is front sensor reading

DB is rear sensor reading

In this project, LF and LB is set to 4 cm. To make sure robot is still align to the wall, value θ_A must be less than 35 degree. So from equation 2, maximum value of DFB can be derived as follows:

Maximum value of DFB= (LB+LF) tan θ_A

= (4+4) tan 35 = 5.6 cm

Considering this value, maximum value of DFB is set 5 cm. The value of DFB and DA values are used as input to the fuzzy process to generate the value for turning angle, θ_T needed. In fuzzification, input DFB is assumed in linguistic variable as negative, zero and positive with a range from -5 cm to 5 cm. And Input DA is assumed in linguistic values as decrease, steady and increase with a range from 10 cm to 70 cm with 40 cm is a centre distance.

2.4 Line detection

In line following mode, there are a few factors that can influent the performance of robot. The sensor arrangement can affect performance because wrong arrangement the line cannot be detected accurately. In this project, sensor is placed at the centre of robot because at robot centre, the turning effect is very small. Line width also can affect the performance. If the line width is small than specific width, sensors cannot detect the line properly. Here the line width is set to minimum 1 cm related to the line sensor gap is also 1 cm. If the line width is less than 1 cm, the line sometimes cannot be detected. Figure 2.4 shows how the arrangement of the line sensors installation.

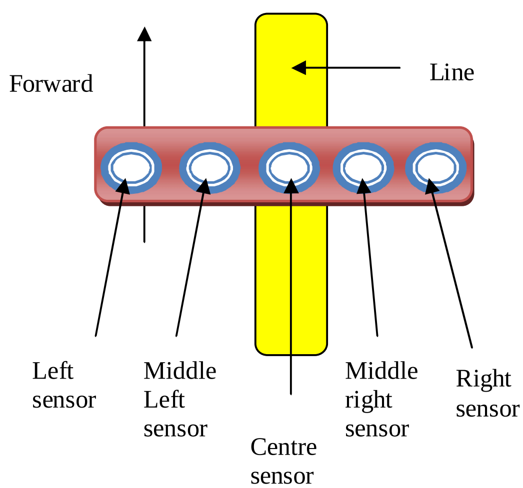

Figure 2.4: The line sensor installation arrangement

Each sensor will give a digital output either line is present or not. Using the arrangement like in figure 2.4, the condition of sensors output with can reflect how the line is place under the sensor. Table 2.1 shows how an analog range is created from sensors output.

Table 2.1: Sensor output to analog value

	Sensor arrangement				
	Left	Mid left	Centre	Mid right	Right
Analog value, L (cm)	-2	-1	0	1	2

Referring to the table above, if left sensor is triggered, L value is set to -2 cm. If two or more sensor is triggered, the average L value is calculated. For example, if mid right and right is triggered, L= (1+2)/2 = 1.5 cm. Then the position of line is located between mid right and right. The value of L will be used as input to the fuzzy process to generate the value for turning angle, θ_T needed. In fuzzy process, input L is defining as left, centre and right with a range from -2 cm to 2 cm.

2.5 Forward movement and turning

In robot fabrication, planning is needed to make sure robot can move. Here how the step of forward movement is planned. Firstly, right leg is in forward position, left leg in backward position and centre leg is lifting the body at left side. Then right leg is moving to backward position which makes a robot body move to forward at right side. At the same time, left leg move to forward position but there is no effect to the body because the left body is still in lifting condition. The details of robot mechanism are represented in figure 2.5 at no 1 and no 2.

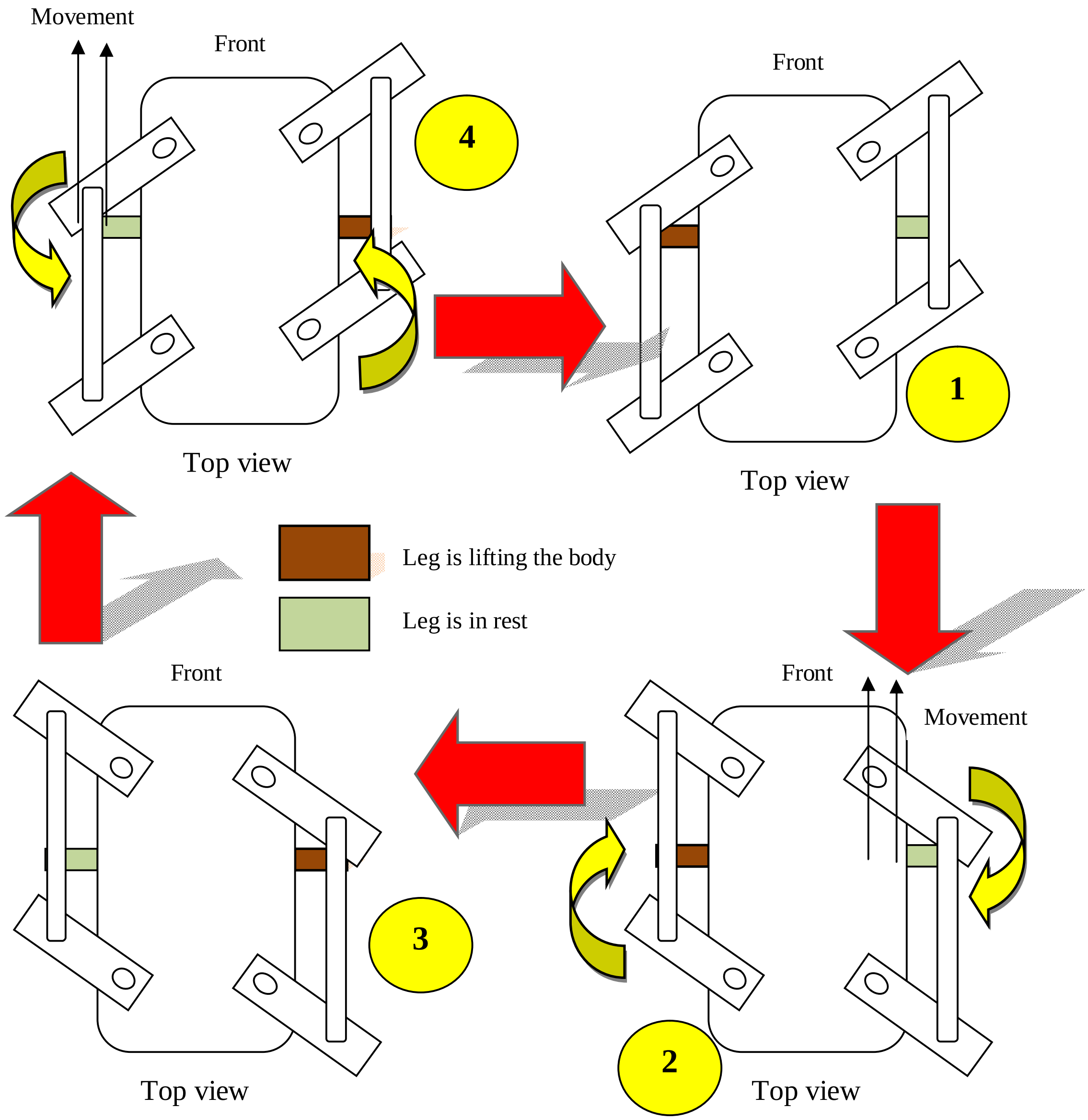

Figure 2.5: Forward movement sequence

After that, the centre leg will change position which cause the robot body is lifting at right position. Then left leg is moving to backward position which makes a robot body move to forward at left side. At the same time, right leg move to forward position but there is no effect to the body because the right body is still in lifting condition. Combinational of forward movement of left and right side makes the forward movement of the robot. . The details of robot mechanism are represented in figure 2.5 at no 3 and no 4.

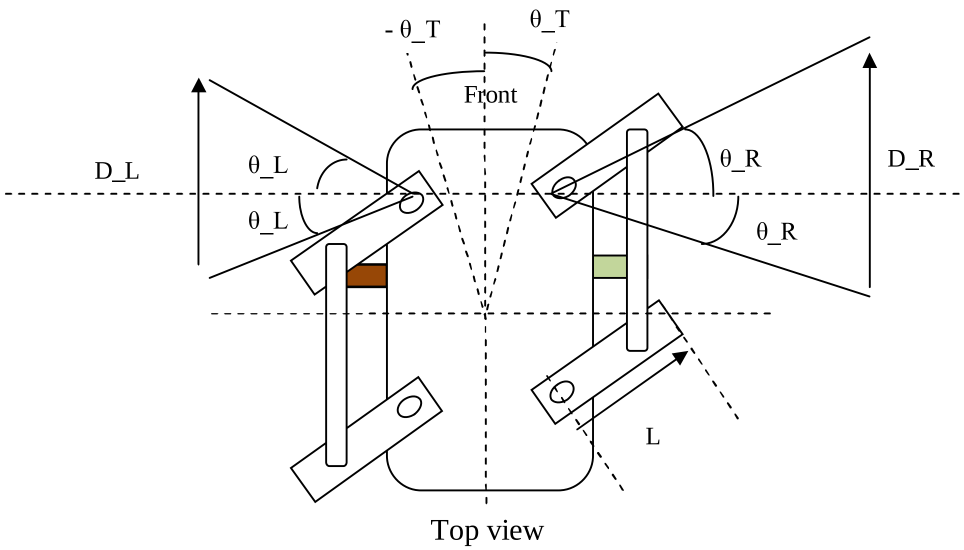

Figure 2.6: Parameter definition

Referring to figure 2.6, there a few parameter defined. L is a leg length. D_L is left forward distance movement. D_R is right forward distance movement. θ_L is left servo angle. θ_R is right servo angle. θ_T is a turning angle of robot body after a complete forward movement. If is positive them it is assume right turn happen but if θ_T is negative, it is assume left turn happen. These parameters can be linked as follows:

$$D\_L = 2 \times (L \times \sin (\theta\_L)) \quad (4)$$

$$D\_R = 2 \times (L \times \sin (\theta\_R)) \quad (5)$$

Where L is assumed same for all leg

From the equation 4 and 5, the servo angle is affecting the forward movement of left and right side. If D_R and D_L is same, then the movement is forward with no turning angle is involved. If D_L is more than D_R, then forward movement with turning angle of θ_T is involved. Then if D_R more than D_L, then forward movement with turning angle of - θ_T is involved. So here we can say:

$$(\theta\_L - \theta\_R) \propto \theta\_T \quad (6)$$

$$(\theta\_L - \theta\_R) = P \times \theta\_T \quad (7)$$

Where P is a constant.

Constant P is a ratio difference between turning angle and servo turning. This value is different depending on robot length and width. For starting, here P and Q is considered equal to 1. This will value will be adjusted at the future to get accurate turning. Equation 6 and 8 can be rewrite as follows:

$$(L\_A - R\_A) = \theta\_T \quad (8)$$

Where P is assumed equal to one

At fuzzy controller, the value of servo angle of left leg, L_A and right leg, R_A is get. Referring to equation 8, the value of θ_T is known. All of this value is used for line and wall following modelling simulation in Matlab.

CHAPTER III

METHODOLOGY

3.1 Fuzzy controller design and modelling

In this project, two controller is designed which for line following and wall following. Sugeno method inference technique is used. This because Sugeno method is computationally efficient which suitable for microcontroller application. The fuzzy controller is designed and simulated into Matlab. After a tuning process is done, then the controller is transfer into microcontroller program for real time application.

3.1.1 Wall following

Two inputs which are front distance sensor, DF and back distance sensor, DB are used to detect a wall at the right position of robot. From DF and DB, centre position of distance, DA and sensor different value, DFB is calculated. DA and DFB become inputs to the fuzzy controller. The membership functions are shown in figure 3.1 for DA and in figure 3.2 for DFB.

DA membership functions are defined as decrease, steady and increase with triangle shape for steady and trapezoidal shape for decrease and increase. The range of inputs is defined as 10 cm to 70 cm. DFB membership functions are defined as negative, zero and positive with triangle shape for zero and trapezoidal shape for negative and positive. The range of inputs is defined as -5 cm to 5 cm.

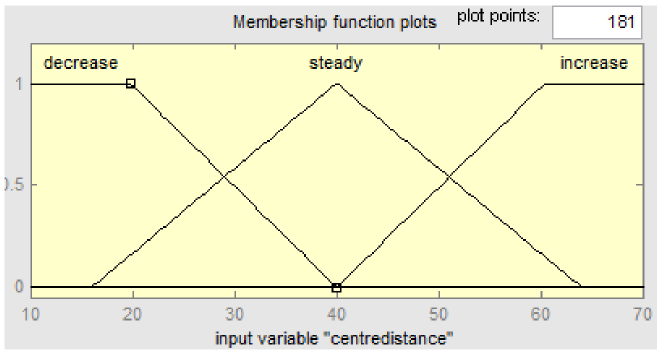

Figure 3.1: Centre distance, DA (cm) membership function

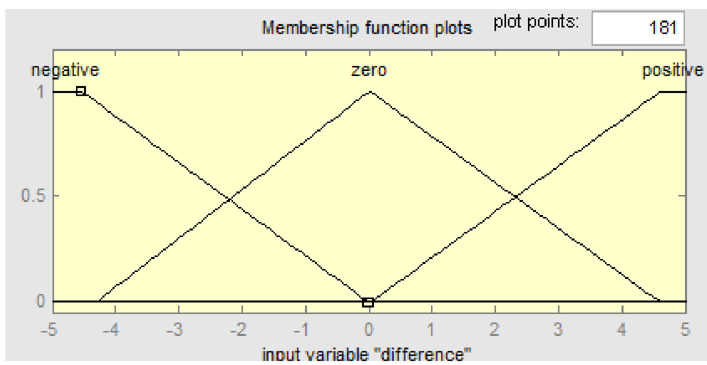

Figure 3.2: Distance difference, DFB (cm) membership function

There are two output uses for a wall fuzzy controller which is left motor angle, L_A and right motor angle, R_A. The membership functions of these 2 outputs are defines as small, medium and large which in singleton form. Small is defined as 0 degree, medium is defined as 20 degree and large is defined as 40 degree. Figure 3.3 shows the fuzzy controller structure:

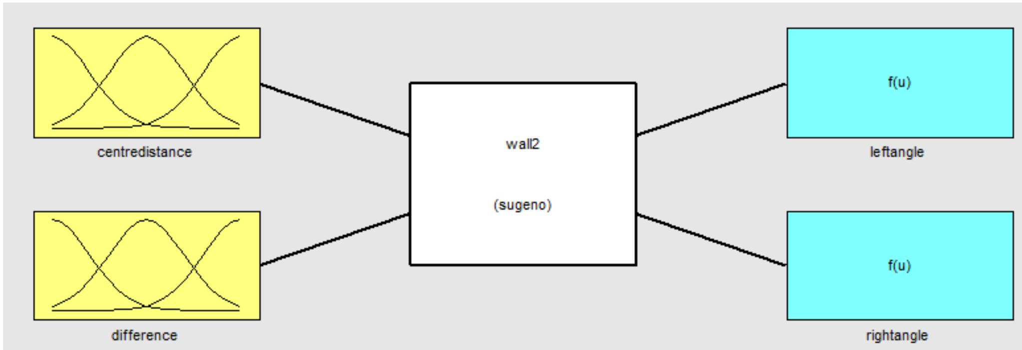

Figure 3.3: Wall following Fuzzy controller

At the controller, rules are design to create proper outputs depending on inputs. In Matlab simulation for robot modeling, these some rules then need to be altered to get a good response. The final rules for this controller are shown in table 3.1 and table 3.2 which shows how the output based on the inputs.

Table 3.1: Rules for left motor angle output

Left motor angle, L_A (degree)		**Centre distance, DA (cm)**		
		Decrease	Steady	Increase
Distance difference, DFB (cm)	Negative	Small	Medium	Medium
	Zero	Small	Large	Large
	Positive	Small	Large	Large

Table 3.2: Rules for right motor angle output

Right motor angle, R_A (degree)		**Centre distance, DA (cm)**		
		Decrease	Steady	Increase
Distance difference, DFB (cm)	Negative	Large	Large	Large
	Zero	Large	Large	Medium
	Positive	Large	Medium	Small

Then using rules designed and also membership function of inputs and output, simulation of controller is done in Matlab. The rules viewer is shown in figure 3.4 which here the possible output is simulated based on inputs value.

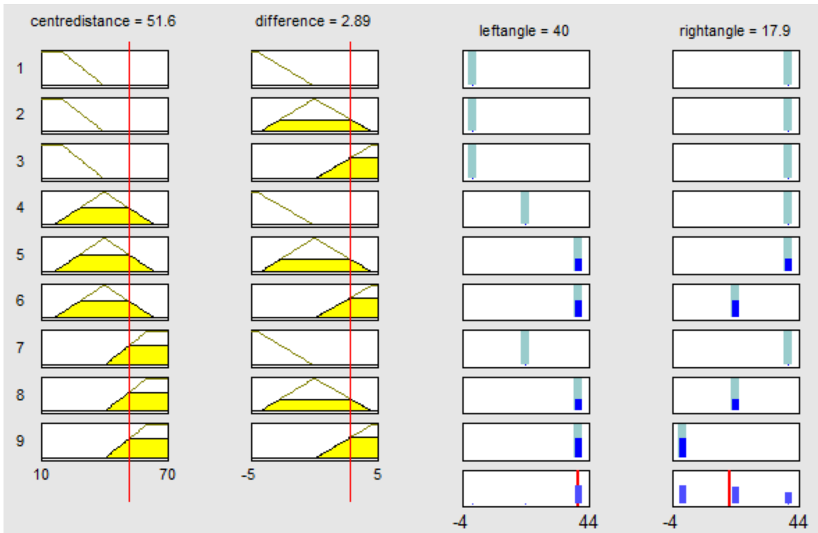

Figure 3.4: Rules Viewer of Wall following Fuzzy controller

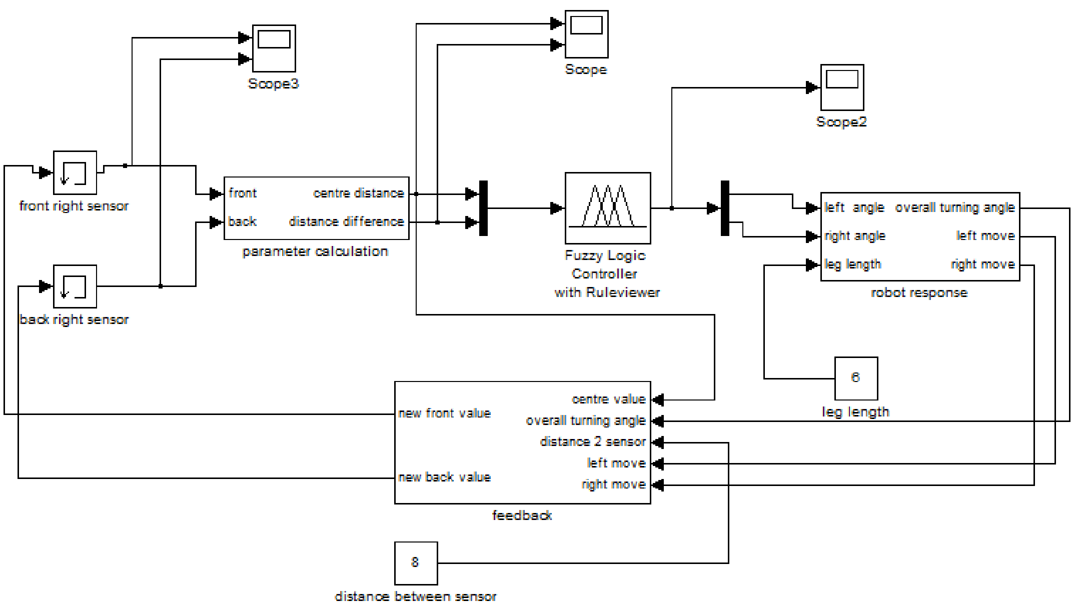

Figure 3.5: Wall following behaviour modelling

To simulate robot behaviour in wall following, fuzzy controller is included in robot modelling in figure 3.5. There are 4 major sections in the wall following modelling which are parameter calculation block, fuzzy controller block, robot response block and feedback block. Parameter calculation block is to calculate the centre distance, DA and distance different, DFB from distance sensors input. These two inputs is needed for fuzzy controller block to generate the output of left servo angle, L_A and right servo angle, R_A based on membership functions and rules created.

Robot response block is to calculate the robot movement based on servo angle generated by fuzzy controller. Feedback block is to calculate new value of distance sensor after the robot response is calculated. Then the new value is used for next robot response. This process is running continuously as this simulates the actual response of robot in real world when the fuzzy controller is applied at the robot.

3.1.2 Line following

Line distance sensor, LD is used to detect a line position under the robot. LD becomes input to the fuzzy controller. The membership functions are shown in figure 3.6. LD membership functions are defined as left, centre and right with triangle shape for centre and trapezoidal shape for left and right. The range of inputs is defined as -2 cm to 2 cm.

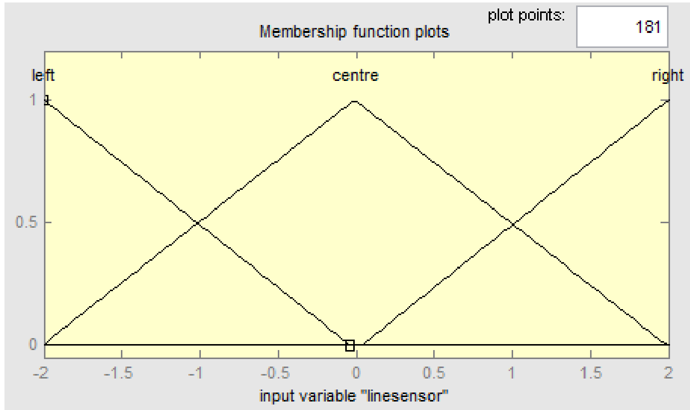

Figure 3.6: Line distance sensor, LD membership function

There are two output uses for a line fuzzy controller which is left motor angle, L_A and right motor angle, R_A. The membership functions of these 2 outputs are defines as small, medium and large which in singleton form. Small is defined as 0 degree, medium is defined as 10 degree and large is defined as 20 degree. Figure 3.7 shows the fuzzy controller structure:

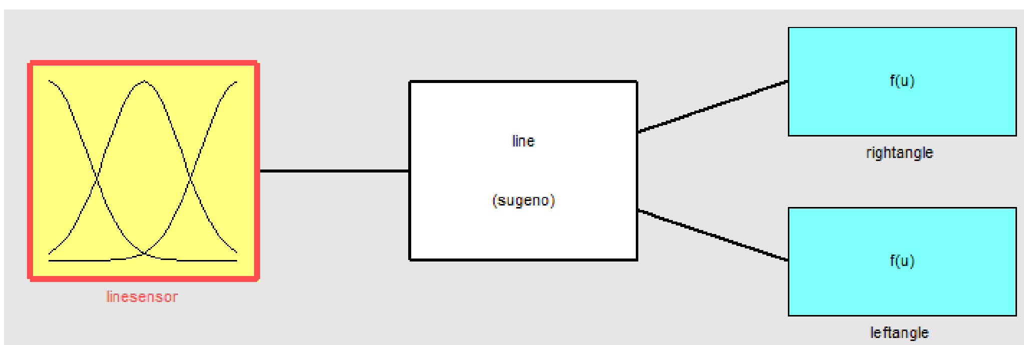

Figure 3.7: Line following fuzzy controller structure

Rules are design to create proper outputs depending on inputs. When in Matlab simulation for robot modeling, these some rules then need to be altered to get a good response. The final rules for line following fuzzy controller are shown in table 3.3.

Table 3.3: Rules for line following fuzzy controller

Input		**Output**	
AND		**THEN**	**AND**
Line position, LD (cm)		**Left motor angle, L_A (degree)**	**right motor angle, R_A (degree)**
Negative		Small	Large
Zero		Medium	Medium
Positive		Large	Small

Then using rules designed and also membership function of inputs and output, simulation of controller is done in Matlab. The rules viewer is shown in figure 3.8 where the possible output is simulated based on inputs value.

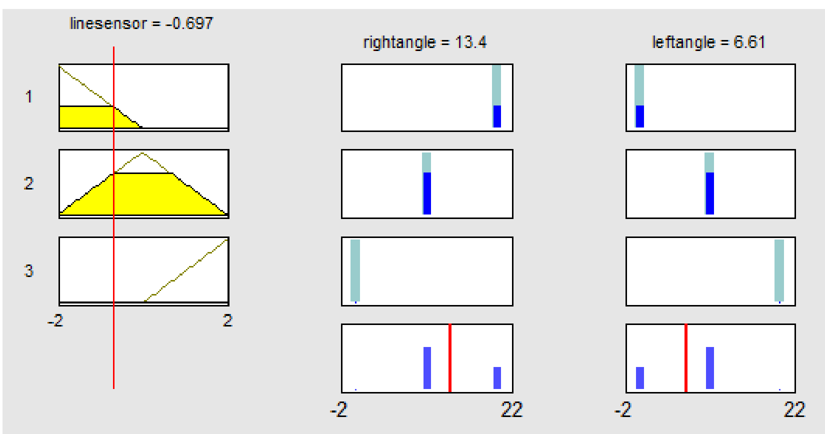

Figure 3.8: Rules viewer of line following fuzzy controller

To simulate robot behaviour in line following, fuzzy controller is included in robot modelling in figure 3.9. There are 3 major sections in the line following modelling which are fuzzy controller block, robot response block and feedback block. Fuzzy controller block to generate the output of left servo angle, L_A and right servo angle, R_A from a line position input, LD using a membership functions and rules created. .

Referring to figure 3.9, robot response block is to calculate the robot movement along the line based on servo angle generated by fuzzy controller. Feedback block function is to get a new line sensor reading using the robot response value and current line position value. Then the new value is used for next robot response. This process is running continuously as this simulates the actual response of robot in real world when the fuzzy controller is applied at the robot.

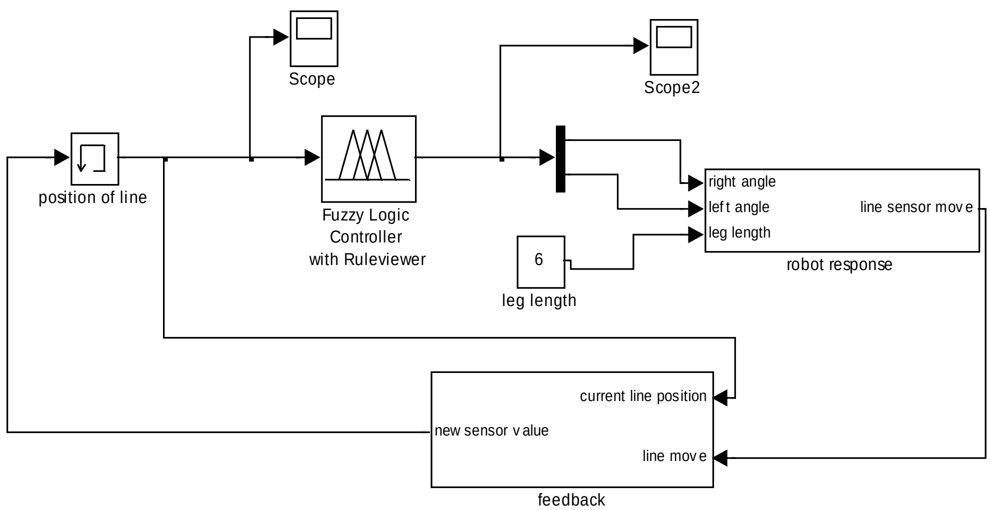

Figure 3.9: Line following behaviour modelling

3.2 Robot structure

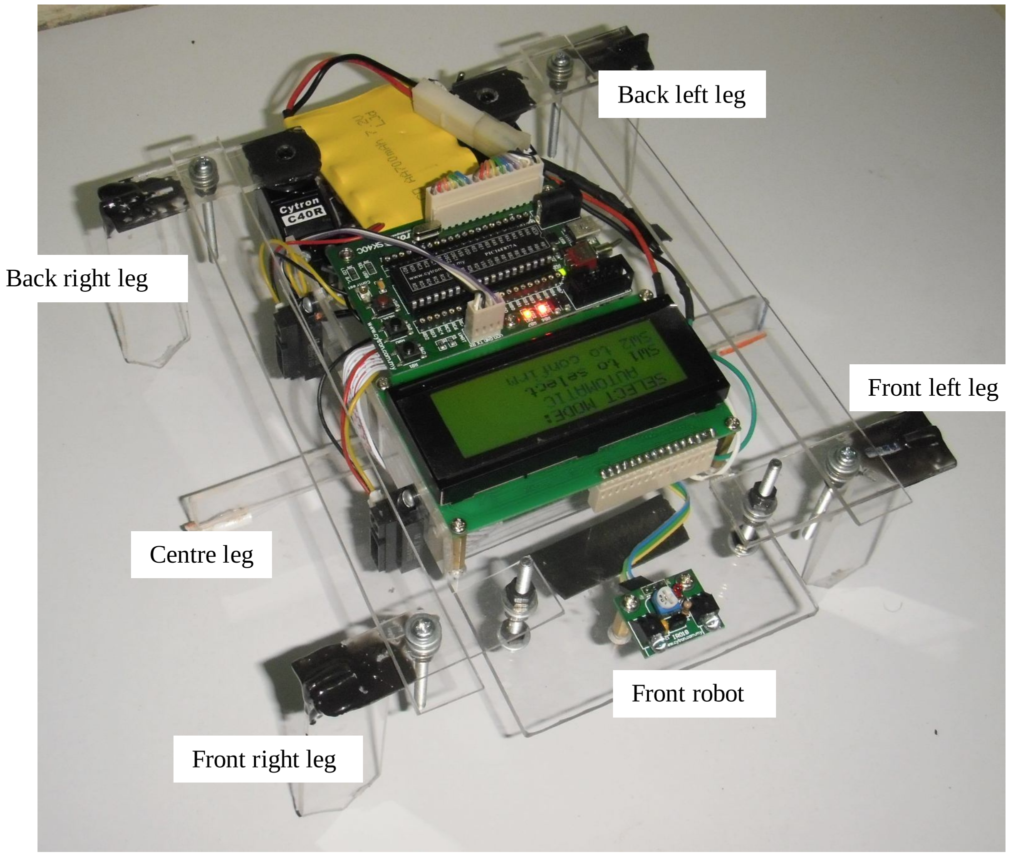

Figure 3.10: Hexapod Robot Structure

Figure 3.10 shows the robot structure. It has a front and back leg which link together with one rod to make the same movement. This combination of leg is controlled by one servo motor for forward and backward. At the centre, there is a leg which is to lift up the robot body either left lift or right lift. Servos are used to create a movement of this robot.

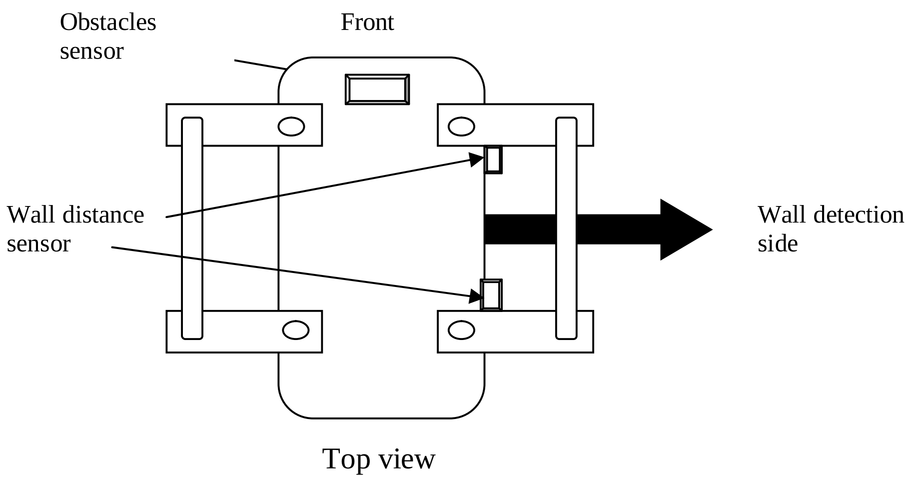

Figure 3.11: Position of wall and obstacle sensor from top view

Figure 3.11 describes the installation position of the wall detection sensor and obstacles sensor at the front of robot. Obstacle sensor has function to detect any object or wall in front of robot to avoid any collision happen to the robot when operation. Wall distance sense the right side distance between robot and wall. The distance reading is send to fuzzy controller to be the input variables for wall following mode.

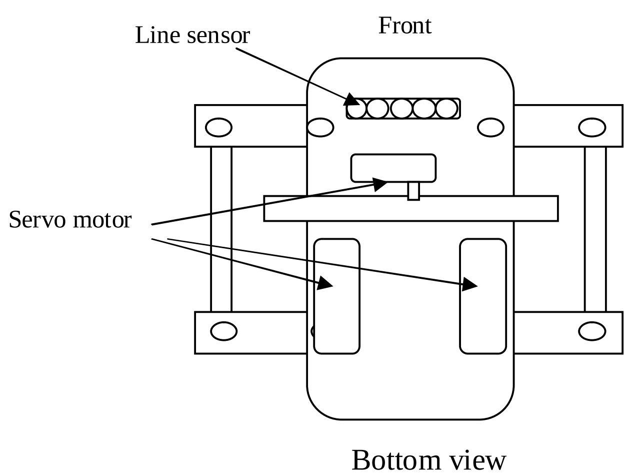

Figure 3.12: Position of line sensor from bottom view

Figure 3.12 shows the position of line for detecting line on the floor. There are 5 sensors which placed in one row. Each sensor will give a digital output. The line reading is send to fuzzy controller to be the input variables for line following mode.

3.3 Robot Program Operation

General program for robot operation is created for robot behaviour. Figure 3.13 shows the flow chart of the general robot operation. At first step the program read all sensor value that attached to the robot. Then the value of obstacle sensor is processed. When obstacle detected, the robot then will make one turning about 45 degrees to the left. This turning process is done with open loop program where the angle is fixed and no fuzzy process is applied here. When the turning process is complete, the sensor value again is read. If there is obstacle again, the avoiding process still running until there is no obstacle.

After no obstacle is detected, line detector sensor value is read to make sure if there is a line or not on the floor. If there is a line detected, a fuzzy control of line following process take place. Here by reading the line sensors value, fuzzy process is done and then the value of servo angle for left and right leg is generated. These two values then is use for forward movement. After each movement, then the sensor is read again to continue the next movement process.

If no line is detected, fuzzy control of wall following is take place. Here the wall distance at right robot between front sensor and back sensor is read. From the sensor reading, the mathematical rule is applied to find the centre distance and sensor difference value. With these two values, fuzzy control adjusts the servo angle output of left and right leg. Then the forward movement is executed. After the movement is done, the sensor value is read and processed for another forward movement.

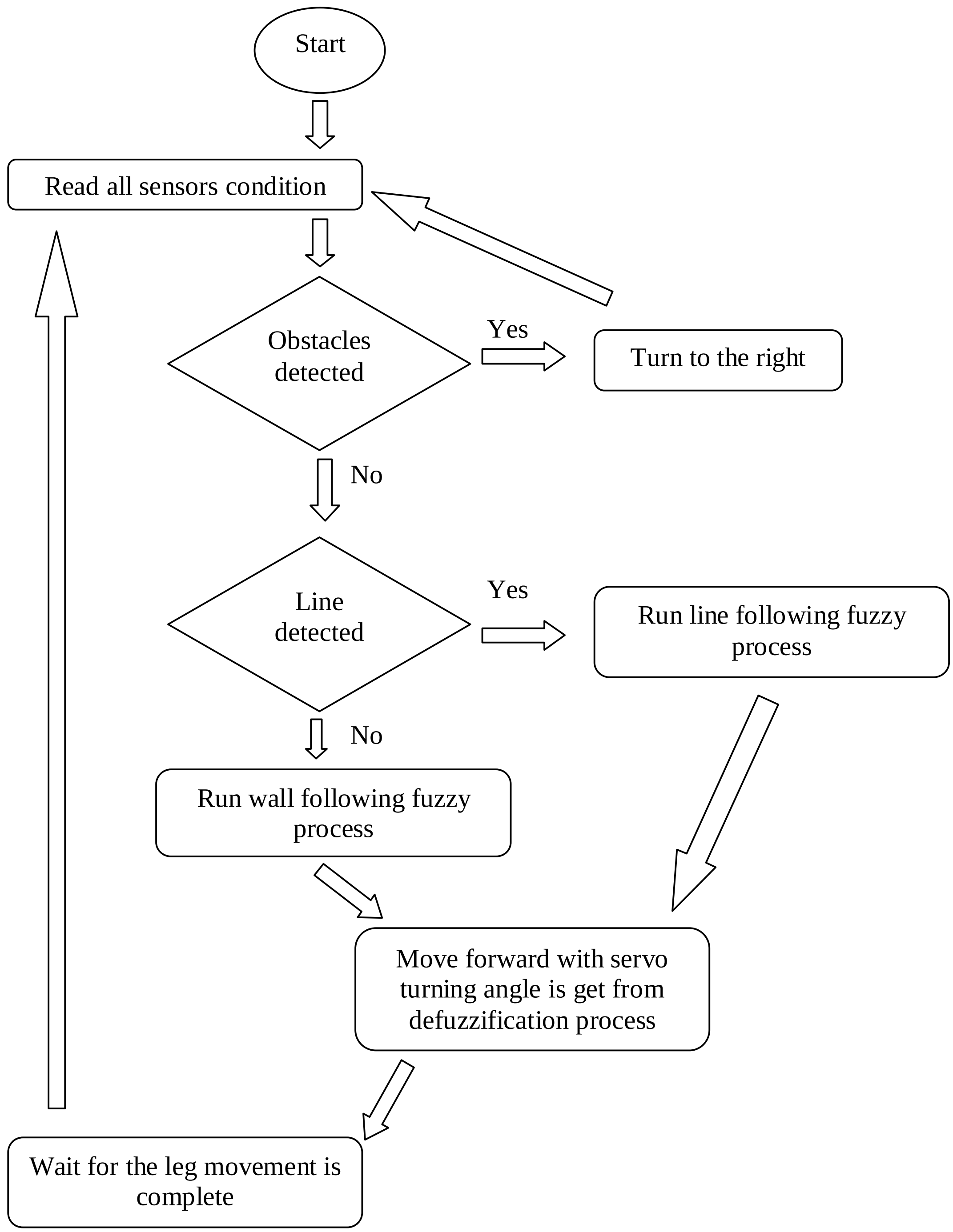

Figure 3.13: Flow chart of robot operation

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