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Review Article:

Fuzzy Logic Control Systems and Applications

(Review, Critiques and Research Directions/Methods)

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1- Abstract

Fuzzy Logic implements a formal core for creating systems manifesting good numeric performance (sureness) and semantic representation (interpret-ability). Throughout the preceding decades, fuzzy logic control has been one of the most influential and productive areas for research in applying the fuzzy set approach. In this review paper, Fuzzy Logic control systems were introduced, and some of the applications were conferred.

Keywords: fuzzy Logic, control system, subset, application, technology.

2- Introduction

The control system design, extension, and implementation require the designation of plants, machines, or processes to be controlled. A control system consists of a controller and plant and needs an actuator to interface the plant and controller. The operation and execution of a control system depend on the synergy of all the elements. The dynamical control systems design, modeling, and simulation in the local and shared environment necessitate exposing the behavior of quantitative control sys tem of MIMO variables control environment to ascertain the relation connecting actions and outcomes of the control approaches.

Current processing systems are profoundly reliant on automatic control systems. Control automation has converted crucial for machines and processes to run strongly to deliver steady operation, more excellent quality, diminished operating costs, and more excellent safety.

Throughout the earlier decades, fuzzy logic control has been one of the most active and fruitful research areas in applying the fuzzy set approach. It has been a crucial subject in automation and control theory as Mamdani's work introduced in 1974 based on Zadeh's fuzzy sets approach (1965) to deal with the system control dilemmas, which is not simple to be modeled.

The research in fuzzy control has been snowballing in recent years, making it challenging to impersonate a broad survey of the wide variety of applications that have been created. Fuzzy Logic, which is the Logic on which fuzzy control is based, is closer to human thinking and common language than the conventional logical systems. It affords an efficient means of capturing the fair and imprecise nature of the real world. The fuzzy logic controller collects scientific control laws associated with the dual notions of fuzzy inference and the compositional inference rule. The FLC implements an algorithm that can transform the morphological control strategy based on proficient knowledge into an automatic control strategy.

The theory of FLC is to employ the qualitative experience of a system to compose a practical controller. A fuzzy control algorithm plants an operator designer and researcher's intuition and skill for a process control system. The fuzzy control method is proper for systems with non-specific models. Hence, it accommodates a method where the model is unknown or ill-defined, especially to systems with unknown or complicated dynamics.

Fuzzy Logic is a multi-valued philosophy that lets intermediate values be represented between standard evaluations like true/false, yes/no, high/low, and so on.

Professor Lotfi A. Zadeh made a pioneering effort on fuzzy Logic.

Lotfi A. Zadeh - the University of California - Berkeley in 1965. He introduced the fuzzy set approach, which drove to a new control method called 'fuzzy control.' Zadeh's work started to gain attention after Dr. E.H. Mamdani of London University sensibly applied the fuzzy Logic notion to the steam engine's automatic control in 1974. Throughout the preceding few decades, Fuzzy Logic has been extensively applied in nearly all our society's perspectives, including manufacturing, automatic control, automobile creation, banks, hospital, and more applications. Today, fuzzy Logic is still well recognized. Worldwide, thousands of researches are conducted out yearly on this field

There are two types of control rules in fuzzy control: The Mamdani type and the Sugeno type. The Mamdani control rules are significantly more linguistically intuitive, while Sugeno rules appear to have more interpolation power even for a relatively small number of control rules (A. Adepoju, A. Adeyemi and S. Oni, 2014)(Meshram, 2013)(Ghani and Tahour, 2012)(M. Abbas, M. Saleem Khan, 1967).

3- Fuzzy Logic Control Background

There are two sorts of fuzzy logic inference systems (FIS) available: Mamdani and Sugeno. These techniques essentially contain the same steps; the only variance is that the Sugeno method outputs are usually linear. In terms of the fuzzy logic processes, there are three main processes, shown in Figure 1.

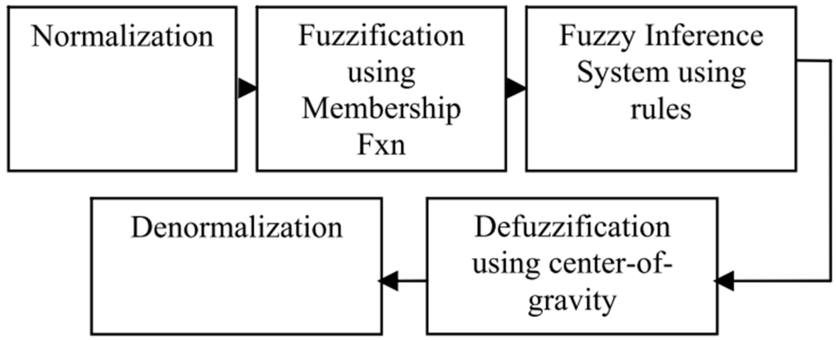


Figure 1: Main processes of fuzzy logic method

In the first primary fuzzification process, a crisp value is "fuzzified," which means that a fuzzy set characterizes it. It is followed by the inference process, whereby the fuzzified inputs described in the form of membership functions are linked and used to demonstrate the experts' knowledge in the form of rules. In the final process known as defuzzification, the output value is "defuzzified," allowing for significant crisp value.

The construction of a complete fuzzy control system consists of the subsequent main parts: -

1. Fuzzification,
2. Knowledge base.
3. Inference engine.
4. Defuzzification.

Figure 2 shows the internal configuration of a fuzzy logic controller.

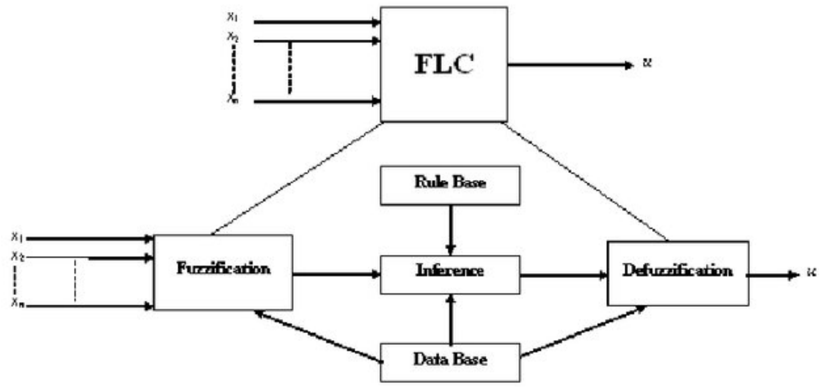


Figure 2: The Internal Configuration Of A Fuzzy Logic Controller

The fuzzification module transforms the crisp states of the control inputs into fuzzy states. A fuzzy variable has values represented by semantic variables (fuzzy sets or subsets) such as Low, Medium, high, prominent, slow, where a steadily altering membership function defines each one.

In fuzzy set vocabulary, all the potential values that a variable can assume are called the universe of discourse, and the fuzzy sets (described by membership functions) include the whole universe of discourse. The form of fuzzy sets can be triangular, trapezoidal.

A fuzzy control embeds a human operator's intuition and experience, and sometimes those of a designer and researcher. The database and the laws form the knowledge base used to get the deducing relation R. The database includes a representation of input and output variables using fuzzy sets. The rule base is typically the control policy of the system. It is usually acquired from expert knowledge or heuristics. It holds a collection of fuzzy conditional statements represented as a set of IF-THEN rules, such as:

$$R^{(i)}: \text{If } x_1 \text{ is } F_1 \text{ and } x_2 \text{ is } F_2 \dots \text{ and } x_n \text{ is } F_n \text{ THEN Y is } G^{(i)}, i = 1, \dots, M \quad (1)$$

Where: (x_1, x_2, …, x_n) is the input variables vector, Y is the control variable, M is the number of rules, n is the number of fuzzy variables, (F1, F2… Fn) is the fuzzy sets.

The mathematical method of converting fuzzy values into brittle values is known as 'defuzzification.' The option of defuzzification methods depends on the application and the available processing power. A standard fuzzy classifier splits the signal x into five fuzzy levels: -

1. LP: x is large, positive.
2. X is medium positive.
3. S: x is small
4. MN: x is medium negative.
5. LN: x is a large negative.

(Bickraj *et al.*, 2006)(Ghani and Tahour, 2012)(Sharma, 2011).

Fuzzy Logic needs numerical parameters to function, such as a notable error and a critical rate-of-change-of-error error. Still, exact values of these numbers are usually not critical unless a very sympathetic performance is required, in which case practical tuning would determine them. A fuzzy expert system is a system that utilizes fuzzy Logic rather than Boolean Logic. They are used in various wide-ranging areas, including (Bai and Wang, 2006) (Singh and Mishra, 2015):

1. Linear and nonlinear control.
2. Pattern recognition.
3. Financial systems.

4- Fuzzy Control Approaches

As mentioned by (Sharma, Disha), there are two main approaches for designing Fuzzy Logic Controllers, and they are:

1. A Model-Free approach
2. A Model-Based approach
3. Adaptive Fuzzy control

A model Free approach of fuzzy logic control operates for trajectory tracking for a standard, even complicated, dynamic system that does not have a specific mathematical model.

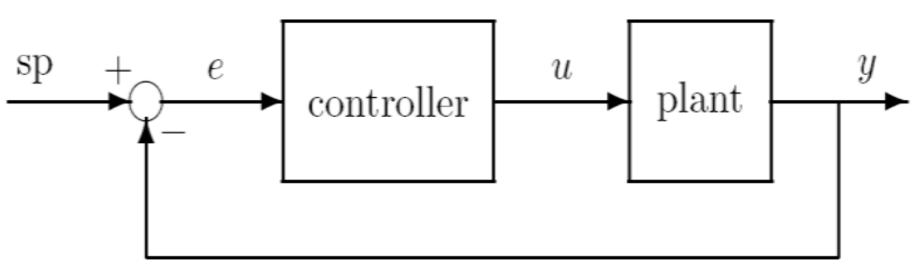


Figure 3: A typical setpoint tracking control system

The goal here is to establish a controller to achieve the goal *e(t)* → 0 as t → ∞, without any mathematical formula of the plant except for the assumption that its inputs and outputs are measurable by sensors on line. It is one of the advantages of the Fuzzy Logic approach in that it enables the design of a controller without knowing the system's mathematical description.

If a mathematical model of the system, or a reasonably good estimate of it, is available, one may design a fuzzy logic controller with more excellent results such as performance specifications and ensure stability; this constitutes a model-based fuzzy control approach.

When the parameters are immediately adjusted according to some adaptive law, reduce the plant's output and the reference model's variance.

Many aspects concerning Fuzzy Logic system modeling, structure identification, and parameters identifications cab be found in (Sharma, 2011).

5- Fuzzy Logic Applications

A. Motion Control of Wheeled Mobile Robots

(Meshram, 2013) worked on the motion control of mobile robots utilizing a Fuzzy Logic controller. He used a simulation environment to achieve his mission. The leader robot controller was designed to reach the desired position, and the follower robot keeps a constant distance and angle from the leader robot. The simulations were performed in a Matlab simulation environment.

He studied the leader-follower approach for the wheeled mobile robot. The purpose is to develop a controller for a mobile robot using Fuzzy Logic.

He declared that the control problem as follows: A group of "n" robots will be used, and when the leader changes the position, all the follower robots will change their spot and positions without colliding with the leader robot and with each other as well.

To design the Fuzzy Logic controller, he proposed calculating the simulation environment model in two-dimensional model x and y. The robot's position can be expressed by three parameters (x,y, and theta). The author mentioned that the position represented by x is not valid. Two points, x, and y can express the position of a mobile robot. The third parameter is the orientation of the robot.

A group of "n" number robots were involved in this study R_i(i=1, 2…n). The position and orientation variables will be denoted $R_i(x_i, y_i, \theta_i)$. For example, the leader's state will be $R_1(x_1, y_1, \theta_1)$, and the first follower robot state will be $R_f(x_f, y_f, \theta_f)$ respected.

In this work, when the required number of robots is entered, the user will be asked to pick the leader robot among the robots entered. After selecting the leader, the user should decide whether the leader's motion goes forward, back, left, or right. If the user decides to move the leader forward and backward, the equation for calculating the distance between the robots is:

$$y_l = y_l \pm y_d \qquad (2)$$

A positive sign for forwarding motion and a negative sign for backward motion. When the user selects the left and right motion for the leader, the following equation will be used:

$$\theta_l = \theta_{l+}\theta_d \qquad (3)$$

The span between the leader and the follower calculated using the equation below:

$$\theta_{12} = \theta_f - \theta_d \qquad (4)$$

$$\text{If } \theta_{12} < 0 \text{ ,then } \theta_{12} = 180 + \theta_{12} \qquad (5)$$

$$\text{Else } \theta_{12} = 180 + (\theta_{12} / 2) \qquad (6)$$

$$d_{12} = \sqrt{(x_f - x_l)^2 + (y_f - y_l)^2} \qquad (7)$$

For linking the leader with the followers, the following equations will be used:

$$x_f = \sin(t) + x_l \qquad (8)$$

$$y_f = \cos(t) + y_l \qquad (9)$$

The controller design for the fuzzy logic controller can be shown below.

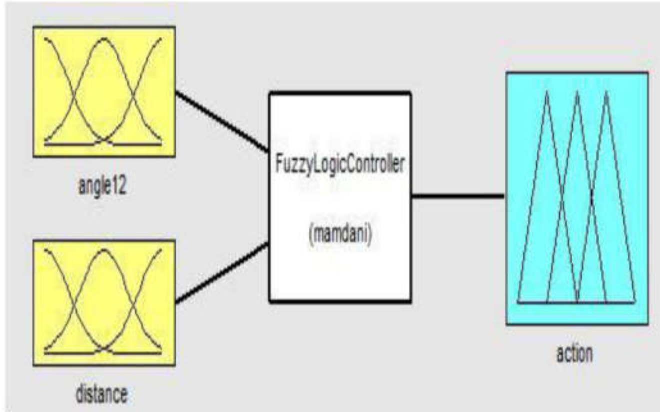


Figure 4: Fuzzy Controller design for robot behavior.

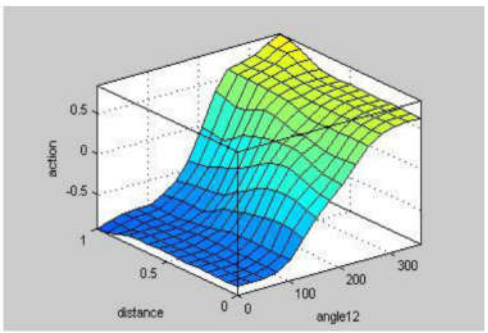


Figure 5: The control surface

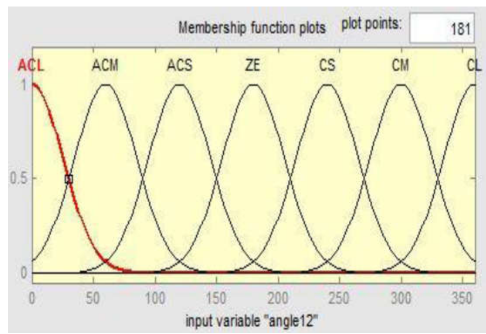


Figure 6: Input membership function of angle12

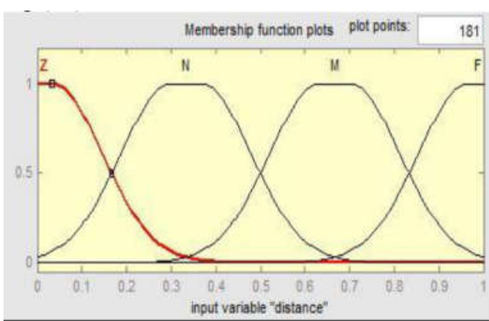


Figure 7: Input membership function of distance.

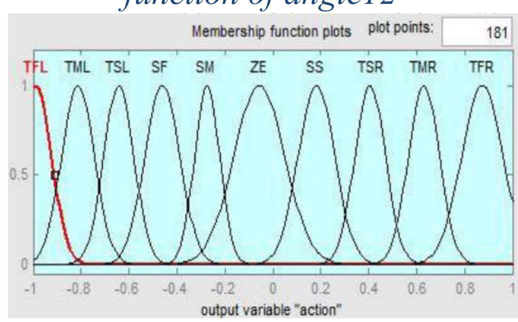


Figure 8: Output membership function action

θ_{12} / d_{12}	ACL	ACM	ACS	ZE	CS	CM	CL
Z	TML	TML	TSL	ZE	TSR	TMR	TMR
N	TML	TML	TSL	SS	TSR	TMR	TMR
M	TML	TML	TML	SM	TMR	TMR	TMR
F	TMF	TML	TML	SF	TMR	TMR	TFR

Figure 9: Table of rules.

Linguistic variables were for both functions angle12(), and distance () selected, for example (ACL) which is Anticlockwise Large Anticlockwise Medium and so on. The complete set of rules and Linguistic variables can be found in Figure 9.

In this work, nine robots were used in the simulation program, and one was selected as a leader. Initially, the robots will get the initial position and orientation. When the user selects the leader and the leader's new orientation, it is expected for the followers to change their position and follow the leader according to the equations above.

The initial position of the leader and the followers are shown in Figure 10.

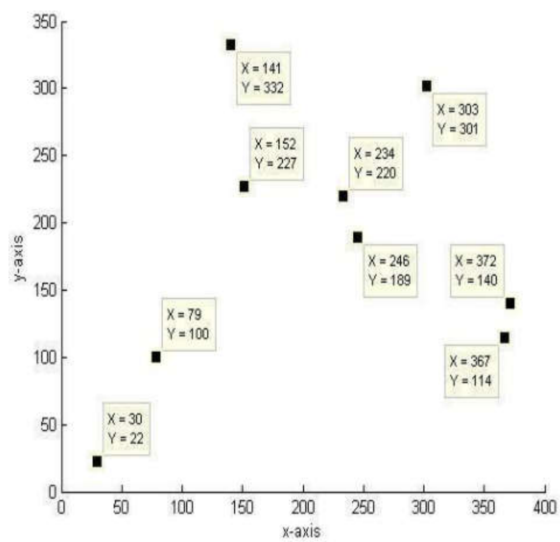


Figure 10: Initial position for the leader and follower robots

The author designed a GUI menu and used it to select the leader robot's motion and behavior.

Figure 11: A GUI for selecting the leader motion.

The author selected five random motions, and the final result and destination of the robots were presented as below:

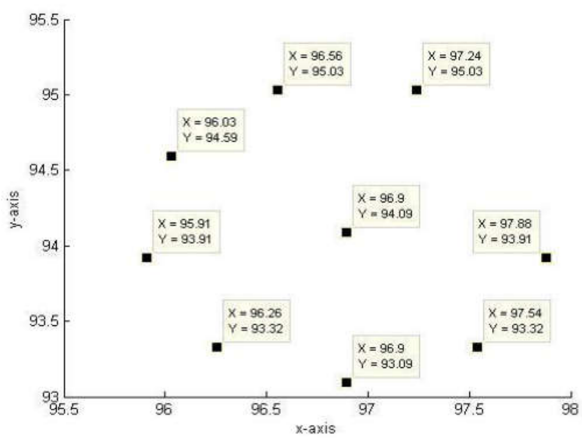


Figure 12: Final Position of the leader and follower robots.

B. Autonomous Bay Parking of Automobiles

(Wang et al., 2011) investigated the problem of Automatic Parking of Automobiles. Nowadays the streets and parking lots are very crowd and lots of cars will be on the streets in the future. The main issue of the drivers is parking the car correctly without any accident. One of the reports in china states that the majority of car accidents is during car parking.

The authors mentioned several methods and approaches to achieve autonomous parking. For example, reversing radar is one way to assist the driver in parking by alerting the driver about the obstacles.

An autonomous parking system can park the car without the help of the driver. The system consists of two parts, parking spot detection, and an autonomous parking algorithm. The detection module is responsible for finding a proper parking space, and at the same time, the algorithm will calculate the correct orientation for the car to be actuated and moved to the desired spot without any collision with the surroundings.

In this work, the main focus is developing a maneuvering algorithm for parking autonomously by tuning the fuzzy logic controller. The fuzzy logic controller can be appropriately used if experimental data provided and inserted into the controller. For that reason, the authors collected data for the controller by measuring the vehicle data when an experienced driver drove the car during parking.

Because the backward speed and steering can vary from different parking trails, two fuzzy controllers were designed. The first one is for speed control, and the other one is for steering. Matlab tool (ANFISedit) is used for simulating the process of parking.

There are four procedures in parking patterns. The first one is to drive the car to a place close to the parking spot. Then, the system will detect the parking space. Next to this step, the algorithm will find the correct orientation and steering angle to actuate the vehicle for correct parking. After that, the car will be moved to the parking spot.

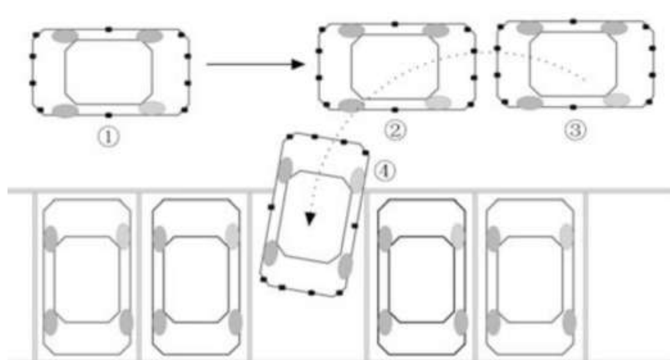
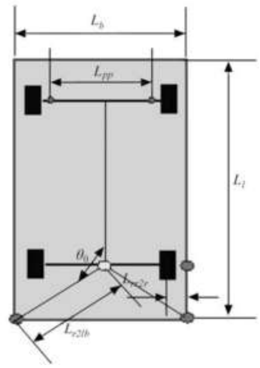


Figure 13: The steps of parking.

The Jetta car parking algorithm used, the dimension parameters, and their values are shown below:



Dimension parameter	Value (mm)
Length (L_l)	4 428
Width (L_b)	1 660
Wheel base (L_a)	2 471
Front overhang (L_{fa2h})	825
Rear overhang (L_{ra2t})	1 070
Front tread (L_{fw})	1 429
Rear tread (L_{rw})	1 422
Distance between two king pins (L_{pp})	1 329
Distance between the rear wheel to the right side (L_{rr2r})	119

Figure 14: Jetta Car Dimension parameter and the values

The angle denoted with Θ_0 can be calculated from the following equation:

$$\theta_0 = 90^\circ + \arctan\left(2 \times \frac{L_{ra2t}}{L_b}\right) = 90^\circ + \arctan\left(2 \times \frac{1\,070}{1\,660}\right) = 143^\circ. \qquad (10)$$

The parking lot dimensions are not identical from place to place. Comparing the slot to the vehicle size, maybe the slot suitable for parking the car used in this work, and this slot can be set as a reference slot size. However, when the slot is smaller than the reference slot dimension, it will not be easy to park the car. After measuring the car dimension and comparing it to the slot sizes, two criteria proposed for successful parking:

1- The car's projection on the ground should not touch the left, right, and rear boundaries.
2- In the final position, the car should be inside the slot.

The dynamics of the tires were neglected and assumed not to affect the process of parking. The kinetic model of the system can be made by drawing the following frame and coordinate systems.

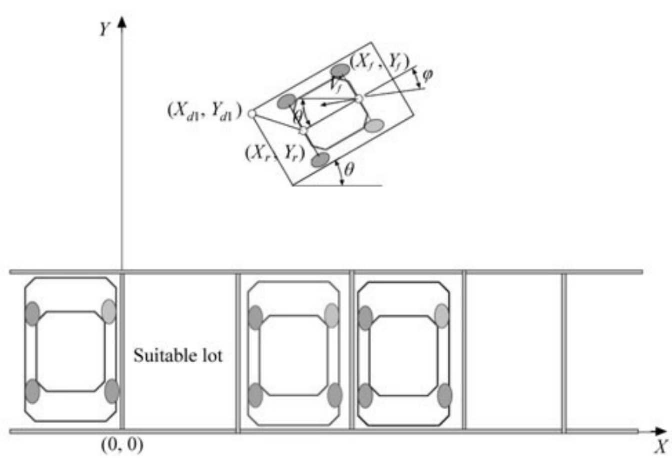


Figure 15: Jetta Car Dimension parameter and the values

The (r) letter denotes the rear axis coordinates, and (f) denotes the front. It is clear that from the diagram, the orientation of the car can be changed by tuning the value of the angle (Θ) and, the φ angle can control the steering of the car. The speed at the rear shaft is zero according to the following equation:

$$\dot{X}_r \sin(\theta) - \dot{Y}_r \cos(\theta) = 0. \qquad (11)$$

The relationship between (X_f, Y_f) and (X_r, Y_r) can be described as:

$$\begin{cases} X_r = X_f - L_a \cos(\theta) \\ Y_r = Y_f - L_a \sin(\theta). \end{cases} \qquad (12)$$

In the same way, the relation between (X_{d1}, Y_{d1}) and (X_r, Y_r) is :

$$\begin{cases} X_r = -\int_0^t V_f \cos(\theta) \cos(\phi) \mathrm{d}t \\ Y_r = -\int_0^t V_f \sin(\theta) \cos(\phi) \mathrm{d}t. \end{cases} \qquad (13)$$

$$\begin{cases} X_{d1} = -\int_0^t V_f \cos(\theta) \cos(\phi) \mathrm{d}t + L_{r2lb} \cos(\theta_0 + \theta) \\ Y_{d1} = -\int_0^t V_f \sin(\theta) \cos(\phi) \mathrm{d}t + L_{r2lb} \sin(\theta_0 + \theta). \end{cases} \qquad (14)$$

The steering angle (φ) can be measured using three angular transducers, one for the steering wheel and two for the left and right tires. The equation of these three sensors are:

$$\lambda = 16.6\phi \qquad (15)$$

λ is the steering angle of the wheel.

The control strategy for the backward movement is to gradually maintain a three km/h speed from zero, then making the speed constant until the car enters the parking spot; at the end, the car speed will be decreased to reach zero when the car is on the final position. The concept itself is a fuzzy process.

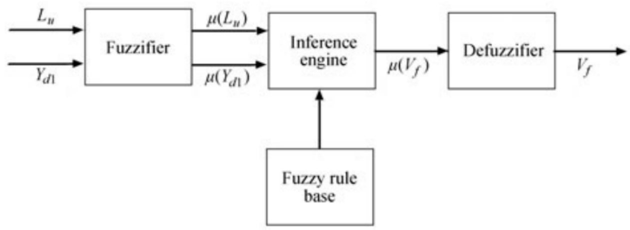


Figure 16: Fuzzy speed controller

From the Figure above, the speed controller has two inputs Y_{d1} and $L_{u,}$ which is the speed of the rear shaft. The fuzzy rules are illustrated in the following Figure:

1) IF Y_{d1} is S, THEN V_f is S;
2) IF Y_{d1} is M, THEN Y_f is M;
3) IF Y_{d1} is B AND L_u is not S, THEN V_f is B;
4) IF L_u is S AND Y_{d1} is B, THEN V_f is S;
5) IF L_u is M, THEN V_f is M.

Figure 17: Five rules for the fuzzy controller

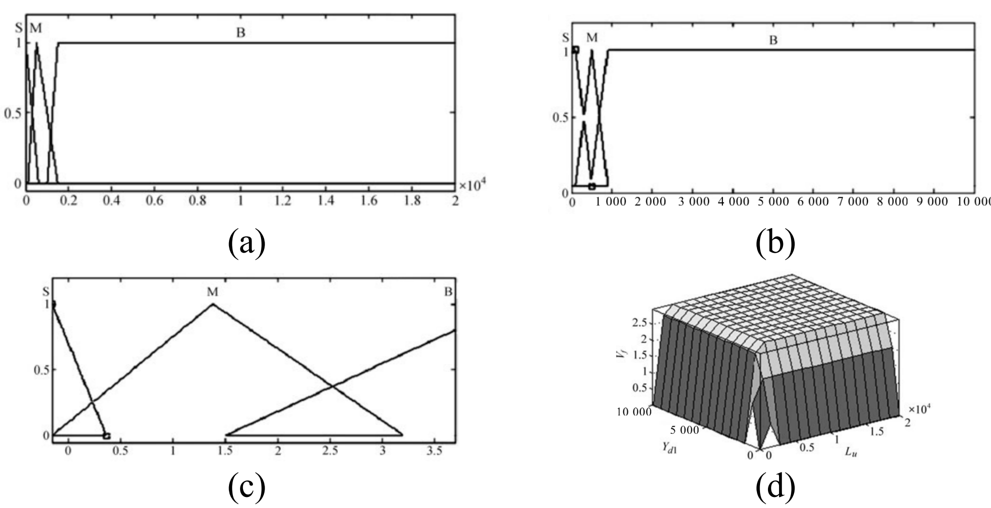


Figure 18: (a) Membership function (Lu) (b) Membership function (Yd1) (c) Membership function (V_f) (d) Input and output relation.

The main reason behind using the speed controller is to maintain a constant speed of three Km/h during the parking process and then reducing it to zero when the parking did successfully.

Besides the speed controller, the steering controller's role is significant in the parking process. For this reason, a fuzzy steering controller was introduced, and two inputs were used for the controller.

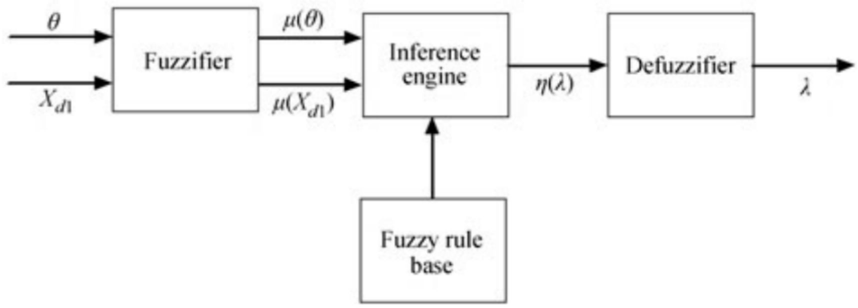
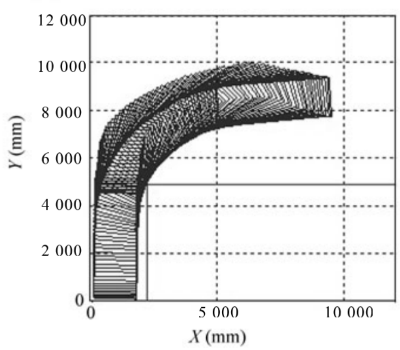


Figure 19: Fuzzy steering controller

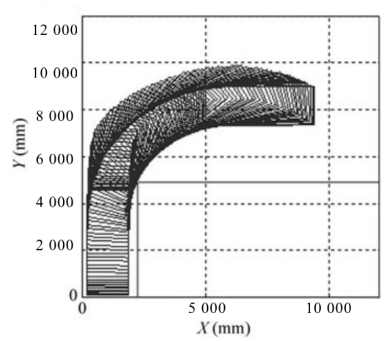
We can see that the output is the steering angle of the wheel, which was previously mentioned. The algorithm proposed to make use of θ, X_{d1}, and Y_{d1} in terms of the output angle is:

1. Smoothing the data for the distance center point of the front shaft and derive the function with time.
2. Taking the equation's derivative in (1), obtaining velocity and then smooth it, then find the velocity function with time.
3. Smooth the Yaw velocity.
4. Integrate the Yaw velocity function concerning time.
5. Smooth the steering angle of the wheel.
6. Calculate the coordinates using the equations mentioned above.

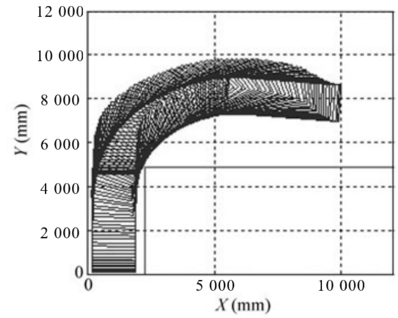
Matlab ANFIS toolbox was used to plot member functions. The simulations were performed using several initial conditions, and the trajectory of the vehicle can be shown below:



Initial orientation 5 deg.



Initial orientation 0 deg.



Initial orientation −5 deg.

Figure 20: The trajectory of the vehicle for different initial conditions

C. Speed Control of DC Motor

In (A. Adepoju, A. Adeyemi and S. Oni, 2014) work, to overcome the downsides of the old and classic methods of controlling DC motors, the Fuzzy control method was used. The fuzzy logic controller can be applied to nonlinear and complicated systems without knowing the mathematical system model. A model for DC motor and a fuzzy logic controller was designed, and Matlab Simulink was used.

Dc motors are prevalent types of motors, and they are used in wide applications because of their reliability, flexibility, and low cost compared to other types of motors. They are widely used in Manufactures and industrial plants. This type of motor can be controlled quickly and without complexity. For that reason, it is used in electric cranes, electric vehicles, robot manipulators, and many other electric devices in which the control of position and speed is interested.

PID controllers are used as a traditional way to control motor speed and position. This control method depends on simple multiplication, integration over time, and rate of change over time. PIDs' main disadvantages are they are susceptible to changes in motor parameters and load disturbances; besides, tuning the controller gains is an excruciating procedure.

To fill the gap and overcome the PID controllers' downsides. Fuzzy logic controllers can be used, and it can work correctly with systems with unknown inputs and variations in parameters.

Two methods can be used to control DC motors' speed. The first method is the armature voltage control, and the second method is the field flux control. The first method has the advantage of maximum torque capability and maintaining speed limits below the rating speed.

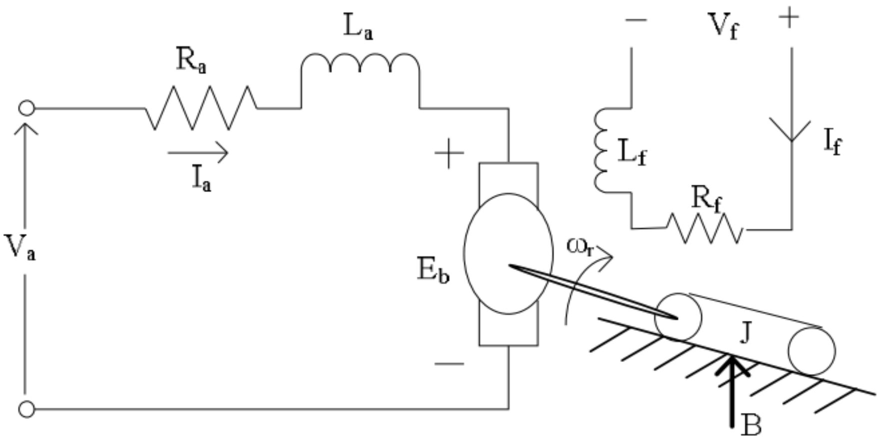


Figure 21: Separately excited DC motor

Figure 21 shows the structure used in this work. The armature reaction constraints are neglected in the description of the motor. The field voltage fixed, and the current justified to a constant value. The dynamic equations can be described as follows:

$$V_a(t) = E_b + I_a R_a + L_a \frac{dI_a}{dt} \qquad (16)$$

$$V_a(S) = I_a(S)R_a + L_a(S)I_a(S) + E_b(S) \qquad (17)$$

$$\frac{I_a(S)}{[V_a(S) - E_b(S)]} = \frac{1}{[R_a + L_a S]} \qquad (18)$$

$$V_a(t) = E_b + I_a R_a + L_a dI_a/dt \qquad (19)$$

Laplace transform of both sides:

$$V_a(S) = I_a(S)Ra + L_a S I_a(S) + E_b(S) \qquad (20)$$

$$I_a(S) / [V_a(S) - E_b(S)] = 1 / [R_a + L_a S] \qquad (21)$$

$$T_e(t) = J\ d\omega_r/dt + B\omega_r + T_L(t) \qquad (22)$$

$$T_e(S) = JS\omega_r(S) + B\omega_r(S) + T_L(S) \qquad (23)$$

$$\omega_r(S) / [T_e(S) - T_L(S)] = 1 / [JS + B] \qquad (24)$$

$$E_b = K_E * \omega_r \quad \text{and} \quad Te = K_T * \omega_r \qquad (25)$$

The table below shows the DC motor characteristics, and the equations of the system presented above were simulated using MATLAB/Simulink.

Parameter Name	Value
Armature resistance (Ra)	0.5Ω
Armature inductance (La)	0.02H
Rated Armature voltage (Va)	200V
Rotational inertia (Jm)	0.1Kg.m^2
Viscous friction (Bm)	0.008 N.m/rad/sec
Rated speed (ω_r)	1500 rpm
Motor torque constant	0.5N.m/A
Back emf constant (k)	1.25V/rad/sec
Table 1: DC MOTOR PARAMETERS	

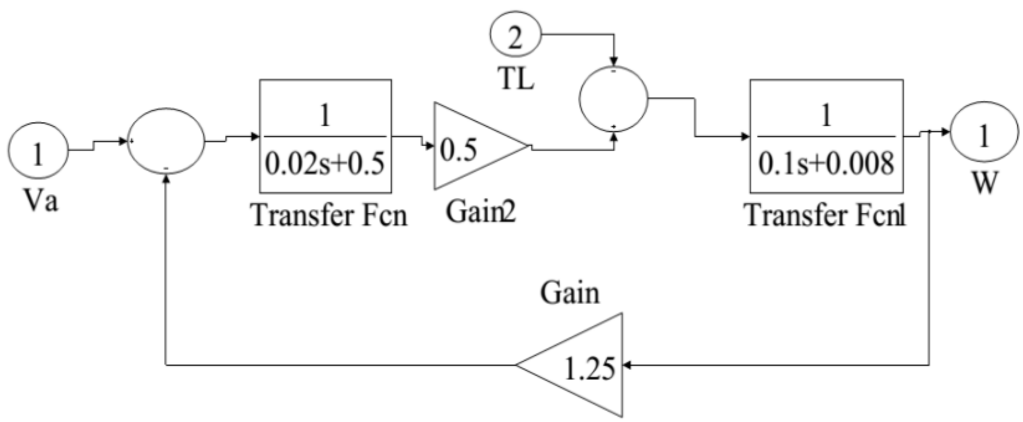


Figure 22: Separately excited DC motor

The fuzzy logic controller is mainly used to reduce the speed error because if the speed error is high, the input will be high. The speed error was calculated by comparing reference speed and the speed signal from the feedback. The inputs of the fuzzy controller are speed error and speed error changing.

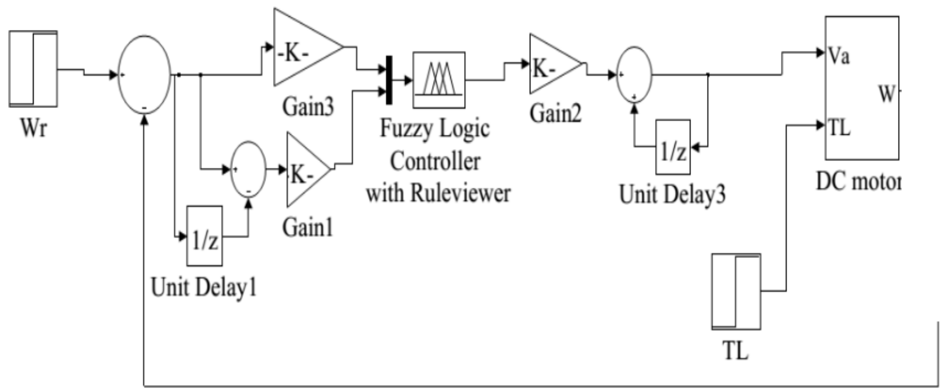


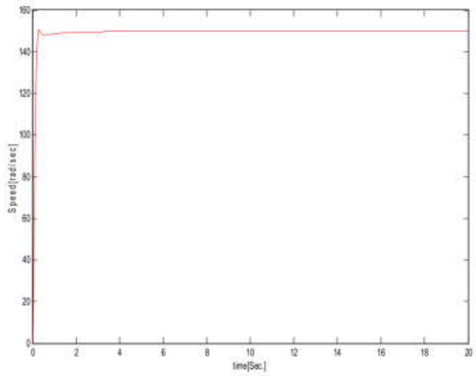
Figure 23: Separately excited DC motor with the fuzzy logic controller

E \ CE	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PL	PM	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

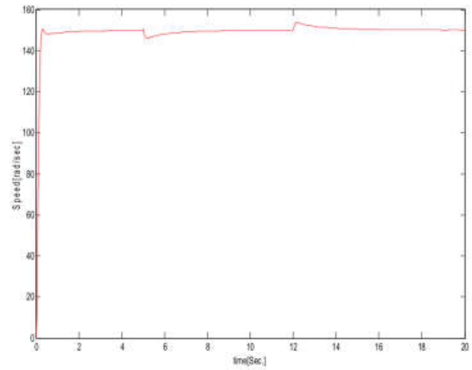
Figure 24: The rules Database

Four simulations were performed on the system shown in figure 23 without modifying the fuzzy logic controller. The first simulation is for the no-load test and the second one was for investigating the system's reaction to disturbances. The robustness of the proposed system was tested in the third and fourth simulations. The moment of Inertia and the armature resistance was considered (±50%), and the simulation time was twenty seconds.

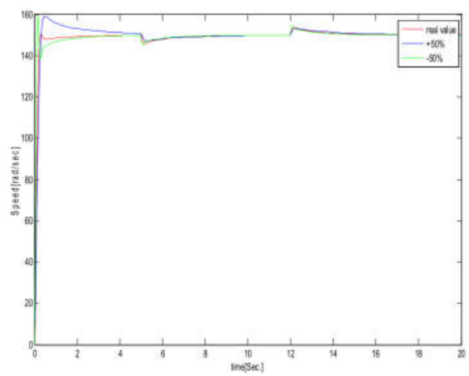
The results obtained can be shown in the following figures.



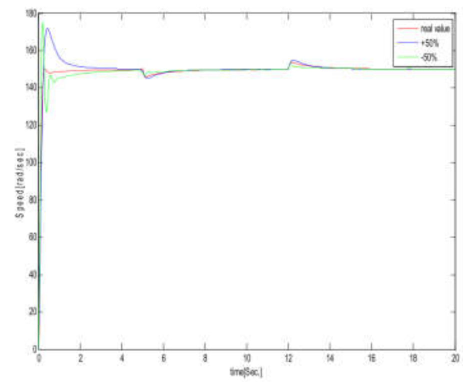
A) Angular speed - with no load



B) The angular speed - with load



C) The angular speed with change in the moment of Inertia (±50%)



D) The angular speed with change in armature resistance (±50%)

Figure 25: Simulation Results

Figure 25 (A) shows that the fuzzy logic controller has a good response in maintaining the goal trajectory without overshoot and minor steady-state error. (B) Show the system's response to disturbance of 5 N.m applied to the motor after the time reached 5 seconds and removed after 12 seconds. It is clear that with the fuzzy logic controller, the system's response was good, and the effect was minimal.

Figure 25 (C and D) shows that the increase and decrease of Inertia do not affect the system's performance.

D. Smart Fish Feeder

(Harani, Sadiah and Nurbasari, 2019) studied the design and implementation of a smart fish feeder using Arduino based on fuzzy logic control.

With this design, the fish owners and hobbies can feed the fish according to the standard doses and specified feeding frequency, and this makes the fish tank clean and tidy. Besides, overdose feeding will cause health issues to the fish and sometimes cause the fish pet's death. Collecting data was performed by interviewing the ornamental fish traders and literature studies.

For the database management system, Firebase was used, and for interpreting the system, the Laravel framework was used. This automatic fish feeding device was implemented using a microcontroller and android as a front end with the user or fish owner. The tasks are performed quickly, and it is calculated to be in milliseconds—the data collected from the sensors installed inside the aquarium.

This project's FLC will ensure that the system is well optimized by giving standard feeding doses by the water tank's temperature and turbidity sensing. The procedure of working can be summarized as follows:

1. The input of the controller will read the data from the sensors.
2. The fuzzification process will transform the input data into the fuzzy set.
3. The inference process will process the fuzzy set, which will be used as a basis of decision making.

Figure 26 shows the system's main components and shows that the system's input is the temperature sensor's data and the turbidity. It can also work when the user sends the signal to the system using the android platform. The Arduino Uno board collects data from the input, and then the output of this board will be fed to the wireless module esp8266.

Once the signal is received, the servo motor will be activated to dispense the food into the fish tank.

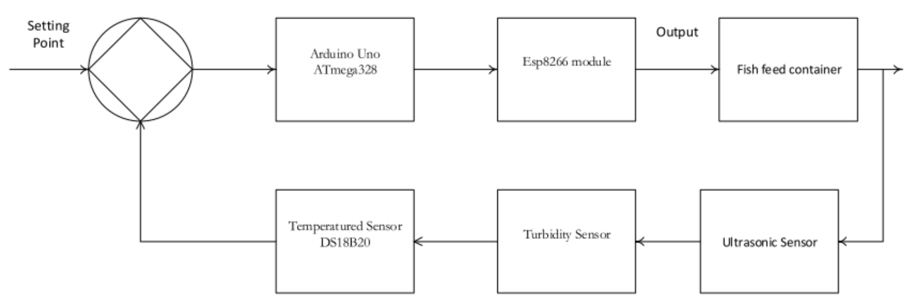


Figure 26: The system Block diagram.

With the Fuzzy recipe, Temperature and turbidity rates will be calculated and set to obtain an automatic feeding process for the fish in the fish tank. The diagram for the whole system is shown below.

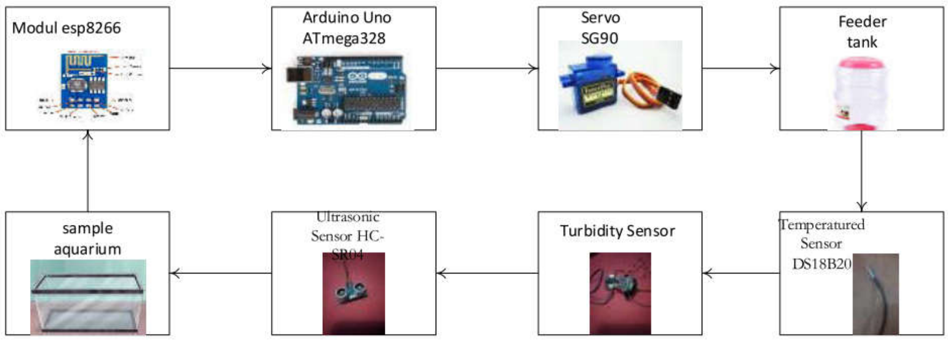


Figure 27: The Hardware used in the system.

The Flowchart shown below is the workflow of the system. The user can set the feeding timing when it is activated manually on the screen. When the manual feeding is OFF, the fuzzy logic controller will be executed, and the defuzzification will take place by calculating the interval of feeding the fish.

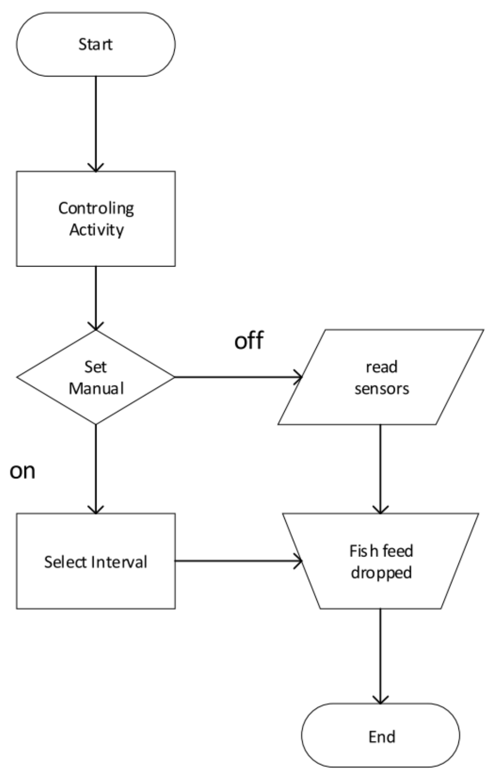
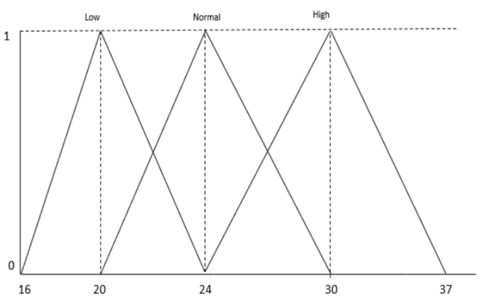


Figure 28: The Flowchart of the system

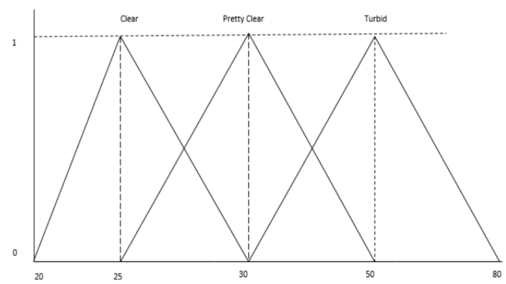
The system's results were calculated by setting the Temperature as 20 °C, and 26% of turbidity is used as inputs. The Fuzzy set input variables are, for Temperature (Low, Normal, High) in which 0 to 20 will be considered Low, Medium is 20 to 30, and so on.

For the turbidity, the variables are, Clear, Pretty clear, and turbid.

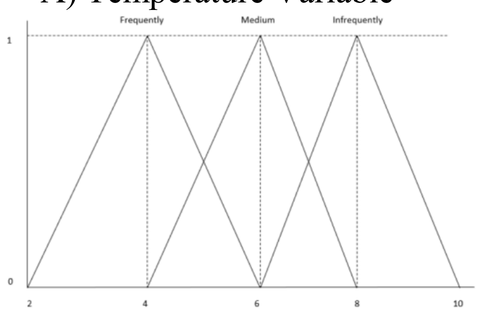
The temperature variable X, Turbidity variable Y, and the output variable Z are shown below:



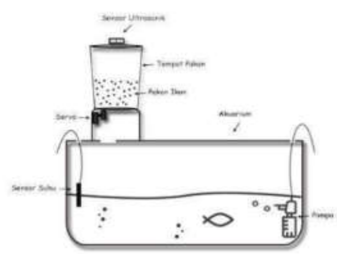
A) Temperature Variable



B) Turbidity Variable



C) Output Variable



D) Smart Fish Feeder

Figure 29: Variable Functions and Smart feeder system.

Nine rules were developed, and all the variables were used in the rules.

[R1] = IF LOW Temperature and Turbidity CLEAR THEN Medium feeding duration
[R2] = IF LOW Temperature and Turbidity PRETTY CLEAR THEN Long feeding duration
[R3] = IF LOW Temperature and Turbidity TURBID THEN Long feeding duration
[R4] = IF NORMAL Temperature and Turbidity CLEAR THEN Often feeding duration
[R5] = IF NORMAL Temperature and Turbidity PRETTY CLEAR THEN Medium feeding duration
[R6] = IF NORMAL Temperature and Turbidity TURBID THEN Long feeding duration
[R7] = IF HIGH TEMPERATURE and Turbidity CLEAR THEN Often feeding duration
[R8] = IF HIGH TEMPERATURE and Turbidity PRETTY CLEARITY THEN Often feeding duration
[R9] = IF HIGH TEMPERATURE and Turbidity TURBID THEN Medium feeding duration

From the input variables above, the calculation score of the fish feeding duration using FLC is 3.25. The results were obtained by testing the system by switching between manual and automatic modes, then the system's response was recorded. The results were obtained by testing the system for ten weeks and then recording the data. The most prolonged period of working was in week 10th, and the system worked for 27360 seconds. The shortest period was in the first and second weeks; the system worked for 14400 seconds.

6- Conclusions

In (Meshram, 2013), the author tried to use several equations and behaviors for designing the Fuzzy controller, but it was better for him to show more effort in showing up his results. It is not clear under what idea or criterion he used this set of equations, and for what reason, he selected random motion for the robots? He did not even explain why he did not select the other behaviors presented in Figure 12. Moreover, the paper contains many syntax and spelling issues.

In (Wang et al., 2011), the author proposed an excellent knowledge concerning autonomous parking and parking strategies. The weak points are (1) The technique was made by assuming that the wheel constraints do not affect the system dynamics, making it ideal and not applicable for applying it in the real world. (2) No technique was presented for parking spot detection.

This work (A. Adepoju, A. Adeyemi and S. Oni, 2014) shows an exemplary method for using the fuzzy Logic to control motors' speed and minimize the speed error. The robustness of the system shows the performance of the system against the disturbances and variations in parameters. However, the paper contains several mistakes in formatting the paragraphs and images, and even the author mentioned incorrect figure numbers in the last paragraph. Nevertheless, overall the paper can be considered just enough.

In (Harani, Sadiah and Nurbasari, 2019), the system is an excellent system for fish owners to perform feeding automatically without human interaction. The system uses FLC to predict and calculate the feeding sessions to overcome the fish feeding process's overdose problem. This system is used to ensure that the tank is not getting dirty and the fish will remain safe from illness that might cause by the problems mentioned above. The author mentioned that the Arduino is not suitable for performing the fish feeding task because of memory limitation. Moreover, delays in internet connection cause some issues in communicating with the server and the system on the other side. For future work, one should perform the same task using a different MCU type and then compare the results with this work to decide which one is better for this Automatic feeding process.

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