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AN IMPROVED OF DUAL SINGLE INPUT FUZZY LOGIC CONTROLLER FOR UNDERWATER REMOTELY OPERATED VEHICLE (ROV) – DEPTH CONTROL

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ABSTRACT

This paper presents an improvement of Dual Single Input Fuzzy Logic Controller (DSIFLC) of an underwater Remotely Operated Vehicle (ROV) system for depth control. Proportional Integral Derivative (PID) controller are used as the basic controller and compared with the SIFLC controller. The technique used is the conventional Fuzzy Logic Controller simplified to Single Input Fuzzy Logic Controller (SIFLC) by using signed distance method. The SIFLC were upgraded to DSIFLC by using double feedback of disturbance. The controller was upgraded until the system response shows the satisfied result in terms of rise time and percentage of overshoot. This method was verified and validated in MATLAB/Simulink platform. The result shows it was found the proposed method have better performances analysis of the system response which is faster rise time and lower percentage of overshoot.

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Keywords: dual single input fuzzy logic controller; remotely operated vehicle; depth control.

1. INTRODUCTION

Automated Underwater Vehicle (AUV) is basically an extension of the Underwater Remotely Operated Vehicle (ROV) technology. The ROV is manually controlled by human and needs steering control from the station ship on the surface, whereas the AUV is controlled by its on-board controller guided by built-in pre-programmed instructions free from a chain. The first AUV was developed by Stan Murphy, Bob Francois and later on, Terry Ewart at the Applied Physics Laboratory, University of Washington. AUV development began in the 1960s at the University of Washington and made very large leaps in the early 1990s with the backing of Massachusetts Institute of Technology (MIT) and the Office of Naval Research (ONR) [1].

Recently, the interest in the underwater vehicle has been increasing. Depth control is necessary to exploit the full operation of the vehicle, and plays an important role. Various methods have been applied to control the dynamics of the underwater vehicle. Modern control approaches like PID and fuzzy logic have been proposed as they present high degree of robustness and resistance to disturbance [2]. In designing a controller for underwater vehicle, the difficulty lies in obtaining an accurate mathematical model of the vehicle as it is highly non-linear. Secondly, it is extremely difficult to find all hydrodynamic parameters affecting the underwater vehicle dynamics with reasonable accuracy.

Control technique in small and low-cost mechanism for large thrust when try to run the same depth to consume a lot of energy, a variety of hypotheses about the vertical control submarine seems suspicious. The model of controller to control the underwater Remotely Operated Vehicle (ROV) depth control system such as Proportional Integral Differential (PID) controller, conventional Mamdani Fuzzy Logic Controller (M-FIS), Adaptive Neural Fuzzy Inference System (ANFIS) controller, Single Input Fuzzy Logic Controller (SIFLC) or Dual Single Input Fuzzy Logic Controller (DSIFLC) able to control the depth [3].

Remotely underwater vehicle (ROV) was developed by Technology Research Group (UTeRG) as shown in Figure 1. The issue rise is the stability depth control system. The ROV was designed and will be tested in an open-loop system for the output-input signal is measured. Input and output signals of the system are recorded and analyzed to deduce the model as shown in Figure 2. Then the MATLAB System Identification Toolbox is used to generate the ROV model. The model obtained is used to design the appropriate controller for depth control [4]. The focus is to control the depth of the ROV remains stationary at the desired depth with a feedback pressure sensor. A simulation study was conducted to obtain the ROV controller. This method is particularly useful for the ROV model for designing the best basis for the depth control. Conventional controllers will be used to validate the model and give presentations ROV acceptable system response.

The Single Input Fuzzy Logic Controller (SIFLC) was proposed by [5] which is the researcher introduce new parameter in fuzzy logic controller by using signed distance method. It was simplified the membership function according to Lyapunov Popov criterion structure model. The total number of rule greatly reduced compared to existing fuzzy logic controller. The SIFLC have been adding to new study and many researchers attend to apply it application. For example, in [6] have apply it to underwater vehicle system and found a way to tune the SIFLC. In addition, the control performance is nearly the same as that existing fuzzy logic controller which is revealed via computer simulations using two linear plants.

This paper presents model of controller to control the underwater Remotely Operated Vehicle (ROV) depth control system. The ROV is controlled externally by Proportional Integral Differential (PID) controller, conventional Mamdani Fuzzy Logic Controller (M-FIS), Adaptive Neural Fuzzy Inference System (ANFIS) controller and Single Input Fuzzy Logic Controller (SIFLC). The various controllers is design to gain comparison and improvement of controlling the depth control system, especially to minimize the overshoot and steady-state error.

Fig.1. Prototype of ROV

Since to retrieved the model of underwater ROV using mathematical modelling is almost impossible because cannot find all dynamic parameter effected on the ROV. The other method to generate the model of underwater ROV is by using MATLAB System Identification Toolbox's. In order to generate the model of underwater ROV, an open loop experiment was setup. The underwater ROV was tested in open loop experiment which done in tank as shown in Figure 2.

Fig.2. ROV tested in the tank

2. CONTROLLER MODEL

Controller Design (CD) use the concept of bionics ideas for reference, it was based on emulating intelligent phenomenon in nature. CD endeavors to recreate and return the characters of intelligent with the goal that it can be another new research domain in nature and engineering reconstructing [7]. Controller design using the MATLAB software such as PID, fuzzy logic controller and neural network are used. The controller uses in controlling the underwater ROV are stated next section.

Various methods have been applied to control the dynamics of the underwater vehicle. Recently, modern control approaches like PID and fuzzy logic have been proposed as they present high degree of robustness and resistance to disturbance. In designing a controller for underwater vehicle, the difficulty lies in obtaining an accurate mathematical model of the vehicle as it is highly non-linear. Secondly, it is extremely difficult to find all hydrodynamic parameters affecting the underwater vehicle dynamics with reasonable accuracy. The environmental disturbances may also arise [8].

2.1. Proportional Integrated Differential (PID) Controller

PID is an aerodyne for the mathematical terms of proportional, integral and derivative. The controller used to improve the dynamic response, which is to reduce the steady state error. The derivative gives a finite zero to an open loop plant and improve the transient response, while the integral adds a pole at the origin to increasing system type by one thus eliminate the steady state error due to step function to zero [9]. Figure 3 shows the model of PID controller.

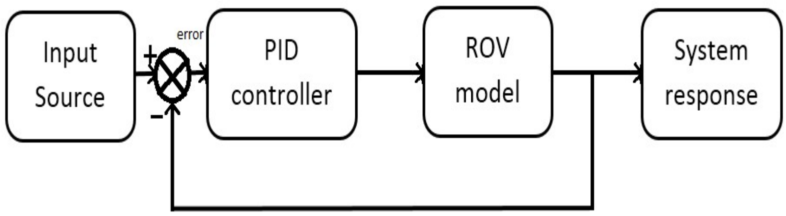


Fig.3. Block diagram of PID controller

The process of selecting the controller parameters to meet given performance specifications is called PID tuning. Most PID controllers are adjusted on-site, many different types of tuning rules have been proposed by other researchers. Using those tuning rules, delicate & fine tuning of PID controllers can be made on-site. Also, automatic tuning methods have been developed and some of the PID controllers may possess on-line automatic tuning capabilities. The MATLAB/Simulink of the PID controller for ROV-depth control as shown in Figure 4.

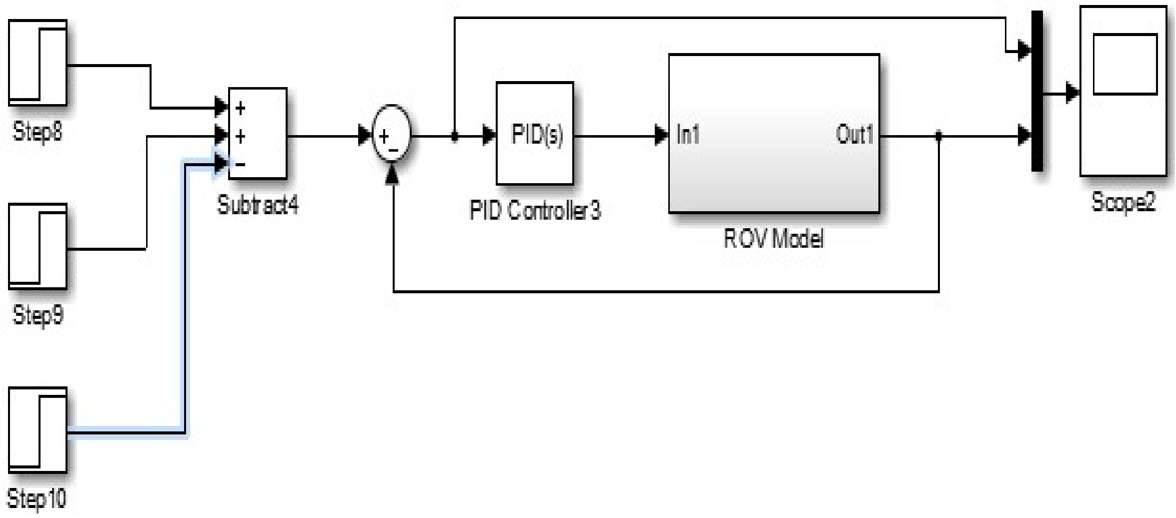


Fig.4. MATLAB Simulink block of PID controller

The PID controller set up as a close loop controller and tune by using auto tune in the MATLAB Simulink PID block. It can be tune either to have faster rise time or slower rise time. But there are directly proportional with the percentage of overshoot which is if the rise time is fast, then the percentage of overshoot also high or if the rise time is slower, and then the percentage of overshoot will become lower. Figure 5 shows the auto tuning in MATLAB Simulink PID block.

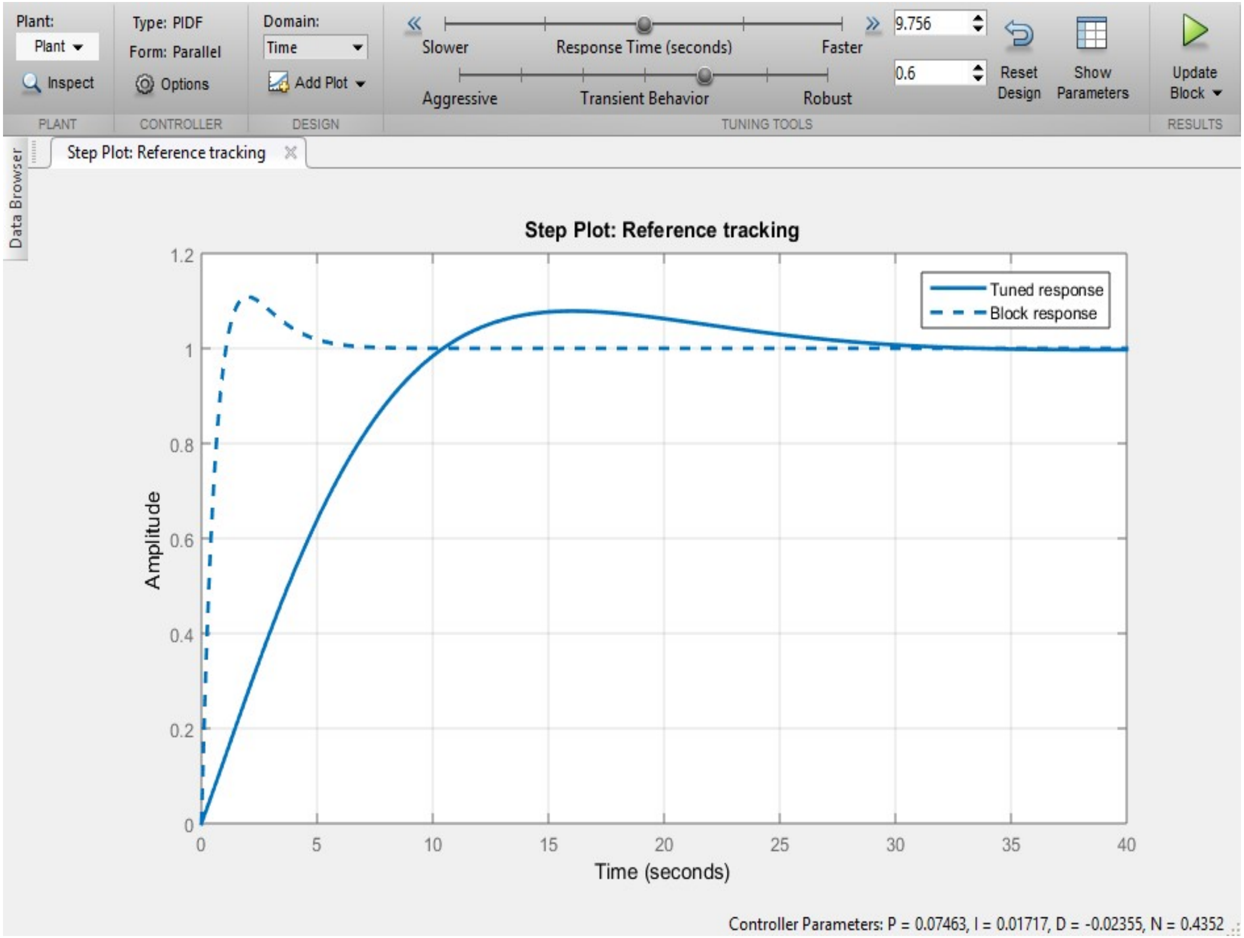


Fig.5. Auto tuning in MATLAB Simulink PID block

2.2. Mamdani Fuzzy Logic Controller (M-FLC)

Conventional controller requires mathematical model of physical system. Interestingly, Fuzzy Logic Controller (FLC) does not require a numerical model of the system and fuzzy logic can manage the vulnerability of human intelligence. In FLC modelling, designer needs just to build up phonetically how the control output ought to differ with the input and set up the variable range of the different fuzzy set. The way of these two techniques is a general approximator and they have the capacity of non-linear model.

The Mamdani fuzzy logic controller consist of a fuzzifier, rule base, fuzzy inference engine and de-fuzzifier were employed. In this paper, multiple input single output (MISO) type of controller designed and use in formulation of control law [10]. The fuzzy logic controller was designed in order to control the depth of an underwater ROV.

The FLC was designed using multiple inputs single output (MISO) type of FLC, which was included two inputs and one output. Each input and output set by 5x5 membership functions (MF) and the rule table of fuzzification set as default rule. Figure 6 shows the MATLAB Fuzzy platform use to design the FLC.

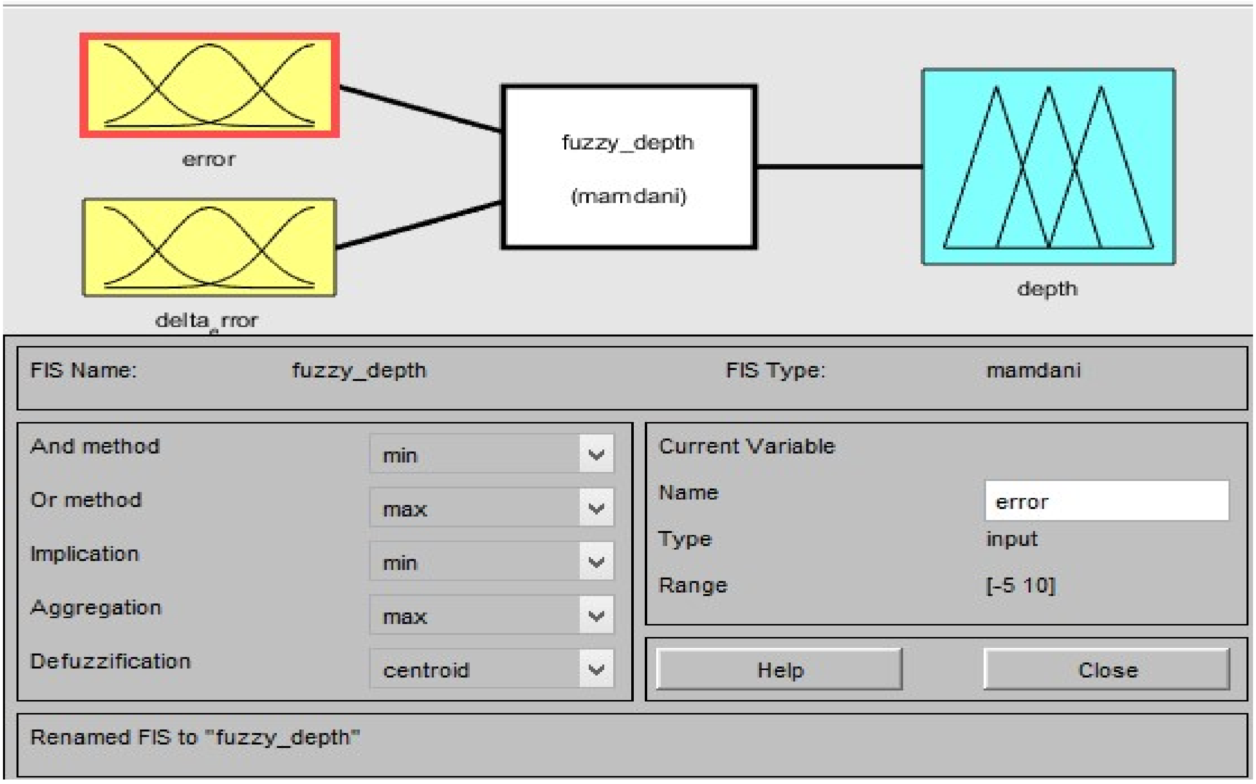


Fig.6. MATLAB fuzzy platform

The membership function was labelled with negative large (NL), Negative (N), Zero (Z), Positive (P) and Positive Large (PL) which have relationship for each other. The Rule table was set by default rule which assuming the value of NL, N, Z, P and PL in the first input was same with the second input. Figure 7 shows the default set of rule table in the FLC.

$\dot{e}$ \ e	NL	N	Z	P	PL
PL	Z	P	PL	PL	PL
P	N	Z	P	PL	PL
Z	NL	N	Z	P	PL
N	NL	NL	N	Z	P
NL	NL	NL	NL	N	Z

Fig.7. Default set of Rule Table

A FLC controller were design with the parameter in fuzzification set up includes the input and output membership function, scale and the rule table. The set of FLC was sent to workspace in order to validate the controller. A simulation of underwater ROV controlling by the FLC were set up [11]. The derivative block added to make FLC as the hybrid Fuzzy. The MATLAB Simulink block as shown in Figure 8.

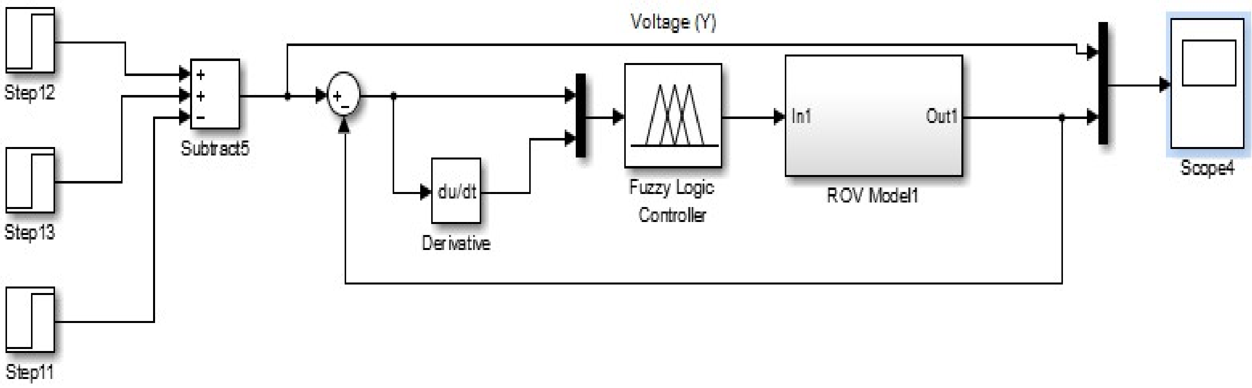
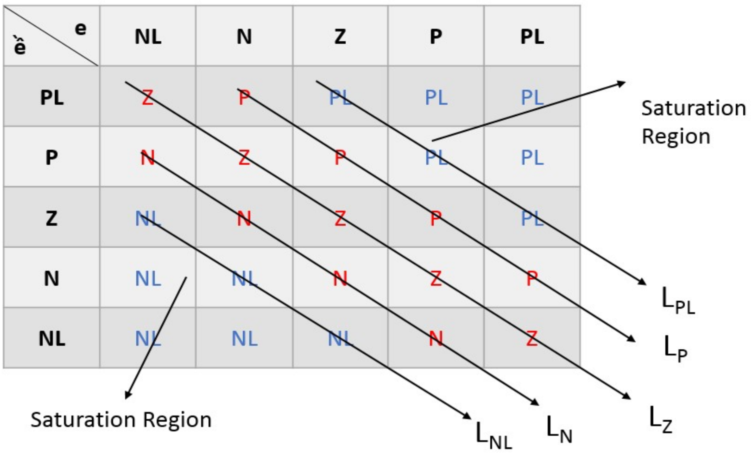


Fig.8. MATLAB Simulink block of Hybrid Fuzzy controller

2.3. Single Input Fuzzy Logic Controller (SIFLC)

The Single Input Fuzzy Logic Controller (SIFLC) was first introduced by [5] propose a simplified method in fuzzy logic controller by using "signed distance" method that reduced the rule and membership function. There are formulae proposed in using this method as shown in Equation (1).

$$d = \frac{\dot{e} + \lambda e}{\sqrt{1+\lambda^2}} \tag{1}$$



è \ e	NL	N	Z	P	PL
PL	Z	P	PL	PL	PL
P	N	Z	P	PL	PL
Z	NL	N	Z	P	PL
N	NL	NL	N	Z	P
NL	NL	NL	NL	N	Z

Fig.9. Rule table with TOEPLITZ structure

Fuzzy Logic controller (FLC) is a controller that linguistic-based controller that tries to emulate the way human thinking in solving a particular problem by means of rule inferences. Basically, a fuzzy logic controller has two controlled inputs, namely error (e) and the change of error (è). Its rule table can be created on a two-dimensional space of the phase-plane (e, è) as shown in Figure 6. It is common for the rule table to get the same output membership in a diagonal direction. Additionally, each point on the particular diagonal lines has a magnitude that is proportional to the distance from its main diagonal line LZ. This is known as the Toeplitz structure. The Toeplitz property is true for all FLC types, which use the error and its derivative terms namely e, è and $e^{(n-1)}$ as input variables [12].

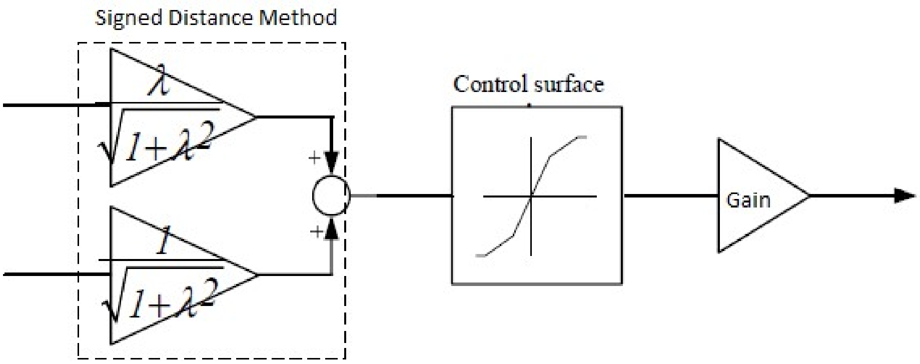


Fig.10. SIFLC control structure

Base on Equation (1), the value of straight line given and form in the look-up table. Basically, the SIFLC only have an equation of simplified fuzzy but there are added gain to control the feedback of error. The MATLAB/Simulink of the SIFLC for ROV depth control as shown in the Figure 11.

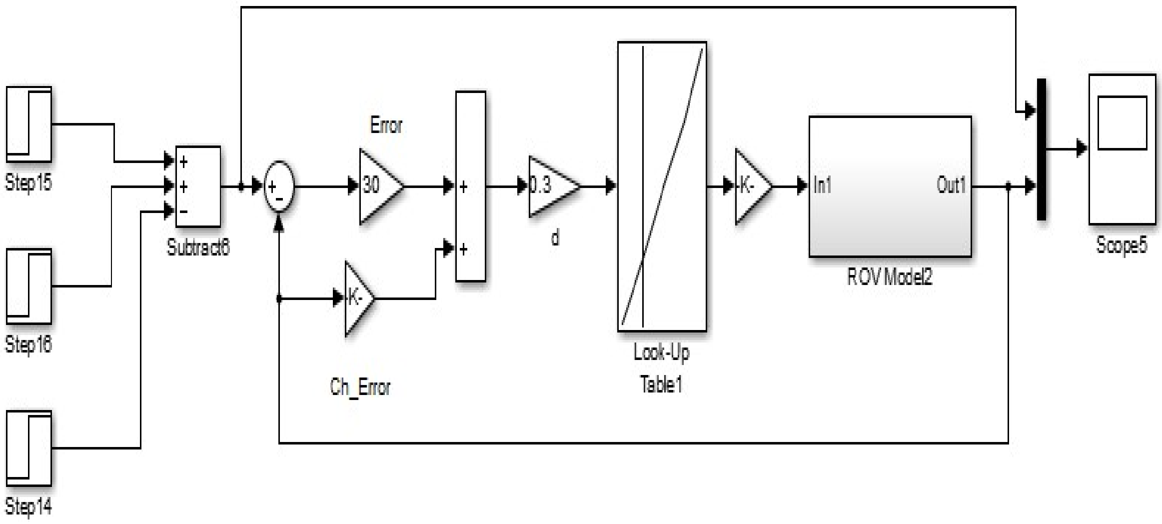


Fig.11. MATLAB Simulink block of SIFLC

2.4. Dual Single Input Fuzzy Logic Controller (DSIFLC)

An underwater ROV usually have two thrusters to control the depth level. In the previous controller designed to control the depth by apply same voltage to both thrusters which mean one controller to control two thrusters [13]. The dynamic disturbance may occur differently on both sides of thrusters. Due to this situation, each thruster has to controller separately in order to better feedback response for difference disturbance effect on both sides. The controller for each thruster will be control by hub-controller to have same desired depth level. The illustrated model of underwater ROV as shown in Figure 12.

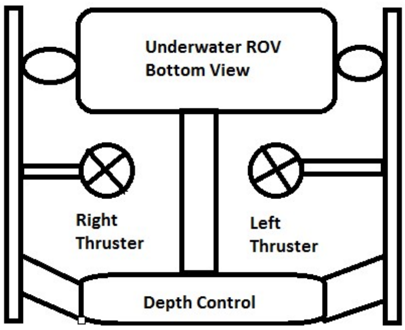


Fig.12. Underwater ROV with two thrusters for depth control

The DSIFLC control the thrusters by separately. Each of the thrusters has their own controller itself. The idea of controlling both thrusters separately is because the performance of each thruster was not same and the environmental disturbances for both side not equivalent [14]. So, the DSIFLC separate the feedback of the controller for both thrusters to gain more efficiency and faster response. Both controllers for both thrusters were optimizing in the hub-controller to have the same desired depth level. The MATLAB/Simulink of the DSIFLC for ROV depth control as shown in Figure 13.

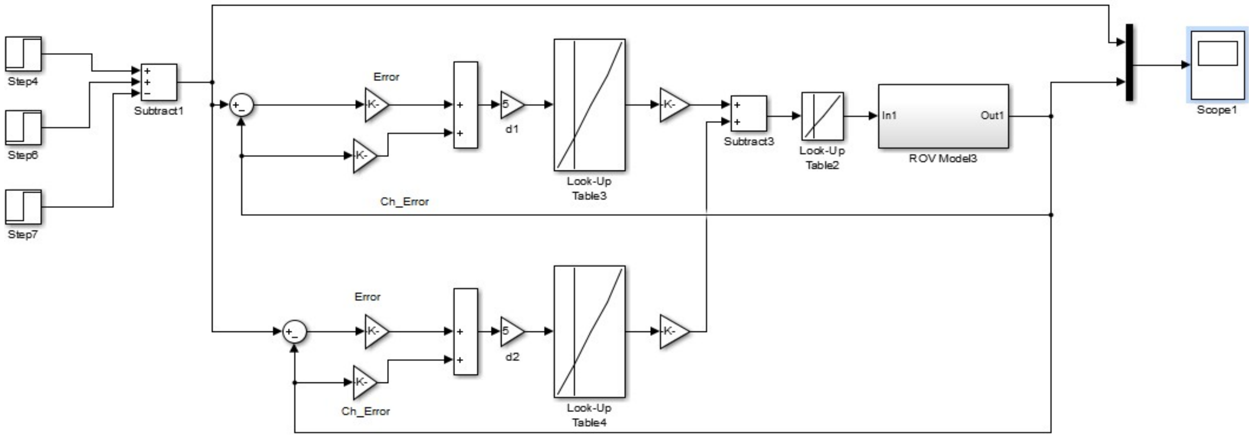


Fig.13. MATLAB Simulink block of DSIFLC

3. RESULTS AND DISCUSSION

The PID controller was designed as the reference controller in order to design the FLC in achieves better response than the PID controller in term of rise time and percentage of overshoot. There are several upgraded of FLC started with the SIFLC controller designed based on “Signed distance” method and the DSIFLC using double feedback controller method with hub-controller. The upgraded of FLC is because the conventional FLC does not shown the satisfied output response than the PID controller.

The PID controller able to have lower percentage of overshoot but also slower in rise time by tuning in the auto tune function in the PID Simulink block. It can be faster rise time but the percentage of overshoot also increase along with the rise time. By choosing the faster rise time as the reference controller model even there were high percentage of overshoot because the objective of designing the FLC and upgraded FLC is to eliminate the percentage of overshoot. The system response of the PID controller as shown in Figure 14.

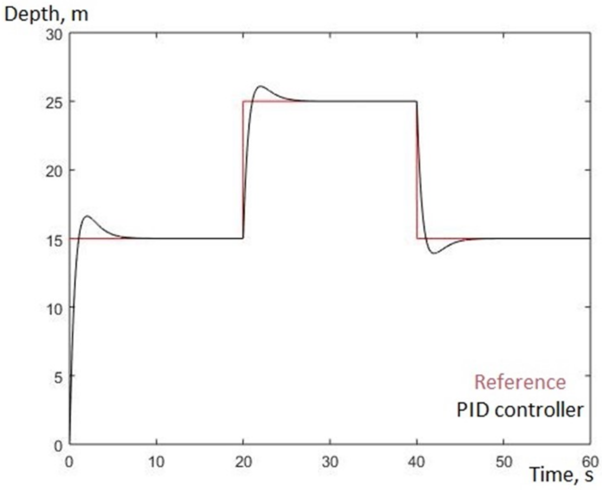


Fig.14. PID controller system response

The conventional FLC were designed as the comparative of performance with the PID controller. The Mamdani type of FLC with two input and single output. The tuning process of the FLC was by tune the scale of membership function at the output first then the input. The tension of the membership function also can be tune to eliminate the oscillation in the system response. As the result of FLC, the FLC does not show the satisfied response than the PID controller. The FLC have none of percentage of overshoot but the rise time slower than the PID controller. The system response of PID controller against the FLC as shown in Figure 15.

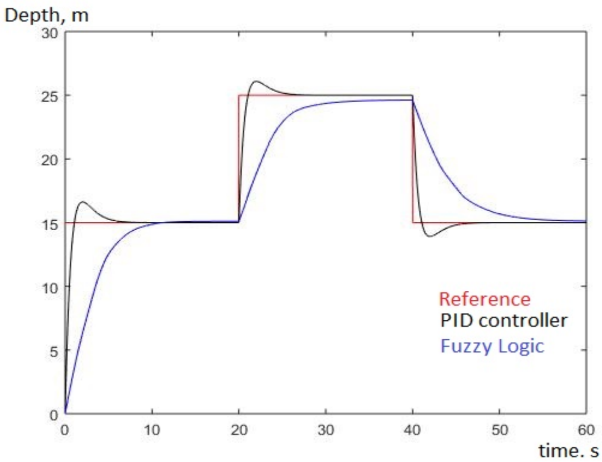


Fig.15. System response of PID controller against FLC

Since the conventional FLC does not give satisfied response, the FLC were simplified to SIFLC using “Signed Distance” method in order to upgrade the FLC. From the fuzzification and rule table function to straight line function which form in the loop-up table. As the result of upgraded FLC to SIFLC, the rise time of the SIFLC few milliseconds lagging than the PID controller but SIFLC minimize the percentage of overshoot. The system response of the PID controller against SIFLC as shown in Figure 16.

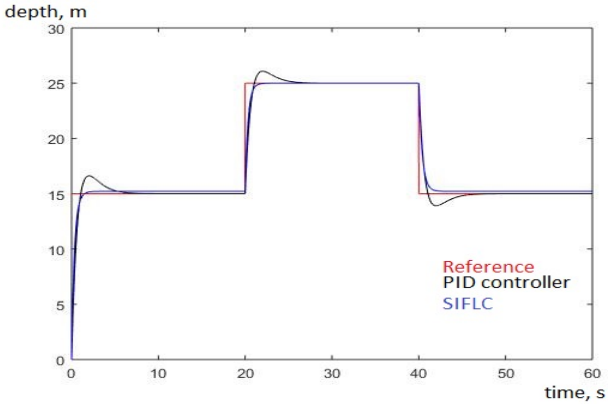


Fig.16. System response of PID controller against SIFLC

The DSIFLC were designed based on the idea of separated controller for each side of thruster for depth level control. By controlling each thruster separately, the controller able to adapt if the difference disturbance occurs for each side of thruster. Each thruster can give fast response to disturbance and high accuracy to dive in desired depth level. As soon the disturbance rejecting controller apply to the controller model will help minimize the dynamic disturbance effect on the underwater ROV model. As the result, the DSIFLC able to give faster response in term of faster rise time without percentage of overshoot. By comparing the response of DSIFLC with PID controller, the DSIFLC were almost perfect controller to control this underwater ROV model. The system response of PID controller against DISFLC as shown in Figure 17.

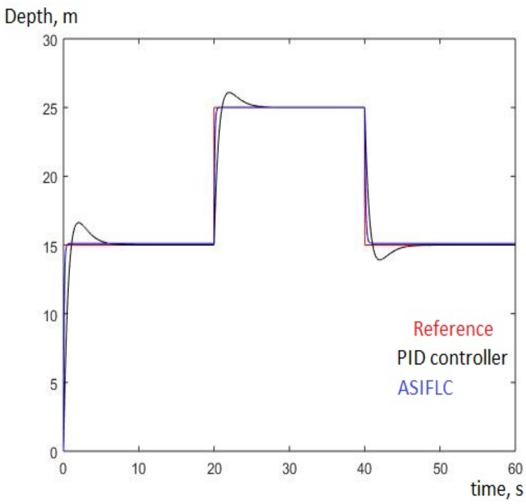


Fig.17. System response of PID controller against DSIFLC

Table 1. Performance parameters of each controller

Controller	Rise Time (ms)	Percentage of Overshoot (%)	Settling Time (s)
PID	251.74	7.6	1.98
FLC	4939	0	9.56
SIFLC	706.93	0	2.35
DSIFLC	210.97	0	0.94

4. CONCLUSION

Controllers design for controlling the underwater remotely operated vehicle (ROV) depth control system in order to improve the overshoot, steady state error and rise time in system response. The PID controller design as reference of the contribution work in order to make an improvement in system response than the PID controller. Firstly, the FLC were compared to PID controller but the FLC did not shows the satisfied response than the PID controller. The FLC were upgraded to SIFLC by using “signed distance” method. The system response of SIFLC has almost faster as PID Controller without percentage of overshoot. But, in close view, the SIFLC still lagging in rise time than PID controller. Then, the SILFC were upgraded to DSIFLC using double feedback control structure method. The system response of DSIFLC were almost perfect than the PID controller which was it have the fastest rise time without percentage of overshoot.

The performance of the controllers has been recorded and analyses. The PID controller able to control the model but there were high percentage of overshoot. The DSIFLC controller able to gain better performance than PID controller in term of percentage of overshoot. The future works to improve the ANFIS controller performance in term of rise time by designing hybrid algorithm to have higher or equal to SIFLC controller performance. This research will also drive to the development of an underwater ROV technology in Malaysia.

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