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Research paper

Comparison of Controllers Design Performance for Underwater Remotely Operated Vehicle (ROV) Depth Control

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Abstract

This paper presented controller designs utilized in controlling the ROV depth control system which involved Single Input Fuzzy Logic Controller (SIFLC), Adaptive Neural Fuzzy Inference System (ANFIS), Mamdani Fuzzy Logic Controller (M-FLC) and Proportional Integrated Differential (PID) controller. The model of ROV was generate using MATLAB System Identification Toolbox's to gain a transfer function representing the ROV model. This ROV design focused on depth control. The main objective of this study was to analyze the performance of system response among the Controller designs. This controller was verified and validated in MATLAB/Simulink platform. The result showed the analysis performances of the system response in terms of rise time and percentage of overshoot.

Keywords: *Single input fuzzy logic controller; adaptive neural fuzzy inference system; Mamdani fuzzy logic controller; remotely operated vehicle; depth control.*

1. Introduction

Nowadays, the world research is expanding to underwater environment and human being have limited ability to explore in the underwater setting. Hence, underwater vehicles have been developed to overcome the limitation. Underwater vehicles such as remotely underwater vehicle (ROV) and unmanned underwater vehicle (UUV) have been designed. Few studies on underwater vehicle performances for depth control stability have been reported. For instance, depth control feasibility studies in Peninsular Malaysia [1-3].

Remotely underwater vehicle (ROV) has been developed by Technology Research Group (UTeRG). The arising issue is the stability of depth control system. The ROV is designed and will be tested in an open-loop system in which the output-input signals are measured. Input and output signals of the system are recorded and analyzed to deduce the model. 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. The focus is to control the depth of the ROV so that it will remain stationary at the desired depth with pressure sensor feedback. A simulation study has been conducted to obtain the ROV controller. This method is particularly useful for the ROV model in designing the best basis for the depth control. Conventional controllers will be used to validate the model and give comparison of ROV in system response. In 1992, Bezdek developed an idea of Computational Intelligence (CI). Since then, CI has attracted much attention among researcher rising and put as another field of study. Computational Intelligence uses the concept of bionic ideas for reference, which is based on emulating intelligent phenomenon in nature. CI endeavors to recreate and return the characters of intelligence aiming to be a new research domain in nature and engineering reconstruction. The quintessence of CI is an all-inclusive approximation, and it has the considerable capacity of non-linear mapping and optimization. Further study on hybrid algorithms in CI has been the more interested. It is ending up plainly to peruse around an application that utilization simply neural network, or developmental calculation, or fuzzy logic. There are numerous potential outcomes for joining the technique [4]. In vast measure, fuzzy logic, neuro network and probabilistic thinking are reciprocal, not competitive. It is winding up clearly that by and large it is profitable to join them. A valid example is developing number of "neuro-fuzzy" purchaser items and systems that utilize a mix of fuzzy logic and neural-network techniques [5].

System Modeling, in view of conventional method (e.g., differential equation), is not appropriate for managing as well not characterized and unstable systems. Fuzzy inference system (FIS) utilizes fuzzy if-then principles which can show the subjective parts of human information and thinking forms without utilizing exact quantitative investigation. Therefore, there are some fundamental parts of FIS which need better understanding. All the more particularly: 1) No standard strategies exist for changing human information or experience into the control base and database of a fuzzy inference system. 2) There is a requirement for viable strategies for tuning the membership function (MF's) in order to limit the yield mistake measure or maximize execution record [6].

The Single Input Fuzzy Logic Controller (SIFLC) has been proposed by [7] in which new parameter in fuzzy logic controller is introduced using signed distance method. It was simplified the membership function according to Lyapunov Popov criterion structure model. The total number of rules are greatly reduced compared with existing fuzzy logic controllers. The SIFLC have been adding to new study and many researchers attend to apply it application. For example, in [8] has applied it to underwater vehicle system and found a way to tune the SIFLC. In addition, the control performance is nearly the same as existing fuzzy logic controller which is revealed through computer simulations using two linear plants.

Recently, interests in the underwater vehicle have been increasing. Depth control is necessary to exploit the full operation of the vehicles and plays an important role. ROV can save lives than the conventional methods can be conduct research or to perform work requiring diving underwater people. Underwater vehicle is mean by the very high order of nonlinear modelling uncertainties are difficult system to measure. Linearized about these point operations since there is no clear model can be applied to linear control is almost impossible. Depth control is a significant problem for underwater robotic systems. Hence, adjusting the depth of water is crucial to operate the entire vehicle. To overcome problem related to depth adjustment, sea water ballast tanks (the MBT, DCT) or pressurized air to change the buoyancy. In small remote operated vehicle (ROV) Depth control can often get the help of thrust. 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 objective was to design an adaptive controller for an underwater Remotely Operated Vehicle (ROV) using single Input Fuzzy Logic Controller (SIFLC) technique. It also improves performance of depth control for an underwater Remotely Operated Vehicle (ROV) system. Besides, another objective was to compare system responses among single input fuzzy logic controller (SIFLC), Adaptive Neural Fuzzy Logic Controller (ANFIS), Fuzzy Logic Controller for an underwater Remotely Operated Vehicle (ROV) depth control system using system identification.

An underwater Remotely Operated Vehicle (ROV) is a submarine like robotic device which is controlled by onboard computer. The main purpose of developing the underwater ROV is to overcome limitations on human endurance such as dangerous underwater task like underwater surveillance task, survey, inspection, recovery, maintenance and repair [9]. The ROV are maneuverable in three-dimension x, y and z axis which can be programmed to float passively or actively to desired location and swim in different levels of depth. Hence, a controller needs to be designed with required performance through an in-depth understanding and performance analysis in terms of percentage of overshoot and rise time of controllers like proportional integrated differential (PID), fuzzy logic, ANFIS and single input fuzzy logic. Experimental result shows that this model can surpass the desired targets and performance.

This paper presented a 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 were designed to gain comparison and improvement of controlling the depth control system specially to minimize the overshoot and steady-state error.

2. Controller Design

Controller design uses the concept of bionic ideas for reference based on emulating intelligent phenomenon in nature. CD endeavors to recreate and return the characters of intelligence aiming to be another new research domain in nature and engineering reconstruction [10]. Controller designs used the MATLAB software such as PID, Fuzzy Logic controller and Neural Network. The controllers used in controlling the underwater ROV are stated in the next section.

Fig. 1: Prototype of ROV

2.1. Proportional Integrated Differential (PID) controller

PID is an aerodyne for the mathematical terms of proportional, integral and derivative. The controller is 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 improves the transient response while the integral adds a pole at the origin to increase system type by one, thus eliminate the steady state error due to step function to zero [11].

The process of selecting controller parameters to meet given performance specifications is called PID tuning. Most PID controllers are adjusted on-site in which many different types of tuning rules have been proposed by other researchers. Using those tuning rules, delicate and fine tuning of PID controllers can be made on-site. In addition, automatic tuning methods have been developed and some of the PID controllers may possess on-line automatic tuning capabilities. Figure 2 shows the model of PID controller.

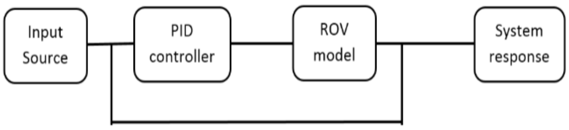


Fig. 2: Block diagram of PID controller

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 to build up phonetically the control output which ought to differ from the input and set up the variable range of the different fuzzy set. These two techniques use a general approximation and they have the capacity of a non-linear model.

The Mamdani fuzzy logic controller consists of a fuzzifier, rule based, fuzzy inference engine and de-fuzzifier. In this paper, multiple input single output (MISO) type of controller is used in a formulation of control law [12]. The fuzzy logic controller is designed in order to control the depth of an underwater ROV.

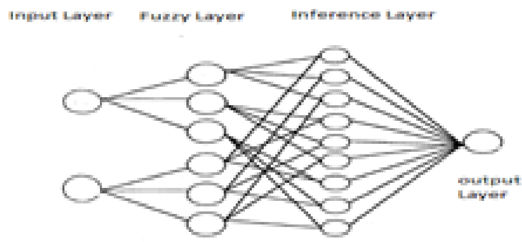


Fig. 3: Fuzzy logic controller structure

2.3. Adaptive Neural Fuzzy Inference System (ANFIS) controller

Adaptive Neural Fuzzy Inference System (ANFIS) architecture consists of two inputs, two rules and one output for the Sugeno type of fuzzy logic controller. The ANFIS controller was generated using “anfisedit” function in MATLAB Sugeno fuzzy platform. The data was gained from the rule table of Mamdani type of fuzzy logic controller as discuss above. The ANFIS generates use to convert from the Mamdani type to Sugeno type of fuzzy logic controller. The controller is designed using MATLAB/Simulink platform as shown in Figure 5.

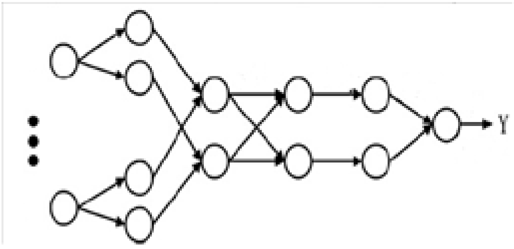


Fig. 4: ANFIS controller structure

ANFIS is utilized for modelling nonlinear of fuzzy input and output data, and for forecast of output as per the input. It applies a blend of the minimum squares technique and back propagation angle plunge technique for training fuzzy inference system membership. Practically, it is identical to the combination of neural network and fuzzy inference system. It consolidates the advantage of neural network learning algorithm and FIS to guide contributions input to an output [13]. Figure 4 shows the structure of ANFIS model using the data from conventional fuzzy logic rule table to create an ANFIS model controller

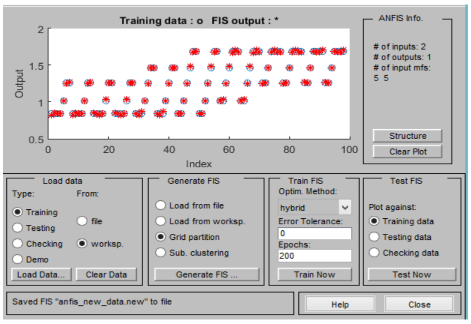


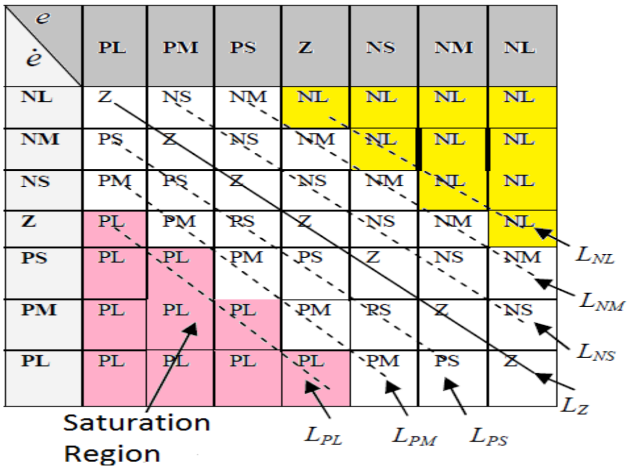
Fig. 5: ANFIS model generator

This mapping is either a linear relationship or a very nonlinear one regarding upon the structure for the system and the capacity for every node. The point is to develop a system for accomplishing a coveted nonlinear mapping that is controlled by an informational collection that comprises various input– output sets of an objective system. These data index are often called the training data set and the strategy that is employed after the alteration of the parameters to enhance the execution of the system and this is regularly referred to as the learning principle or the learning algorithm. Figure 5 shows the ANFIS platform used in MATLAB.

2.5. Single Input Fuzzy Logic Controller (SIFLC)

The Single Input Fuzzy Logic Controller (SIFLC) was first introduced by [14] who proposed a simplified method in fuzzy logic controller using “signed distance” method that reduces the rule and membership function. A formula is proposed in using this method as shown in (1).

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



$\dot{e}$ \ e	PL	PM	PS	Z	NS	NM	NL
NL	Z	NS	NM	NL	NL	NL	NL
NM	PS	Z	NS	NM	NL	NL	NL
NS	PM	PS	Z	NS	NM	NL	NL
Z	PL	PM	PS	Z	NS	NM	NL
PS	PL	PL	PM	PS	Z	NS	NM
PM	PL	PL	PL	PM	PS	Z	NS
PL	PL	PL	PL	PL	PM	PS	Z

Fig. 6: Rule table with TOEPLITZ structure

Fuzzy Logic controller (FLC) is a linguistic-based controller that tries to emulate the human thinking ways 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 ($\dot{e}$). Its rule table can be created on a two-dimensional space of the phase-plane (e, $\dot{e}$) as shown in Figure 6. It is common for the rule table to get the same output 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, $\dot{e}$ and $e^{(n-1)}$ as input variables [15].

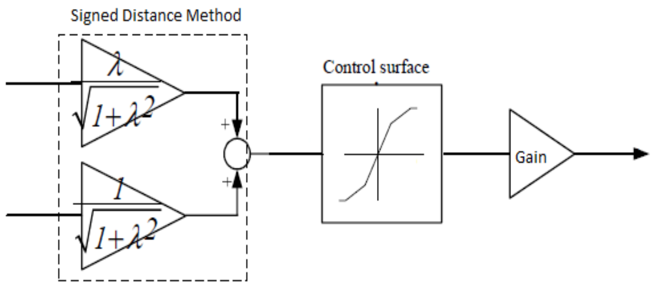


Fig. 7: SIFLC control structure

3. Results and Discussion

The underwater ROV model was represented by the first order transfer function. The transfer function obtained from the simulation of system identification toolbox is stated in (2). This transfer function model was created by transfer function model in system identification toolbox.

$$TF = \frac{2.063}{s + 01151} \tag{2}$$

Based on the transfer function obtained from the simulation, the controllers were designed and run in order to verify the system was stable and could be adapted into any conditions when the ROV was operating in the underwater.

The controllers were designed to control the depth stability. Firstly, the PID controller was able to control the model with good performance and high-rise time but there was an overshoot in the system response. The Mamdani type of fuzzy logic controller was designed to decrease the percentage of overshoot than the PID controller, but the controller had slower rise time. The third, ANFIS was designed to get the higher rise time than the Mamdani type of fuzzy logic controller. The results in Figure 9 showed that the ANFIS controller improved in terms of rise time. The fourth controller, Single Input Fuzzy Logic Controller (SIFLC), was designed based on the formulae in (1) with a good performance.

Table 1: Comparison of controller designs performances

Controller	Rise Time	% of Overshoot	Color Code
Proportional Integral Differential (PID) controller	737.093ms	11.446%	Red
Mamdani Fuzzy Logic Controller (M-FLC)	5.078s	0.764%	Purple
Adaptive Neural Fuzzy Inference System (ANFIS) controller	5.111s	0.919%	Blue
Single Input Fuzzy Logic Controller	720.771ms	0.771%	Brown

The results in Figure 9 showed that the SIFLC had higher rise time than the PID controller and there was lower percentage of overshoot. Hence, the SIFLC is able to control the underwater ROV depth control. All controllers were designed using MATLAB Simulink Platform and the system performances were validated in the simulation. All controllers design performance is illustrated in Table 1. The performance analysis was analyzed in terms of higher rise time and lower percentage of overshoot. Overall, SIFLC is good in rise time performance whereas M-FLC has a minimal score on overshoot of the system response. Figure 10 shows the system response with different set point.

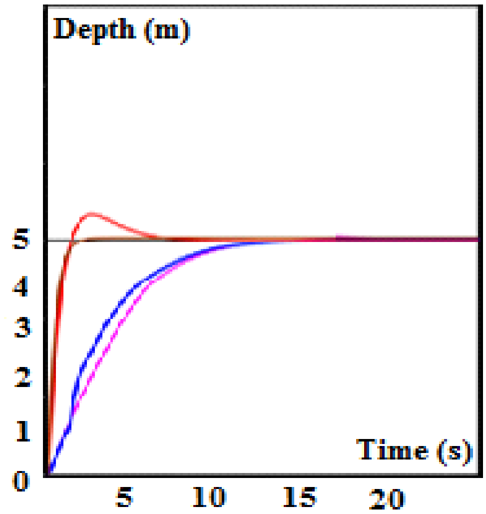


Fig. 9: System response of controller design

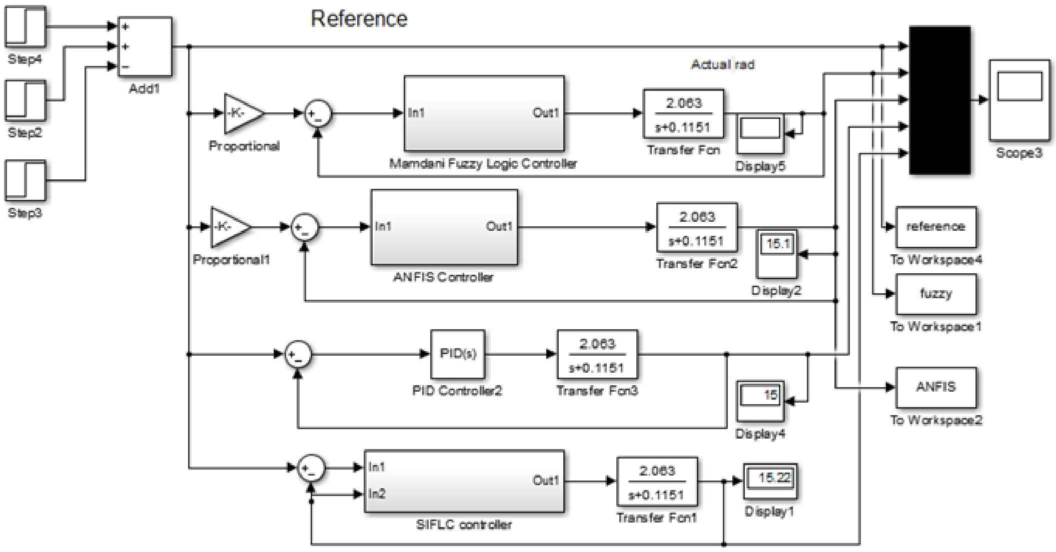


Fig. 8: Controller design of four types of controllers

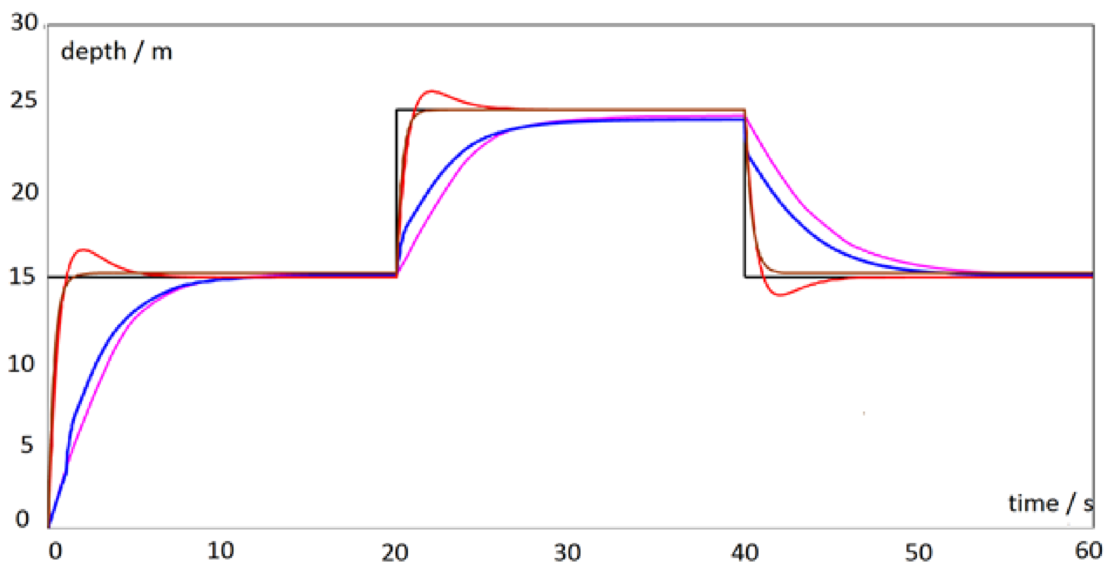


Fig. 10: System response of controller design with different set point

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 design computing intelligence controller to make an improvement in system response than the PID controller. The Single Input Fuzzy Logic Controller (SIFLC) should be better than the ANFIS controller and ANFIS controller gives better result than the Mamdani fuzzy logic controller. The system performance (overshoot percentage, rise time and steady state error) of Proportional Integral Derivative (PID) controller are comparing with Mamdani Fuzzy Logic controller (M-FLC) with Adaptive Neural Fuzzy Inference System (ANFIS) with Single Input Fuzzy Logic Controller (SIFLC).
The performance of the controllers has been recorded and analyses. The PID controller able to control nicely since the model was a first order transfer function but the SIFLC controller able to gain better performance than PID controller in term of percentage of overshoot. The PID controller able to control the lower order of transfer function whiles the fuzzy type controller able to control higher order of transfer function. 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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