Performance Analysis of PID and Fuzzy Logic Controller for Unmanned Underwater Vehicle for Depth Control

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***Abstract*— This paper presents study and discussion of tuning process for PID and Fuzzy Logic Controller for Unmanned Underwater Vehicle (UUV) system. Autonomous Underwater Vehicle (AUV) is considered as an UUV where it is commonly used for detecting and mapping submerged wrecks, rocks, and obstructions that is hazardous to navigation for commercial and recreational vessels. The controllers will be designed to control motor thrusters of the AUV. The paper generally discusses PID and FLC, and the focus stresses more on FLC. Differences between both tuning processes will be discussed in details in this paper by covering method of conducting tuning process. Through the process, performance of the system can be analyzed and studied. The output of the system can be tuned or adjusted to a desired and satisfactory level using both of the methods mentioned. For FLCs, tuning process will be a trial-and-error, by making changes to the mapping of membership functions and fuzzy inference rules whereby PID, tuning can be made to the parameter values of the system.**

***Index Terms*— Autonomous Underwater Vehicle; Fuzzy Logic Controller; PID; Unmanned Underwater Vehicle.**

I. INTRODUCTION

Fuzzy Logic Controllers (FLCs), have been used for the purpose of clustering and classification some fuzzy information. FLCs can handle a certain level of impression and uncertainty. It used to interpret and analyses the input signal in either 1 or 0, yes or no and so on. The output will be certainly a clear result such as digital result. MATLAB will be used to design the fuzzy logic controller and in fuzzy logic controller, there are four important and fundamental components, which are fuzzification, knowledge base, inference engine and defuzzitfication interface [1-3]. The fuzzification part will be responsible to measure and transform the input into a suitable linguistic variable. The necessary information will then be provided by the knowledge bases for further process. Information that used for fuzzification and defuzzification are extracted from here as well [4]. The output of the controller that referred as actual control action comes from the outcome of the fuzzy inference engine.

The University Sains Malaysia AUV is 1m long and 0.5m wide, and its weight is approximately 30kg without accessories payload. It is equipped with two thrusters for diving system and another two thrusters for propulsion functions [5-6]. The AUV is small-scaled and low cost, capable to carry out monitoring and surveillance activities [7-9]. The depth and gyro sensors on the AUV will provide the required feedback signals.

II. THEORY OF TURNING PROCESS

A. Tuning Process of PID

In order to acquire a robust and desired control response, a simple adjustments and tuning are needed. Tuning of PID can be done by using computer software, MATLAB/Simulink. By utilizing this software, parameters of the design can be adjusted and tuned.

A simple tuning process of PID includes these few steps:

i. Initial PID design
ii. Adjusting PID design in PID Tuner
iii. Completing PID design with performance Trade-Off
iv. Writing the Tuned Parameters to PID Controller Block
v. Completing the design

In Figure 1, an example of system block diagram is shown and the red box is highlighted where the adjustments and tuning will be carried on. Initially, the PID Tuner computes a linearized plant model [10-13]. The input and output of the plant will be automatically identified and the result is shown as in Figure 2.

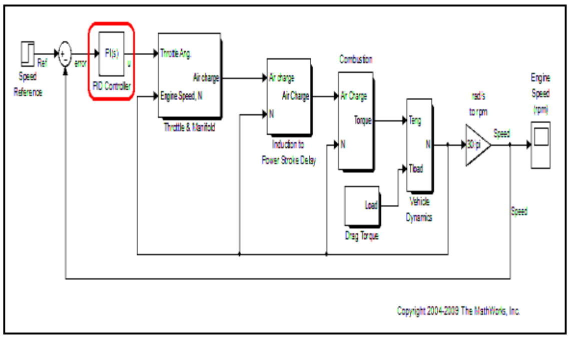

Figure 1: System Overview

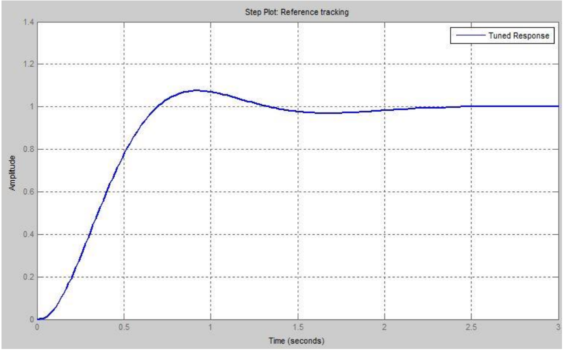

Figure 2: Step Plot (reference tracking)

By using this PID tuner, all the fundamental parameters can be found. Parameters such as rise time, settling time, overshoot and peak can be found from the plot. By knowing all the values for these fundamental parameters, adjustments can be made from here to achieve the desired control response [14]. For instance, in order to reduce the overshoot of the system, the response time of the system can be increased. By adjusting the parameter of the controller, the response plot and the performance measurements will update on time [15]. At last, after finishing the adjustments on the parameters, the system can be tested on the nonlinear model using the same software. After the test, the latest parameters can be written back to the PID Controller block in the Simulink model earlier.

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B. Tuning Process of Fuzzy Logic Controllers (FLCs)

Tuning process for fuzzy logic controllers can be done by using the method of trial-and-error. Several tests and trials will be carried out until a satisfactory result is obtained.

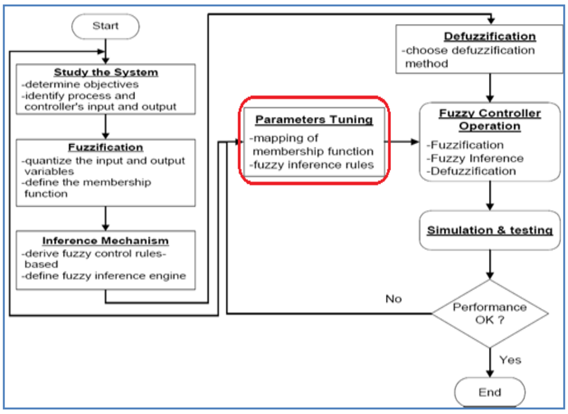

Figure 3: Flow Chart of Design Methodology of FLCs.

As shown in Figure 3, FLC tuning starts from parameter tuning and followed by fuzzy controller operation and simulation and testing. At the stage of parameter tuning, change can be made on the mapping of membership function and the fuzzy inference rules. These changes will bring effect to the next stage, which is the controller. All these methods will then be tested and simulated. The cycle is repeated until a desired outcome is obtained. There are no standard methods or procedures for the tuning process for FLCs. If the outcome is not as expected, adjustment and tuning will be made to the two criteria which have mentioned earlier.

III. Results And Discussion

A. PD, PI and PID

In this section, there are two results from the proportional-integral-derivative (PID), controller block and Fuzzy Logic Controller block. The designed systems can be directly tested in the MATLAB simulation environment. The original transfer function for the AUV controller design is shown in Figure 4. The PID controller simulink block diagram for the AUV controller design is shown in the Figure 4.

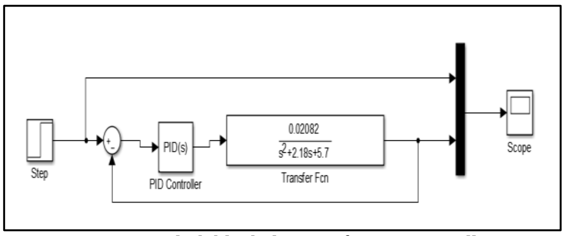

Figure 4: Simulink block diagram for PID controller

From the original graph, the transient response and steady state error have not achieved the best performance. Thus, the changes have been made by using the PID controller. The methods of proportional–integral (PI), proportional–derivative (PD) and proportional–integral–derivative (PID) controller are also carried in order to solve the poor performance of original system model. The focus of this part of controller is related to the relationship of the values of K_p, K_i and K_d and the output response of the new system. The results from the PID will later compare with the fuzzy logic controller method at the discussion part. The blue line shows the input of the system, while the red line shows the response after the function of the system.

Figure 5 shows the system tuned via Proportional Integral (PI) controller. The brown line represents the tuned response, while the step input response is the blue line. It shows the original response is improved for the aspects of the entire transient characteristic. In this PI controller, the proportional value (K_p) and integral value (K_i) are 124.98 and 353.90 respectively.

Figure 6 shows the system tuned via proportional derivative (PD) controller. The brown line represents the tuned response, while the blue line represents the step input. In this PD controller, the proportional value (K_p), derivative value (K_d) and filter coefficient are 18270.1822, 1784.011, and 885.0334 respectively. It becomes smoother compare to the proportional integral controller.

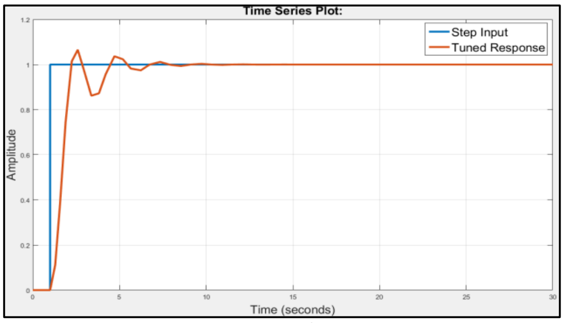

Figure 5: Output response graph after tuned by PI controller

Figure 7 shows the system tuned via proportional integral derivative (PID) controller. The brown line represents the tuned response, while the blue line represents the step input. In this PID controller, the proportional value (KP), integral value (KI), derivative value (KD) and filter coefficient are 575.1258, 784.8297, 100.2977 and 444.2639 respectively. It has less smooth of the response but lesser overshoot compared to the PD controller. Thus, the best result is from the PID controller as the performance is suitable for the whole system. This result is chosen to compare with the best result of Fuzzy Logic Controller later in the discussion part.

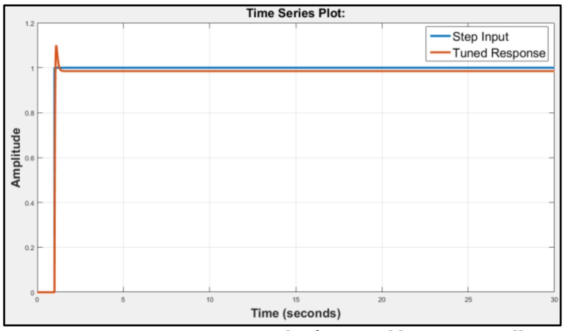

Figure 6: Output response graph after tuned by PD controller

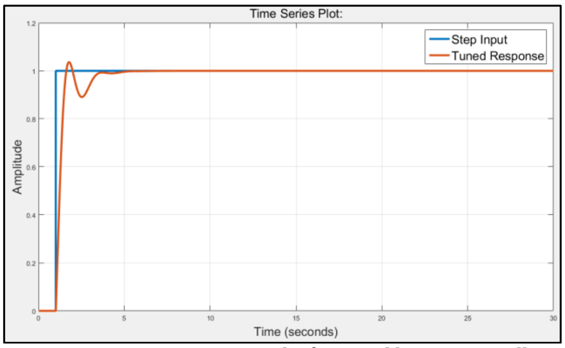

Figure 7: Output response graph after tuned by PID controller

B. Fuzzy Logic Tuning Setup

The process of simulation is discussed in this section. The example system used is based on “AUV Controller Design and Analysis using full-State Feedback” [1]. Figure 8, Figure 9 and Figure 10 shows the membership function of two inputs and an output respectively. The input variables are Motor Thruster 1 and Motor Thruster 2 in the AUV system while output variable is instantaneous depth of the AUV. For easier tuning of fuzzy logic, triangular types of membership functions are used for inputs and output of the system. Based on the AUV system, we implemented 3 X 3 membership functions partition for inputs and output. Based on the description of FIS Editor, rules statements are constructed in Rule Editor according to Table 1 where P is Positive, Z is zero, and N is Negative. Theoretically, number of rules statement is the product of the membership function partition. In this case, 9 rules from 3 X 3 membership function partition are developed.

The Fuzzy Logic Controller Block capable to test and run a fuzzy logic that designed in fuzzy inference system (FIS) in a simulation environment. Figure 11 shows the simulink block diagram for AUV system. Figure 12 shows the output response of AUV system. The output of the system is low which steady at 2% of actual input. Thus, a gain is added to amplify the output response. Figure 15 shows the output response after gain of 400 is added at the output of the system. It seems that the output of the system is elevated by 6 fold of step input. Thus, tuning process is begun to obtain desired output. In this paper, we focus on tuning the output scale of membership function and study the effect of each tuning.

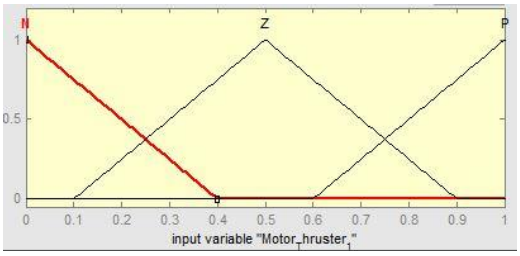

Figure 8: Membership functions of Input 1

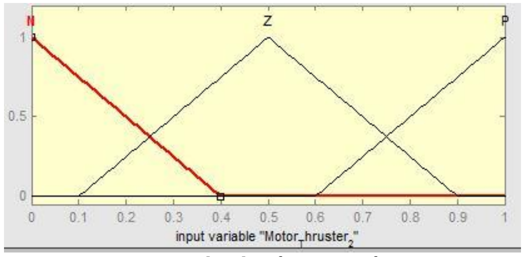

Figure 9: Membership functions of Input 2

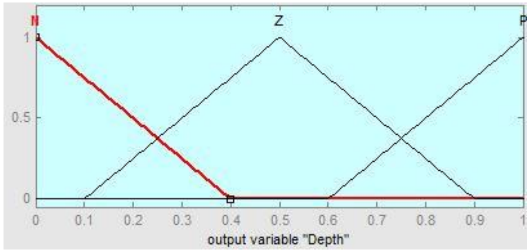

Figure 10: Membership function of Output

Table 1
Rule of Fuzzy logic controller

Motor Thruster 1 / Motor Thruster 2	P	Z	N
N	Z	N	N
Z	P	Z	N
P	P	P	Z

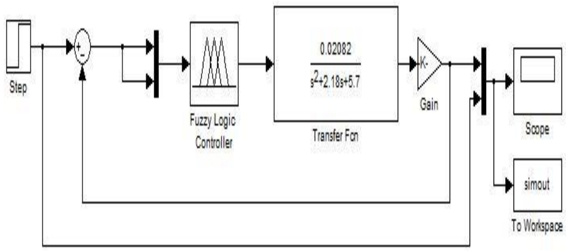

Figure 11: Simulink block diagram for AUV system

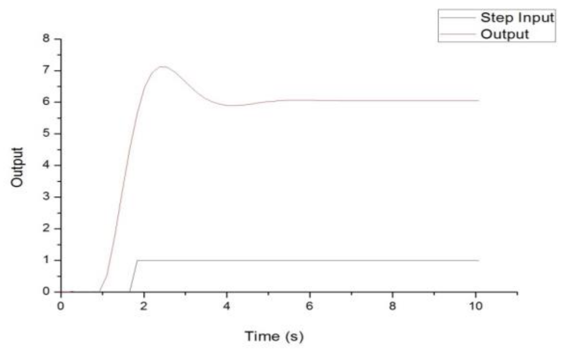

Figure 12: Output response after implemented gain block

IV. TURNING PROCESS

A. PD, PI and PID

In this controller, it is needed to choose one of the controllers from PI, PD, and PID. It is also provided the compensator formula for the whole system. There are three different formulas for the controllers. The next step after choosing the right controller, Tuning button is clicked to launch the PID tuning tool in MATLAB. MATLAB has linearized the plant and generate the output response. Figure 13 shows that the response time and transient behavior of the system can be changed by clicking scroll ball to left and right (highlighted). For example, the transient response is fixed while the transient behavior has changed from 0.3 to 0.6. The result is shown in Figure 18. Their output response graphs have changed in terms of transient characteristic and steady state error. The transient behavior at 0.6 has better performance than the transient behavior at 0.3 from the Figure 13. These changing features are applicable for PI, PD, and PID controller in MATLAB tuning tool. Table 2 shows all the results from the PI, PD and PID in aspects of rise time, overshoot, and settling time.

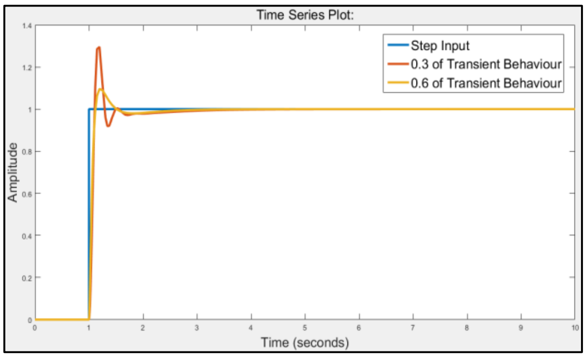

Figure 13: Transient response of AUV system

Table 2
Units for Magnetic Properties Parameter of PI, PD, and PID controller

	PI	PD	PID
Rise Time(s)	0.79	0.0379	0.435
Overshoot (%)	7.02	11.5	3.59
Settling time(s)	5.37	0.265	2.31

B. Fuzzy Logic Control

As tuning a fuzzy logic included of tuning scale of membership function, rules statements and the type of membership function, it will be lost for first time user without any guidance. In this paper, tuning is focused on the scale of membership function for output N as a beginning for tuning process. It is found that the graph of the output response is shifted positive Y-axis when output N is shifted towards positive X-axis and vice versa. With this relationship, we had optimized the output response is expected to be similar with input function. Furthermore, tuning the range of membership functions has the same effect of shifting the output response graph. It is found that by increasing the range of membership function will shift the output response toward positive Y-axis and vice versa. Thus, both methods can be used for optimizing output response graph. Figure 14 shows the last tuned for membership function and Figure 15 output response graph after optimization. Table 3 shows the parameter of the tuned FLC.

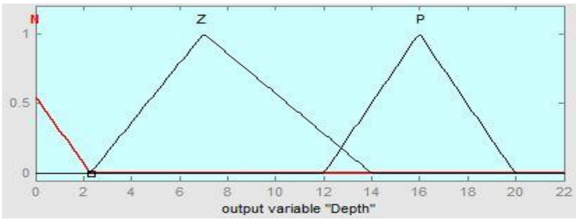

Figure 14: Last tuned of membership function

Table 3
Parameter of tuned FLC

Parameter	FLC
Rise time (s)	0.657
Overshoot (%)	19.88
Settling time (s)	3.82

Table 4 is the summary represents the discussion between PID controller and Fuzzy controller on the study for AUV controller design. Figure 22 shows all the output response after tuned by both controllers.

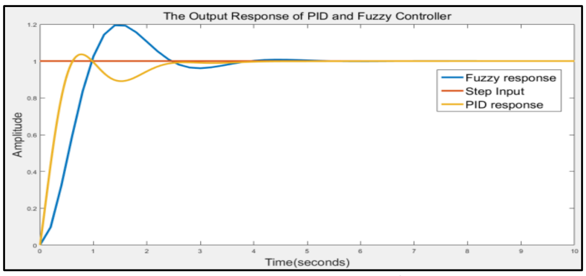

Figure 15: Output response graph after optimization

After the comparison between different controllers, PID controller provides better response in terms of rise time and overshoot. However, PD controller is the best controller for tuning settling time of the output response. Figure 15 is the finest tune can be done with 3 by 3 membership function rules. For a better output response, a higher membership function rules should be implemented.

Table 4
Comparison of PID controller and FLC controller

PID Controller	**Comparison Criteria**	**Fuzzy Logic Controller**
0.435	Rise Time (s)	0.657
3.59	Overshoot (%)	19.88
2.31	Settling Time (s)	3.82

V. CONCLUSION

As a conclusion, PI, PD, PID and fuzzy logic controller is successfully tuned for AUV. The presented result shows that PID provides better performance than the fuzzy logic in term of rise time and overshoot. It is recommended that higher membership function rules should be introduced to fuzzy logic control in order to obtain better performance of output response.

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