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DEVELOPMENT OF FUZZY LOGIC CONTROLLER FOR QUANSER BENCH-TOP HELICOPTER

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ABSTRACT: Bench-top helicopter is a laboratory scale helicopter that usually used as a testing bench of the real helicopter behavior. This helicopter is a 3 Degree of Freedom (DOF) helicopter which works by three different axes which are elevation, pitch and travel. Thus, fuzzy logic controller has been proposed to be implemented into Quanser bench-top helicopter because of its ability to work with non-linear system. The objective for this project is to design and apply fuzzy logic controller for Quanser bench-top helicopter. Other than that, fuzzy logic controller performance system has been simulated to analyze and verify its behavior over existing PID controller by using Matlab & Simulink software. In this research, fuzzy logic controller has been designed to control the elevation angle. After simulation has been performed, it can be seen that simulation result shows that fuzzy logic elevation control is working for 4°, 5° and 6°. These three angles produce zero steady state error and has a fast response. Other than that, performance comparisons have been performed between fuzzy logic controller and PID controller. Fuzzy logic elevation control has a better performance compared to PID controller where lower percentage overshoot and faster settling time have been achieved in 4°, 5° and 6° step response test. Both controller are have zero steady state error but fuzzy logic controller is managed to produce a better performance in term of settling time and percentage overshoot which make the proposed controller is reliable compared to the existing PID controller.

KEY WORDS: *fuzzy logic; controller; bench-top helicopter; Quanser*

1. INTRODUCTION

Fuzzy logic theory is a mathematical reasoning that compute “degrees of truth” that works between value 0 and 1 [1]. Fuzzy logic controller usually determined by some set of rules which later these set of rules will be implemented in the system. Since the numerical variables have been converted to the linguistic variables, mathematical modeling is not required in this fuzzy logic. Fuzzy logic consists of three parts which are fuzzification, inference engine and defuzzification. Fuzzy logic consists of input and output which are represented in form of membership function. This membership function can be represented in various shapes such as triangular, bell, trapezoidal and other shape. The membership function affect the output result of the system. To design fuzzy logic controller, there are several design stages need to be performed such as input and output membership function and fuzzy rules.

Fuzzy logic controller has been used widely in control system. Some of the researchers have introduced the fuzzy logic controller because of its ability in state of stability and better responses compared to other controller [2,3,4]. Other than that, fuzzy logic also has been introduced to be implemented with other controllers such as PID in controlling the aerial vehicles to produce better response of the system [5,6]. Fuzzy logic controller fuzzy logic controller will act as a controller to overcome weaknesses that has been faced by other controllers because of its ability to work with non-linearity system such as a helicopter. Since the designed controller need to be worked with the bench-top helicopter which is a system with high non-linearity and complexity, fuzzy logic has been proposed to overcome weakness by other controller. Therefore, fuzzy logic will improve the performance of the system to produce a better result.

In this research, fuzzy logic has been proposed as a controller to control Quanser bench-top helicopter. There are several researches that have proposed different type of controllers for Quanser bench-top helicopter. One of the techniques that have been developed is quantitative feedback theory which has been proposed by researcher to achieve a desired robust design over a specified region of



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plant uncertainty [7]. Fuzzy logic is a type of controllers that cover a wider range of operating conditions. Other than that, fuzzy logic controller is suitable to deal with nonlinearities and uncertainties. Thus, in this research, fuzzy logic will be introduced as a type of alternative controller to control the bench-top helicopter and its behavior will be identified throughout the research. Other than that, robust adaptive LQR controller also has been developed for Quanser bench-top helicopter [8]. LQR controller is proposed by researcher because it simply creates a stable system without explicitly optimizing anything and it is also straightforward to use for multivariable systems where the design procedure is essentially the same as for single-input-single-output systems.

2. METHODOLOGY

2.1 Bench-Top Helicopter

Quanser bench-top helicopter is a laboratory helicopter model to represent the actual model of helicopter [9,10]. Bench-top helicopter works by moving at 3 Degrees of Freedom (3DOF) which are elevation axis, pitch axis and travel axis. Figure 1 shows the 3-DOF bench-top helicopter while Figure 2 shows the free body diagram for this 3-DOF helicopter system.



Figure 1 : 3-DOF Bench-Top Helicopter [11]

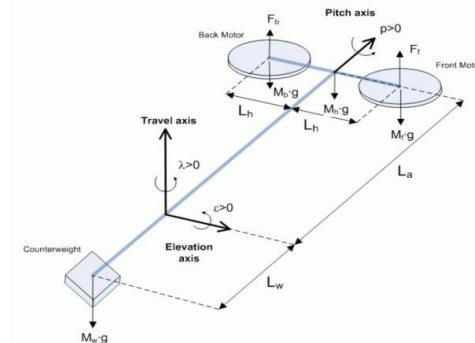


Figure 2: Free body diagram of 3-DOF Helicopter system [11]

Parameters of 3-DOF helicopter are described as follows:

M_h	Mass of the helicopter
M_w	Mass of counter weight
M_f	Mass of front propeller assembly
M_b	Mass of back propeller assembly
L_a	Distance between travel axis to helicopter body
L_h	Distance between pitch axis to helicopter body
L_w	Distance between travel axis to the counter weight
g	Gravitational constant
F_b	Back force
F_f	Front force
p	Pitch

Two electrical DC motor of bench-top helicopter are attached to the body and making two propellers turn. Aerodynamic has caused the total force F to make the total system turn around an angle measured by encoders. The arm has counterweight that helps propellers lift the body weight. With 3-DOF, elevation angle, pitch angle and travel angle can be measured by an absolute encoder and controlled by any kind of controllers such as PD controller [11]. This research will focus on developing a fuzzy logic controller to control elevation angle at certain degree.

This research will identify the response of the Quanser bench-top helicopter by using Matlab & Simulink software. Therefore, in this research, simulation results of bench-top helicopter that has been implemented with the fuzzy logic controller will be presented and discussed.

2.2 Fuzzy Logic Controller Design

The early step in designing the fuzzy control system is to set the fuzzy rules. In this part, set of fuzzy rules consists of two inputs which are *Error* and *Change in Error* while the output is *response* of the system. In order to design the fuzzy logic controller, the subset of input and output will be determined. In this case, each input will consist subset {NEG, Z, POS} while subset of output contain {VS, S, M, H, VH}. Based on the subset of each inputs and output that have been determined, the fuzzy rules will be set.

Table 1 shows the representation of fuzzy rules set. Based on Table 1, there are nine fuzzy rules that have been set for the bench-top helicopter system. Later, this rule will be used in designing the fuzzy logic controller.

Table 1: Fuzzy Rules of Bench-Top Helicopter Response

		ERROR		
DEL ERROR		NEG	Z	POS
NEG	VS	S	M	
Z	S	M	H	
POS	M	H	VH	

List of abbreviation:

NEG	- Negative
Z	- Zero
POS	- Positive
VS	- Very Slow
S	- Slow
M	- Medium
H	- High
VH	- Very High

In order to perform simulation results for the Quanser bench-top helicopter system response, fuzzy rules will be set in FIS editor in Matlab. FIS editor is needed to set the fuzzy rules and determine the membership function for the fuzzy logic controller. 9 fuzzy rules that have been discussed before will be used in designing fuzzy logic controller. The FIS editor will be set by using “and” method which is consider the min value and the defuzzification by using centroid. After inputs and an output have been determined, fuzzy rules that have been discussed earlier will be set in fuzzy logic controller designation by using rule editor in FIS editor.

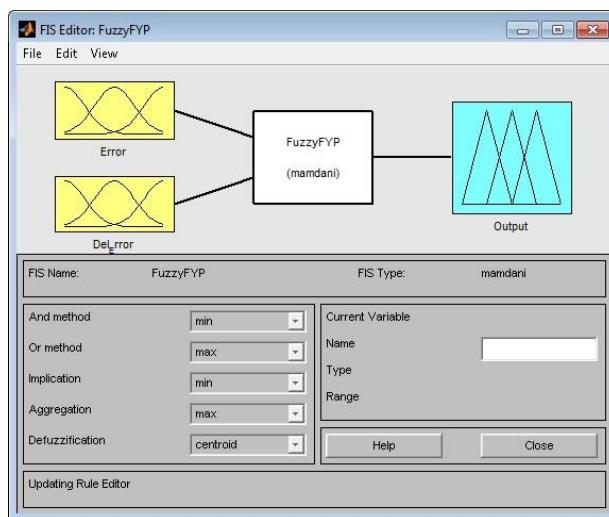


Figure 3: FIS Editor

Figure 3 shows FIS editor in Matlab that has shown two input membership functions which are *Error* and *Change in Error* while an output membership function is the *Response* of the system. In this part, membership functions have been tuned and suitable range of three membership functions has been identified. Other than that, shape of the membership functions also have been determined where are triangular and trapezoidal shape will be used. In order to identify a best response, this method works by changing range of each membership function and observe the output produced. Other than that, position and parameters value of membership functions also will be adjusted. Membership functions will be tuned until the best output response has been identified.

2.3 3-DOF Quanser Bench-Top Helicopter Simulations

In this part, a simulation file named *s_heli3d* that has been supplied by Quanser Inc. will be opened in Simulink in order to determine the behavior of output response regarding with the implementation of controllers. Figure 4 shows Simulink block diagram for Quanser 3-DOF Bench-top Helicopter Simulation.

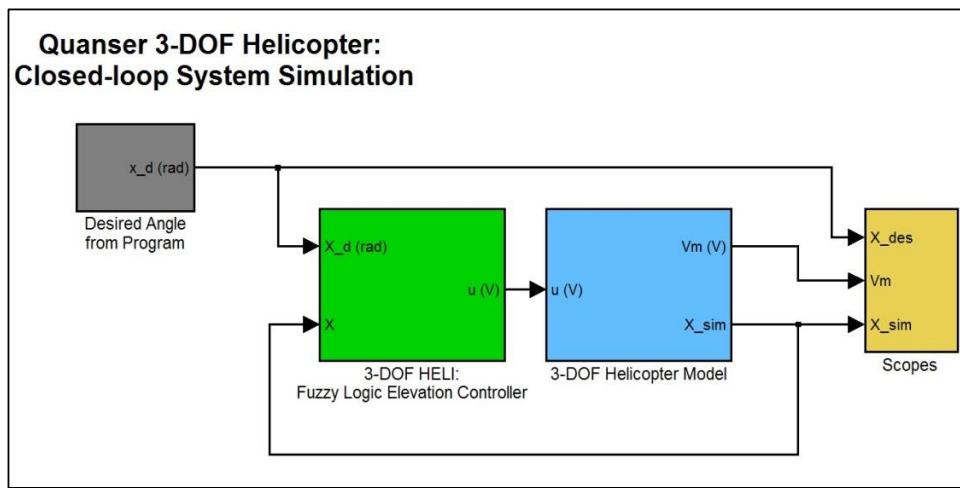


Figure 4: Simulink block diagram for Quanser 3-DOF Bench-top Helicopter Simulation

Based on Figure 4, *s_heli3d* represents the Quanser 3-DOF Helicopter: Closed-loop System Simulation. In this system, there are four blocks that will be used to run the bench-top helicopter system simulation. *Desired Angle from Program* block has been used to set the desired angle that needed to be simulated. In *PID Controller* block, it consist a controller that needed to be used to control the desired angle. In this project, fuzzy logic controller has been developed to replace the PID controller. Then, *3-DOF Helicopter Model* block contains designed parameters for helicopter model to work. This block will receive signals from controller to control certain part of the helicopter. Lastly, in *Scopes* block will display responses of the Quanser 3-DOF Helicopter: Closed-loop system simulation that contains four scopes which are elevation, pitch, travel and motor voltage.

Figure 5 shows the implementation of fuzzy logic elevation controller that has been designed by replacing the existing PID controller. The PID controller has been optimized in controlling the elevation angle by considering the elevation error and travel error. Other than that, the PID controller also will depend on the gain value of the bench-top helicopter. Fuzzy logic controller will consider elevation error and travel error to control the elevation angle where these errors will be added and summation produced will be acted as inputs for fuzzy logic controller in term of error and change in error.

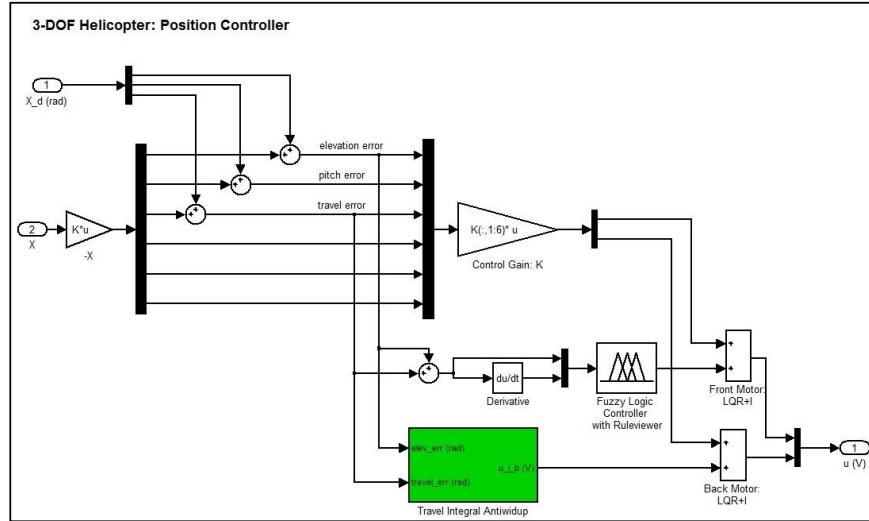


Figure 5: Fuzzy Logic Controller Implementation for Elevation Control

For Quanser bench-top helicopter hardware test, the system that has been used is quite similar to Figure 4 and the controller implementation can be seen in Figure 5. However, the system named Quanser 3-DOF Helicopter: Closed-loop Actual System will be used to connect to the real Quanser bench-top helicopter and it can be run by using Matlab and Simulink by interconnecting the hardware with q4 data acquisition card that attached to the computer. The steps for hardware connection can be referred in Quanser 3-DOF Helicopter Reference Manual [11].

3. RESULT AND ANALYSIS

3.1 Membership Function

In this section, result from the project that has been conducted will be analyzed and discussed. The important part of fuzzy logic controller is the designation and adjustment of membership functions that have been designed in Matlab. In design part, membership functions are designed and the behavior of output response will be observed. In this project, fuzzy logic controller is designed to control the output of bench-top helicopter. Thus, fuzzy logic controller is designed to control the desired elevation angle that will be set at 5° . The best membership functions that have been designed can be seen in Figure 6, 7 and 8 which represent error membership function, change in error membership function and output membership function respectively.

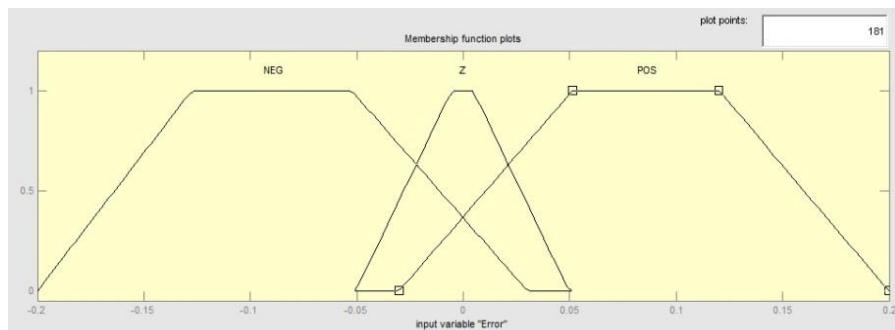


Figure 6: Error Membership Function

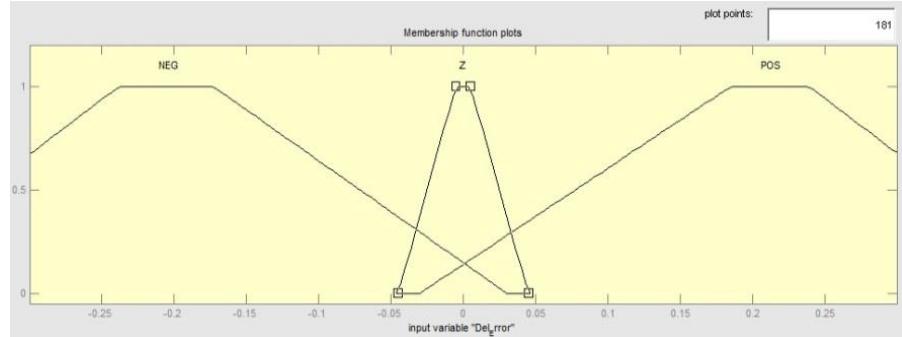


Figure 7: Change in Error Membership Function

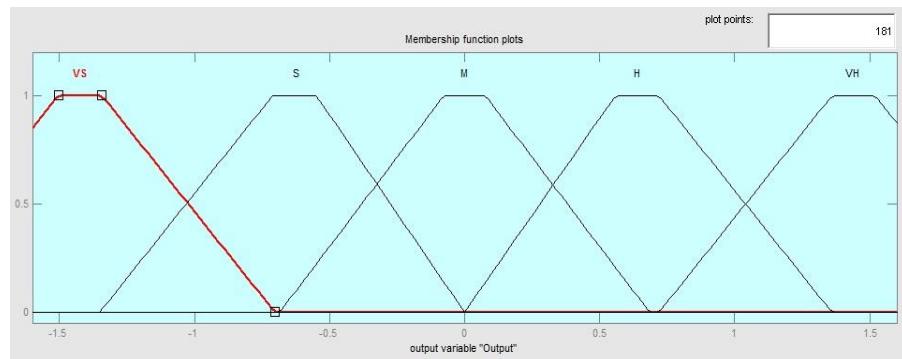


Figure 8: Output Membership Function

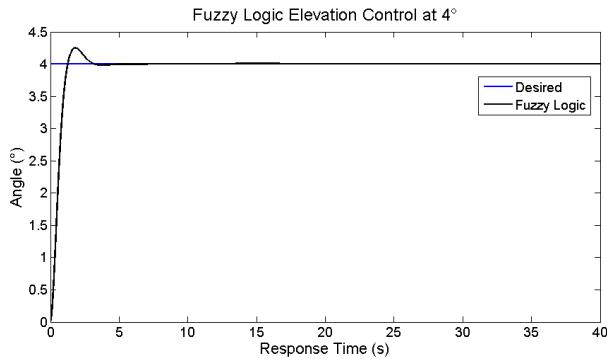
Based on the membership functions that have been designed, it can be seen that every membership functions have different range which are [-0.2,0.2], [-0.3,0.3] and [-1.6,1.6] for *Error*, *Change in Error* and *output* membership function respectively. It also can be observed that each of the membership function has symmetrical position. It can be said that the position of membership function does affect the output response of the system.

3.2 Quanser Bench-Top Helicopter Simulation

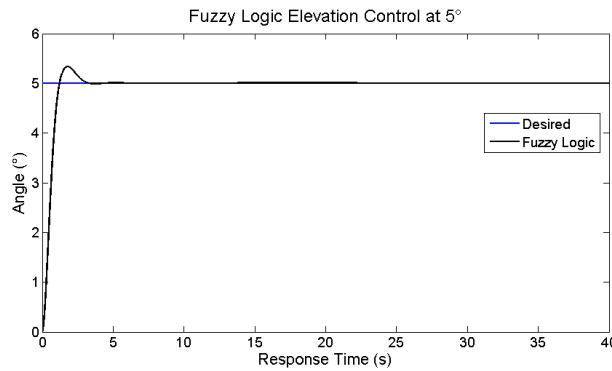
In this part, 3-DOF Quanser bench-top helicopter simulation has been conducted. Simulation is performed to determine the response of bench-top helicopter before it can be tested on real hardware. Therefore, fuzzy logic controller that has been designed is implemented in Quanser bench-top helicopter system to observe its ability in the Quanser bench-top helicopter system controlling. To determine the performance of fuzzy logic controller test on Quanser bench-top helicopter simulation test, three different angles have been chosen which are 4°, 5° and 6°. These angles are chosen because the fuzzy logic controller that has been designed can be optimized by tuning the membership functions to determine which membership functions are working well with these angles. In order to make sure that the fuzzy logic controller works with different angle, the membership functions need to be tuned.

3.2.1 Fuzzy Logic Elevation Control Test

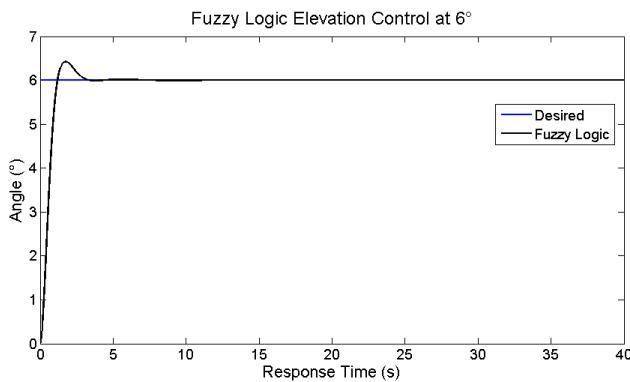
The designed fuzzy logic controller has been tested with three different step input tests to determine its behavior. The first test is step response test at 4° elevation angle. The output response is obtained from the scope block shown in Figure 4. Based on Figure 9, it can be seen that the fuzzy logic elevation control response has faster settling time which is 3.4s and its percentage overshoot is recorded at 6.25%.

Test 1: Step Response (4°)Figure 9: Fuzzy Logic Elevation Control at 4°

The second test is step response test at 5° elevation angle. Based on Figure 10, it can be observed that settling time about 3.3s with percentage overshoot of 8%.

Test 2: Step Response (5°)Figure 10: Fuzzy Logic Elevation Control at 5°

Then, the last test of step response is set at 6° elevation angle. It can be observed from Figure 11 that it settling time is recorded at 4.2s with percentage overshoot of 7%.

Test 3: Step Response (6°)Figure 11: Fuzzy Logic Elevation Control at 6°

Based on the simulation results in Figure 9, 10 and 11, its show that fuzzy logic controller that has been designed and being implemented in the system is succeed in controlling elevation angle at 4° , 5° and 6° . It can be seen that the steady state error for these three angles are 0° . Table 2 shows

the summary of three test results that has been conducted on the Quanser bench-top helicopter simulation system.

Table 2: Fuzzy logic controller elevation response for 4° , 5° and 6°

Test	P.O	Ts	s.s.e
1	6.25%	6.2s	0
2	8%	3.3s	0
3	7%	4.2s	0

Based on Table 2, it can be seen that the steady state error for these three angles are 0° it is a smaller value in term of percentage overshoot and settling time. Therefore, fuzzy logic controller that has been designed has gave a good response for bench-top helicopter system in controlling elevation angle based on simulation that has been conducted.

3.2.2 Comparison between Fuzzy Logic Controller and PID Controller

After simulation has been conducted, the output behavior of fuzzy logic elevation control will be compared with output of PID elevation control. Figure 12 shows comparison between PID controller and fuzzy logic controller that has been designed for elevation control at 5° .

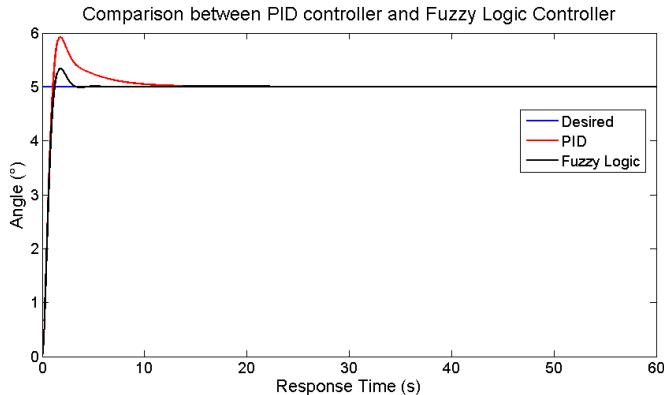


Figure 12: Comparison between PID Elevation Controller and Fuzzy Logic Elevation Controller

Table 3: Comparison between Fuzzy Logic Controller and PID Controller

Controller	P.O	Ts	s.e.e
PID	18%	14s	0
Fuzzy Logic	8%	3.3s	0

Table 3 shows the transient response characteristics of both PID and fuzzy logic controller. Based on Table 3, it can be seen that fuzzy logic controller provides a better response compared to PID controller in state of percentage overshoot and settling time. Meanwhile, steady state error shows that elevation control of both controllers is completed at 5° . Figure 13 shows the simulation result of the system when function generator of 0.04Hz has been implemented in the system. It can be seen that fuzzy logic controller is provides a better output response in term of settling time when the output time is settled at 2.9s compared to PID which is about 11.04s . Other than that, when the output response is observed, it can be seen that fuzzy logic elevation control is managed to reduce percentage overshoot which is 15.2% compared to the PID elevation control which is 36.4% .

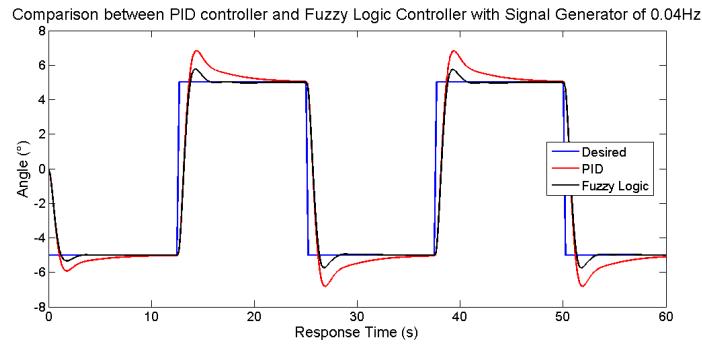


Figure 13: Comparison between PID Elevation Controller and Fuzzy Logic Elevation Controller with Signal Generator

3.3 Quanser Bench-Top Helicopter Hardware Test

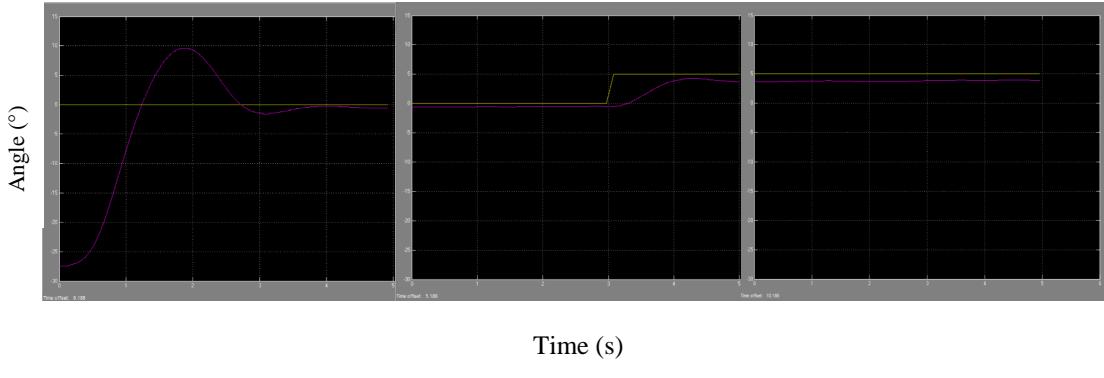


Figure 14: Quanser Bench-top Helicopter Hardware Test (a) 0 – 5 seconds (b) 5 – 10 seconds (c) 10 – 15 seconds

Based on Figure 14, it can be seen that fuzzy logic elevation control has been tested on hardware which is the Quanser bench-top helicopter located at Spacecraft, Guidance, Navigation and Control Lab at E5, Kulliyah of Engineering, IIUM. In the Figure 14, yellow line indicates the desired response and purple line indicates actual response. Figure 14 (a) shows the response of bench-top helicopter from 0 to 5 seconds. Initially, the bench-top helicopter is located at -27.5° . When the system is started and elevation angle is set at 0° , it can be seen that the system response is trying to follow the 0° desired angle until 5° step response is applied at 8 seconds in Figure 14(b). The remaining time shows the response is trying to follow the 5° desired angle. This test shows that the system is managed to elevate at 3.9° angle with 22% of steady state error and takes about 1.8 seconds to achieve the settling time.

Fuzzy logic is expected to give a better performance compared to PID controller not only for simulation test but hardware test as well. In this case, membership function can be tuned in future work in order to make sure that fuzzy logic controller will give a better response for hardware test compared to the existing PID controller.

4. CONCLUSION

Fuzzy logic controller has been successfully designed and implemented in the system of Quanser bench-top helicopter. The objectives of this project are to design the fuzzy logic controller and to verify its performance over the existing PID controller. In this research, it can be seen that fuzzy

logic controller that has been designed for elevation control is working well for 4° , 5° and 6° for simulation system. Other than that, the controller that has been designed are managed to elevate the Quanser bench-top helicopter nearly to 5° for hardware test. Then, the behavior of simulation results show that elevation control of fuzzy logic controller has smaller percentage overshoot compared to PID controller. In addition, the simulation also shows that the settling time for fuzzy logic controller is also faster than the PID controller. It can be concluded that fuzzy logic controller give a better performance when the simulation results have been analyzed.

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