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ROBUST CONTROL OF ADAPTIVE SINGLE INPUT FUZZY LOGIC CONTROLLER FOR UNMANNED UNDERWATER VEHICLE

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ABSTRACT

In this paper the investigation of Adaptive Single Input Fuzzy Logic Controller (ASIFLC) as robust control of an Unmanned Underwater Vehicle (UUV). Robust control methods are designed to function properly with a present of uncertain parameters or disturbances. Robust control methods aim to achieve robust performance and stability in the presence of bounded modeling errors. The UUV applied in this research is a Remotely Operated Vehicle (ROV). Three ROV model will be used to apply ASIFLC such as ROV model was developed by UTeRG Group, ROV Model "Mako" was developed by Louis Andrew Gonzalez and RRC ROV- unperturbed with 6 DOF was developed by C.S. Chin. The simulation of controlling ROV by ASIFLC focused on depth control (heave motion). The ASIFLC for depth control of the ROV was successfully tested in simulation and real time by UTeRG Group. The simulation uses MATLAB Simulink and the performances of system response for depth control of Adaptive Single Input Fuzzy Logic Controller for Unmanned Underwater Vehicle will be discussed. It is proved the Adaptive Single Input Fuzzy Logic Controller is the robust control for different model of the ROV.

Keywords: *Robust Control; Adaptive Single Input Fuzzy Logic Controller; Remotely Operated Vehicle*

1. INTRODUCTION

Adaptive Single Input Fuzzy Logic Controller (ASIFLC) is newly method introduced to reduce complexity of programming or source code to implement in real time by [1]. It also reduces time execution for depth control of the ROV. The XPC target needed to be easier to implement in real time [2-4]. The microprocessor such as PIC, NI DAQ card and Microbox 2000/2000C can be used [5]. The ASIFLC successfully implemented in the prototype of the ROV was developed by the Underwater Technology Research Group (UTeRG) from Universiti Teknikal Malaysia Melaka. The performances of ASIFLC have improved because of there are two parameters to be tuned namely the break point and slope for the piecewise linear or slope for the linear approximation using Particle Swarm Optimization (PSO). This ROV first controlled using a manual controller for 5 Degrees of Freedom (DOF) as shown in Figure 1 (a) before some modification and re-setup again for depth control the ROV for heave motion only as shown in Figure 1 (b). The detail design and specification of this ROV can be refer [6-7].

Robust control is a branch of control theory that explicitly deals with uncertainty in its approach to

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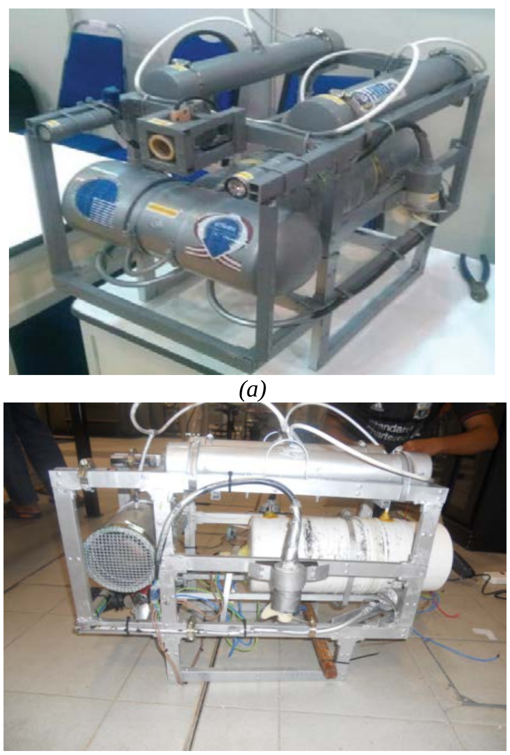
controller design. Robust control methods are designed to function properly with a present of uncertain parameters or disturbances. Robust control methods aim to achieve robust performance and stability in the presence of bounded modeling errors. In contrast with an adaptive control policy, a robust control policy is more static; rather than adapting to measurements of variations, the controller is designed to work assuming that certain variables will be unknown but, for example different model of the ROV . Informally, a controller designed for a particular set of parameters is said to be robust if it would also work well under a different set of assumptions. In Figure 1 (b) the ROV used to test on ASIFLC technique for certain depth. For simulation design consider the thruster as the main component to be controlled so that the ROV will be maintained at a certain depth based on set point. The modeling of thruster can refer [3] and also modeling of ROV can be refer [2].



(a)

(b)

Figure 1: ROV developed by UTeRG

This paper is organized as follows. In section 1, the short brief for introduction to Adaptive Single Input Fuzzy Logic Controller. Next, section 2 will be described the experiments done on ROV by UTeRG using Adaptive Single Input Fuzzy Logic Controller (ASIFLC). The Section 3 will present the Model of Mako was developed by Louis Andrew Gonzalez from Mobile Robotics Laboratory, Centre for Intelligent Information Processing Systems, School of Electrical, Electronic and Computer Engineering, The University of Western Australia, while Section 4 will describe the Nonlinear RRC ROV- unperturbed with 6 DOF was developed by C.S. Chin from Nanyang Technology University (NTU). Finally, the final remarks are elucidated in Section 5.

2. UTeRG ROV

This ASIFLC will be used to control of an ROV for follows certain depth and remain maintain its position. Sometimes this task called station keeping operation mode where the controller service to stabilize the ROV at a certain depth. Figure 2 shows the simulation of ASIFLC that applied to control the depth of ROV based on the set point settled. The results of this simulation as shown in Figure 3 and Figure 4. The control objective is to prove a controller that can guarantee the suppression or limitations of overshoot in the system response. For depth control, overshoot in the system response is particularly dangerous. Clearly an overshoot in the ROV vertical trajectory (heave motion) may possibly cause damage to both the ROV and the inspected structures in [8 -10] . The purpose of this research is to prove the ASIFLC design for depth control of the ROV is the robust control. The main attempt is to develop a controller that can guarantee the limitation of the overshoot in the system response to the depth set point. This controller is to keep the amplitude of the overshoot in the response drastically limited to a depth set-point change, while keeping the response time reasonably contained. The reasons are particularly important when the vehicle operates in a dangerous environment, like that found in offshore structures or during archeological activities. The necessity of assuring vehicle integrity while operating near the bottom or proximity of submersed installations and the need to prevent cable stress, without comprising the system efficiency.

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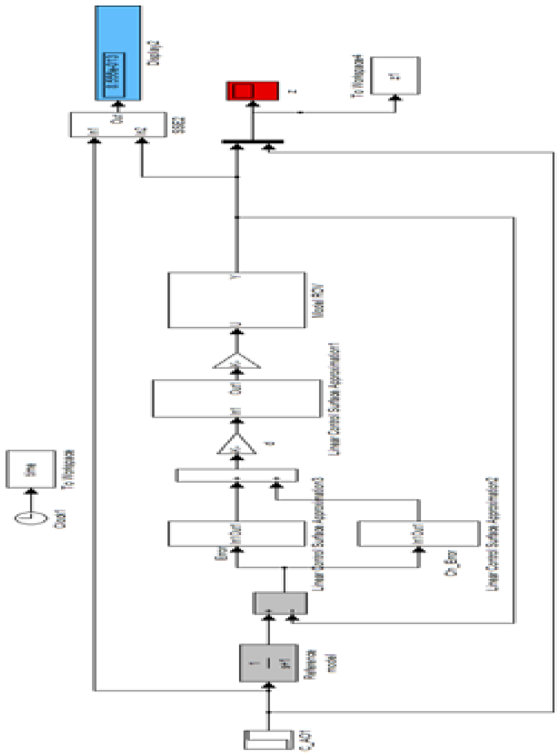
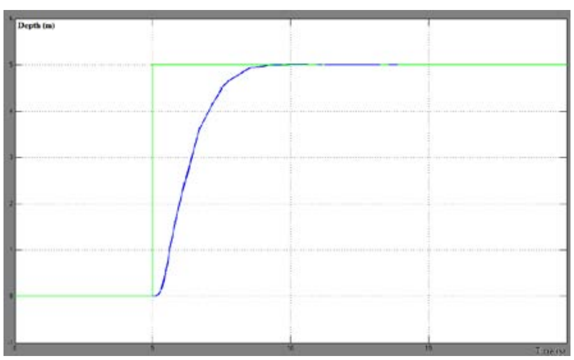
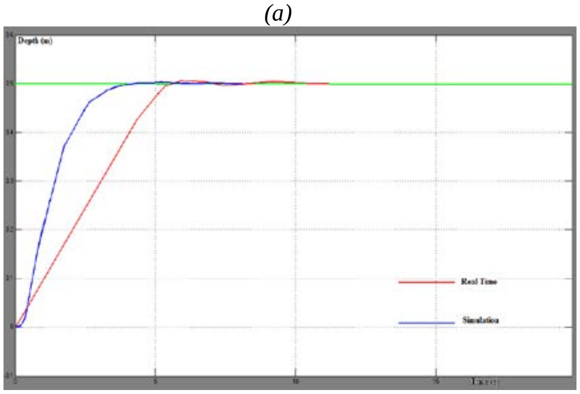


Figure 2: Adaptive Single Input FLC is applied to control the ROV

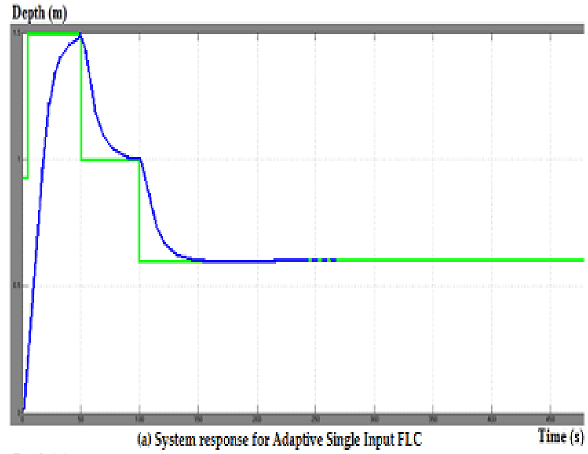


(a)



(b)

Figure 3: System response controlled by ASIFLC



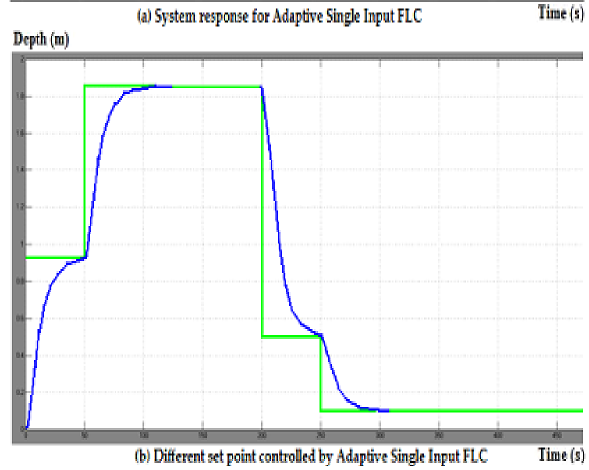


Figure 4: System response for Adaptive SIFLC

This method called as Adaptive Single Input Fuzzy Logic Controller. This technique claims gives the best performances in system response and can adapt any changing of different set point. As proved, another set point also applied in this system for testing the proposed controller as shown in Figure 4 (b). It shows that the Adaptive SIFLC can adapt any changing of set point. Adaptive Single Input FLC is applied to control the ROV with a present of uncertainties or disturbances. In this disturbance assumes comes from environmental disturbances such as waves (wind generated), ocean currents and wind. In general, these disturbances can be represented as both additive or multiplication to the dynamics equation of motion as presented in Figure 5. And the simulation response is shown in Figure 6 (a) (b).

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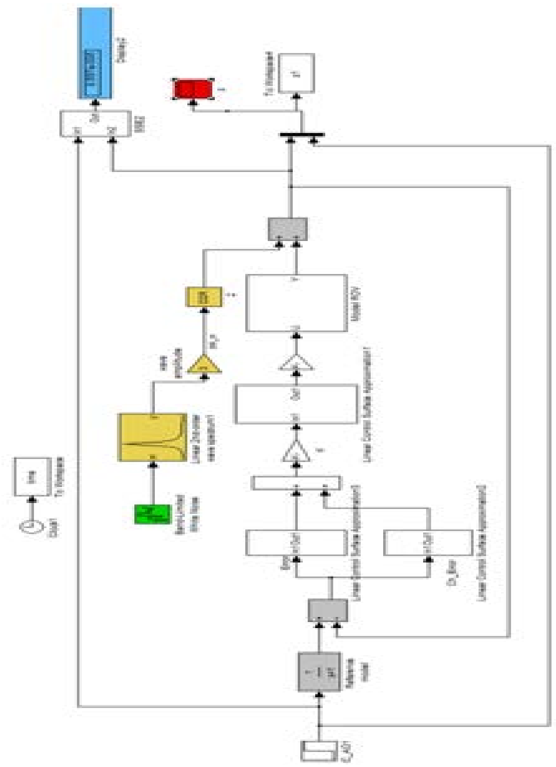
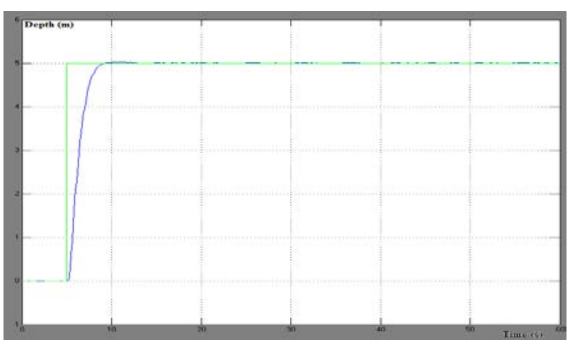
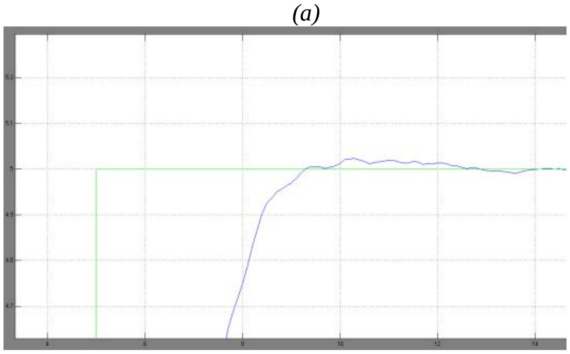


Figure 5: ASIFLC Controller Simulink Block Diagram For Depth Control With Present Of Environmental Disturbances



(a)



(b) Snap to overshoot

Figure 6:System Response of ASIFLC.

The percentage of overshoot in the system response for ASIFLC with present environmental disturbances is 0.46%. The error still lower and can be accepted and ASIFLC is robust controller even present of disturbances. Next section the ASILFC will be implemented in another model of ROV so that the controller can adapt any changing of parameters of the ROV.

3. MAKO ROV

Based on the [11] presented (theoretical for dynamic equation for unmanned underwater vehicle), as well as measurements performed on the vehicle, the matrices of the dynamic model were simplified and adapted to the ROV Model named “Mako” as shown in Figure 7. These simplified matrices are presented in this section so that can be used to apply ASIFLC for depth control. Noted that since sway, roll and pitch are negligible, then the corresponding parameters in the following matrices have been set to zero since they are not required to be identified for controlling the Mako [11]. Model “Mako” was developed by Louis Andrew Gonzalez from Mobile Robotics Laboratory, Centre for Intelligent Information Processing Systems, School of Electrical, Electronic and Computer Engineering, The University of Western Australia.

3.1 Mass and Inertia Matrix

With the vehicle frame positioned at the center of gravity and since the vehicle is assumed fairly symmetrical about all axes, then M_{RB} can be simplified to a good approximation to (1). Since roll, pitch and sway are considered negligible, and then equation (2) can be further simplified to,

Figure 7: ROV Mako

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$$M_{RB} = \begin{bmatrix} 35.3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 35.3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & I_z \end{bmatrix} \quad (1)$$

or,

$$M_{RB} = diag\left\{ 35.3 \quad 0 \quad 35.3 \quad 0 \quad 0 \quad I_z \right\} \quad (2)$$

Where the mass of the "Mako" was measured to be 35.3kg. It can be seen from equations (3) and (4) that the only parameter that needs identification for this matrix is the inertial moment about the z axis corresponding to yaw. Analogous to the simplification of M_{RB}, the added mass matrix, M_A, becomes,

$$M_A = \begin{bmatrix} X_{\dot{u}} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_{\dot{w}} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & N_{\dot{r}} \end{bmatrix} \quad (3)$$

or

$$M_A = diag\left\{ X_{\dot{u}} \quad 0 \quad Z_{\dot{w}} \quad 0 \quad 0 \quad N_{\dot{r}} \right\} \quad (4)$$

3.2 Hydrodynamic Damping Matrix

The hydrodynamic damping matrix, D (V), from equation (5) simplifies to the equation (6),

$$D(V) = \begin{bmatrix} X_u + X_{u|u|}|u| & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_w + Z_{w|w|}|w| & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & N_r + N_{r|r|}|r| \end{bmatrix} \quad (5)$$

Or

$$D(V) = diag\left\{ X_u + X_{u|u|}|u| \quad 0 \quad Z_w + Z_{w|w|}|w| \quad 0 \quad 0 \quad N_r + N_{r|r|}|r| \right\} \quad (6)$$

3.3 Gravitational and Buoyancy Vector

The center of gravity is denoted as $r_G = [\,0\ 0\ 0\,]^T$ while the center of buoyancy is denoted as $r_B = [\,x_B\ y_B\ z_B\,]^T$. By experimental verification, r_B was found to be $r_B = [\,0\ 0\ 0.24\,]^T$ to a good approximation. This shows that the center of buoyancy is aligned with the center of gravity along the x and y axes. In fact, the mass and volume of the Mako were intentionally distributed in such a way that the only misalignment between the centers of mass and buoyancy was via the z axis. This distance of 24cm between the two centroids provides the metacenter righting moment that passively controls the vehicle's roll and pitch. The weight of the Mako was found to be 345.9N while the buoyant force was measured as 361.0N. Keeping in mind that roll and pitch are negligible, equation significantly simplifies as equation (7),

$$G = \begin{bmatrix} 0 \\ 0 \\ -15.1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (7)$$

The value of -15.1N implies that the vehicle has residual buoyancy just as it was designed to have. The residual buoyancy equates to 4.3% of the vehicle's weight which is more than that required by the underwater competition. Equation 7 shows that the gravitational and buoyant forces of the vehicle only affect the heave of the vehicle. This is expected given that the centers of gravity and buoyancy are aligned along the x and y axes, and hence, the gravitational and buoyant forces should then only affect vertical movement.

3.4 Forces and Torque Vector

By measuring the positions of the motors on the "Mako", a layout of the thrusters depicting their respective distances to the vehicle's center of gravity was attained. This can be seen in Figure 8.

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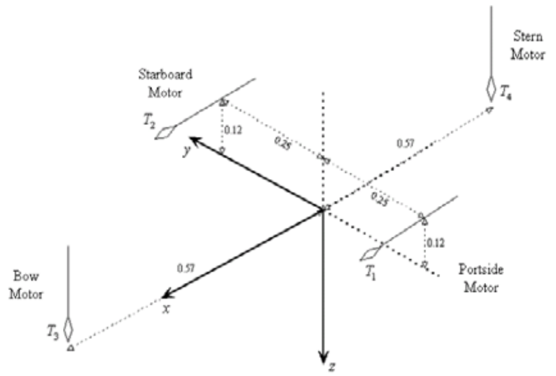


Figure 8: The Mapping Matrix, L (Thrust position)

From Figure 8, the mapping matrix, L, for the Mako is given to a good approximation by,

$$L = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \\ -0.12 & -0.12 & -0.57 & 0.57 \\ 0.25 & -0.25 & 0 & 0 \end{bmatrix} \quad (8)$$

While the thrust vector is given by,

$$U = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{bmatrix} \quad (9)$$

Figure 9 shows the ROV modeling based on parameters given while Figure 10 shows the MATLAB Simulink for Mako ROV using ASIFLC. As mentioned this ROV will set for depth control only. The system response of this ROV as shown in Figure 11.

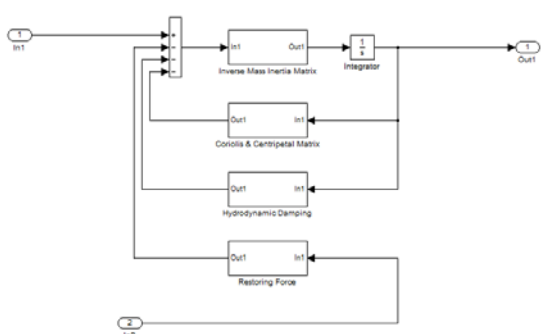


Figure 9: Modelling of Mako ROV

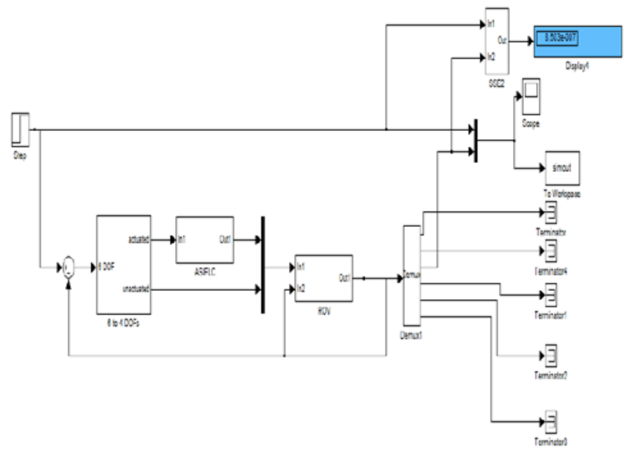
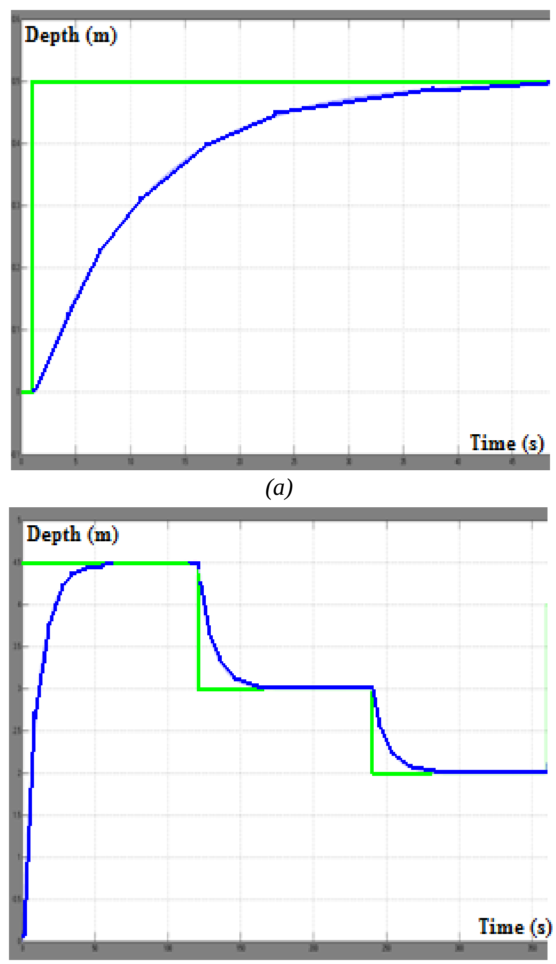


Figure 10: Simulink for Mako ROV using ASIFLC



(a)

(b)

Figure 11: System Response Of Depth Control

4. NONLINEAR RRC ROV-UNPERTURBED (6DOF)

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This Nonlinear RRC ROV- unperturbed with 6 DOF was developed by C.S. Chin from Nanyang Technology University (NTU) [12-13] as shown in Figure 12. This ROV modelling will be used to apply Adaptive SIFLC for depth control. The parameter of ROV totally not changing. Figure 13 shows the simulation of ASIFLC for control the depth of RRC-ROV using MATLAB Simulink. The depth will be set up for 5 meters. And Figure 14 shows the system response of depth control. Even ASIFLC based on UTeRG ROV, it looks like the ASIFLC can control the ROV with same parameter of previous ROV. But it takes time to control this ROV.

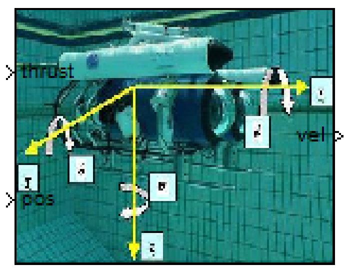

Figure 12: Nonlinear RRC ROV- unperturbed (6DoF)

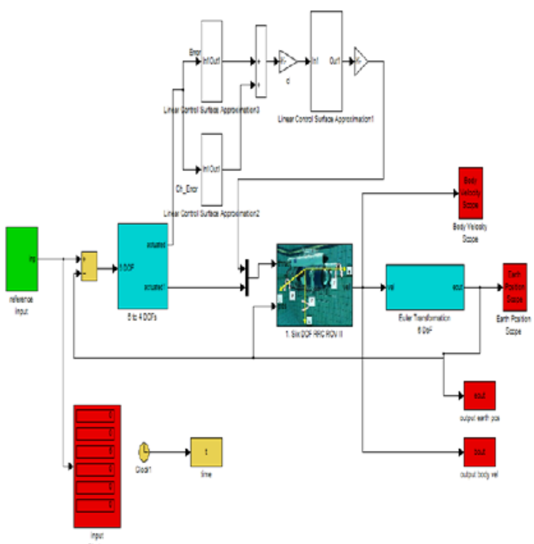

Figure 13:Adaptive SIFLC applied on six DOF RRC ROV II.

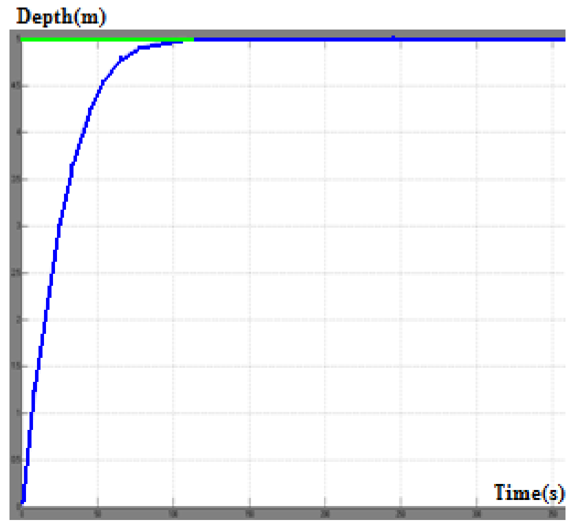

Figure 14: System Response Of Depth Control for RRC ROV II

5. CONCLUSION

Adaptive Single Input Fuzzy Logic Controller (ASIFLC) proved as a robust controller for Unmanned Underwater Vehicle (UUV) especially for Remotely Operated Vehicle (ROV). Three ROV will be used to apply ASIFLC successfully controlled where the simulation of controlling three different ROV by ASIFLC focused on depth control considered done. The performances of system response for depth control of Adaptive Single Input Fuzzy Logic Controller for Unmanned Underwater Vehicle studied and it is proved the Adaptive Single Input Fuzzy Logic Controller is the robust controller even present of environmental disturbances.

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