DESIGN OF ROV STRAIGHT MOTION CONTROL USING PROPORTIONAL SLIDING MODE CONTROL METHOD

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Abstract. *The development of underwater defense technology is commonly related to its usage for security and defense of a country. The need of NKRI (the Republic of Indonesia) for an applicable and multifunctional technology for highly improved unmanned submarines is urgent considering the current necessity of unmanned technology modernization functioning as The Main Weapon System Equipments (ALUTSISTA) to be applied as a spy technology or automatic weapon. This paper focus is on a motion control system design with the motion equation of 2 Degree of Freedom (DOF) applied to an unmanned submarine system or also called a Remote Operated Vehicle (ROV). ROV requires a control system to control its maneuvering motion when underwater, especially in a straight line motion. The ROV motion equation of 2-DOF consisting of surge and roll motions is in the form of a nonlinear equation. The system control design applied to the ROV system used the Proportional Controller method combined with Sliding Mode Control. The simulation results of the Proportional SMC control system with the motion equation of 2-DOF on the ROV system show that the system is stable with an accuracy of surge and roll motions of 95% - 99%.*

Keywords: *ROV,, 2-DOF, Proportional, SMC, Control system*

1. INTRODUCTION

In the current world of military industry, many countries have prepared their weapons for air, sea and land uses. We know that our country is an archipelagic country, so it is of necessity to have such a vehicle for a defense system [1] [2] The development of underwater defense technology commonly focuses on defense. The NKRI's need for an applicable and multifunctional technology is a very important issue in the current effort to modernize unmanned submarines functioning as the Main Weapon System Equipment (ALUTSISTA), which is applied as a spy technology or automatic weapon [3] [4]

Most underwater vehicles being developed by many countries today are unmanned underwater robots or unmanned submarines. Such a robot type, known as the Remote Operated Vehicle (ROV) is a type of underwater robot relatively flexible for underwater exploration and underwater defense system equipment [5] [6]. ROV is an effective technology to protect Indonesia's marine resource potential. ROV is very much needed to assist Indonesia's underwater exploration survey [7]. ROV requires a control system to control its maneuvers under water, especially in a straight line.

One of the motion controls is Sliding Mode Control which is effective for either nonlinear or linear systems [8]. SMC proved to be reliable for nonlinear model control systems, that is, the steam drum boiler system [9], on the AUV with 3-DOF nonlinear models [10] and 6 DOF linear models [11], and ASV linear models [12] [13]with an average error of 5%. PID proved to be reliable for motion control of AUV [14] [15]. In this paper, we try to combine the SMC and Proportional methods of which the Proportional method is a PID controller excluding its integral and derivatives, or in other words the integral and derivative values are zero.

This paper starts with the preparation of a motion equation model with 2-DOF, that is, surge and roll motions. Surge and roll motions are translational and rotational motions for straight motion on the x-axis. Then, a motion control system design for forward motion is developed using a combination of the Proportional Controller method and the Sliding Mode Controller. Next, the error and accuracy of the simulation and the settling time generated from the Proportional SMC method are determined by analyzing the simulation results.

2. RESEARCH METHODS

2.1 Mathematical Model of Remote Operated Vehicle

The profile of ROV can be seen in Figure 1, and the specifications of ROV can be seen in Table 1. This paper uses the motion equations of 2-DOF, namely surge and roll, ignoring sway, heave, pitch and yaw motions [16]. Here is the motion equation of 2-DOF:

$$\dot{u} = \frac{X_{ROV\_res}+X_{|u|u}u|u|+X_{prop}}{m-X_{\dot{u}}} \qquad (1)$$

$$\dot{p} = \frac{K_{ROV\_res}+K_{p|p|}p|p|+K_{prop}}{I_x-K_{\dot{p}}} \qquad (2)$$

Of which X_{ROV_res} dan K_{ROV_res} are hydrostatic forces and moments in the x-axis direction, X_{prop} dan K_{prop} as thrust forces and moments. The profile and specifications of the *Rescue* ROV are shown in Figure 1 dan Table 1.
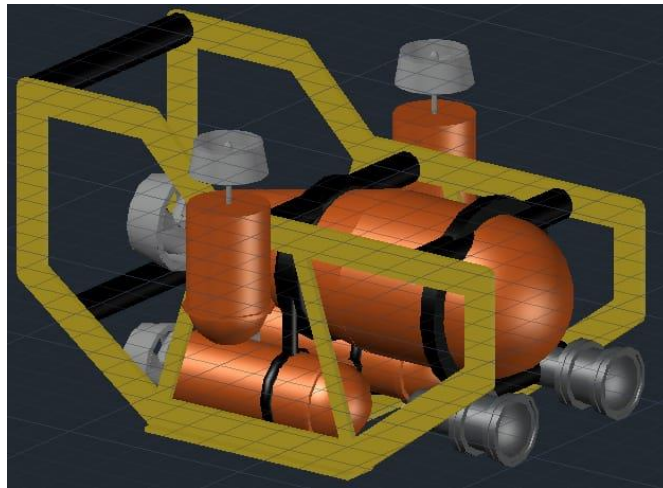
Figure 1. The Profile of the Rescue ROV [5]

Table 1. The Specifications of the Rescue ROV [5]

Weight	15 Kg
Length Overall	900 mm
Beam	300 mm
Controller	Wired Control ArduSUB with Joystick
Sensors	Depth Sensor, Sonar
Camera	TTL Camera
Lighting	1500 LM, 145∘ Beam Dimmable
Battery	11,8 V Li Po 5200 mAh
Material	Carbon Fiber
Main Propulsion	T200 Motor Thruster include propeller
Maneuver Propulsion	T200 Motor Thruster include propeller
Service Speed	1,6 knots
Operation Depth	5 - 10 m

The research methodology in this paper is as represented by the research flowchart below:
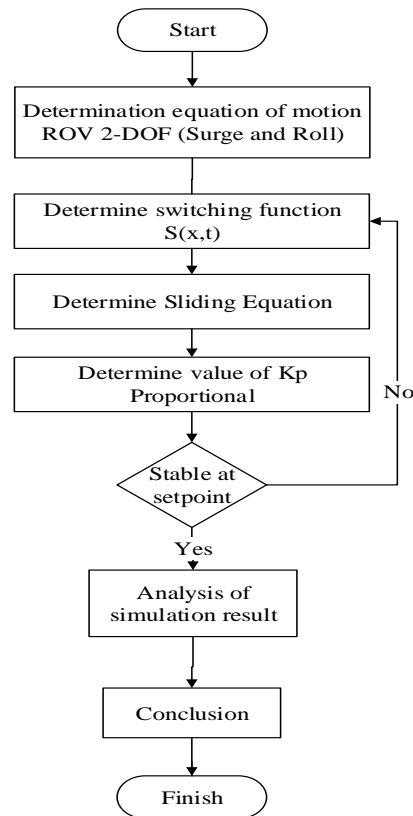
Figure 3. Research Flow-chart

2.2 Design of Proportional SMC Control System

In this section, the SMC control system is designed to obtain control inputs for surge and roll motions. To find control of the surge, first the tracking error of the surge is determined as follows:

$:\tilde{u} = u - u_d \qquad u_d$=constant

Since the system is of order 1, switching function is formed as follows [9]:

$$S(u,t) = \left(\frac{d}{dt}\right)^{n-1} \tilde{u} \text{ dengan n=1}$$

$$S(u,t) = \left(\frac{d}{dt}\right)^{1-1} \tilde{u}$$

$$S(u,t) = \tilde{u} = u - u_d$$

Whereas the derivative of S is as below :

$$\dot{S}(u,t) = \dot{u} - \dot{u}_d \qquad\qquad\qquad (3)$$

Since u_d=constant, then $\dot{u}_d = 0$

By substituting equation (1) into (3), it becomes :

$$\dot{S}(u,t) = \frac{X_{ROV\_res} + X_{|u|u}u|u| + X_{prop}}{m - X_{\dot{u}}} \qquad\qquad (4)$$

After that the value of $\hat{X}_{prop}$ in equation (4) is determined with the value of $\dot{S} = 0$

$$\frac{X_{ROV\_res} + X_{|u|u}u|u| + X_{prop}}{m - X_{\dot{u}}} = 0 \qquad\qquad (5)$$

So, the obtained value of $\hat{X}_{prop}$ is

$$\hat{X}_{prop} = -\left(X_{ROV\_res} + X_{|u|u}u|u|\right) \qquad (6)$$

Based on *control* law, that fulfills the condition of. *sliding* is as below:

$$X_{prop} = \hat{X}_{prop} - K_1\, sgn\,(S) \qquad (7)$$

In the same way of obtaining the sliding equation of the surge motion system in equations (3) – (7), in designing the sliding equation of the roll motion system, we also perform the same algorithmic steps as the surge motion. To find the sliding equation of the roll motion, first the tracking error of the roll is determined as follows:

$$\tilde{p} = p - p_d \qquad p_d = \text{constant}$$

Since the system is of order 1, the *switching* function is determined as follows:

$$S(p,t) = \left(\frac{d}{dt}\right)^{n-1} \tilde{p} \text{ with n=1}$$

$$S(p,t) = \left(\frac{d}{dt}\right)^{1-1} \tilde{p}$$

$$S(p,t) = \tilde{p} = p - p_d$$

Whereas the derivative of S is as below:

$$\dot{S}(p,t) = \dot{p} - \dot{p}_d \qquad (8)$$

Since p_d=constant, then $\dot{p}_d = 0$

By substituting equation (2) into (8), it becomes:

$$\dot{S}(p,t) = \frac{K_{ROV\_res} + K_{p|p|}p|p| + K_{prop}}{I_x - K_{\dot{p}}} \qquad (9)$$

Then, the value of $\hat{K}_{prop}$ in equation (9) is determined with the value of $\dot{S} = 0$

$$\frac{K_{ROV\_res} + K_{p|p|}p|p| + K_{prop}}{I_x - K_{\dot{p}}} = 0 \qquad (10)$$

Thus, the obtained value of $\hat{K}_{prop}$ is

$$\hat{K}_{prop} = k - \left(K_{ROV\_res} + K_{p|p|}p|p|\right) \qquad (11)$$

Based on *control law*, that fulfilling the condition of *sliding* as below:

$$K_{prop} = \hat{K}_{prop} - K\, sgn\,(S) \qquad (12)$$

After obtaining the sliding equation of the surge and roll motion, the combination of the Proportional and SMC control systems, in which the method used to determine the proportional value is trial and error. The Proportional value obtained for the surge motion is 5 and that for the roller motion is 8. Whereas, those for the integral and derivative values are 0. Because it only uses the Proportional method of PID Control.

3. RESULTS AND DISCUSSION

After the design of the Proportional SMC control system on the 2-DOF nonlinear model was made, it was then simulated on the Matlab simulink. This control system was arranged in a block diagram with an ROV in the form of a closed loop as shown in Figure 4.
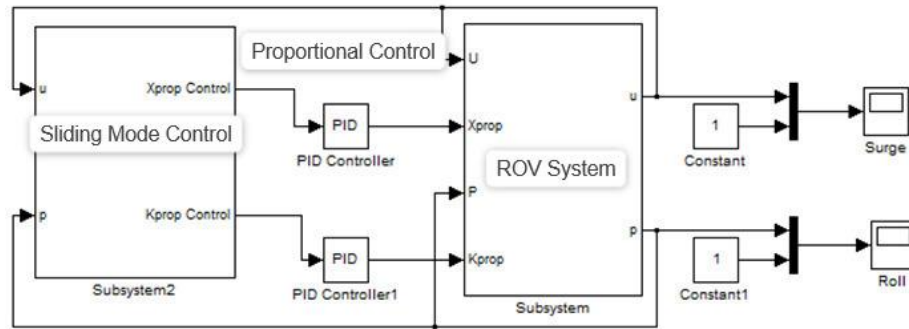
Figure 4. AUV Block Diagram of nonlinear model of 2-DOF and Proportional SMC Control System

After the control systems of SMC + Proportional dan ROV had been simulated, the responses for translational and rotational motions were produced as shown in Figure 5 and Figure 6.
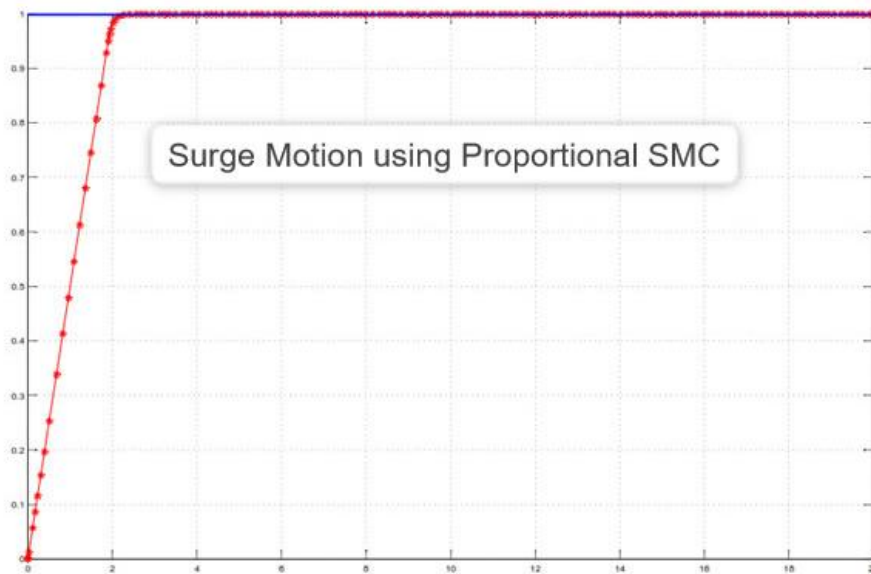

Figure 5. Responses of Surge motion by Proportional SMC Control System
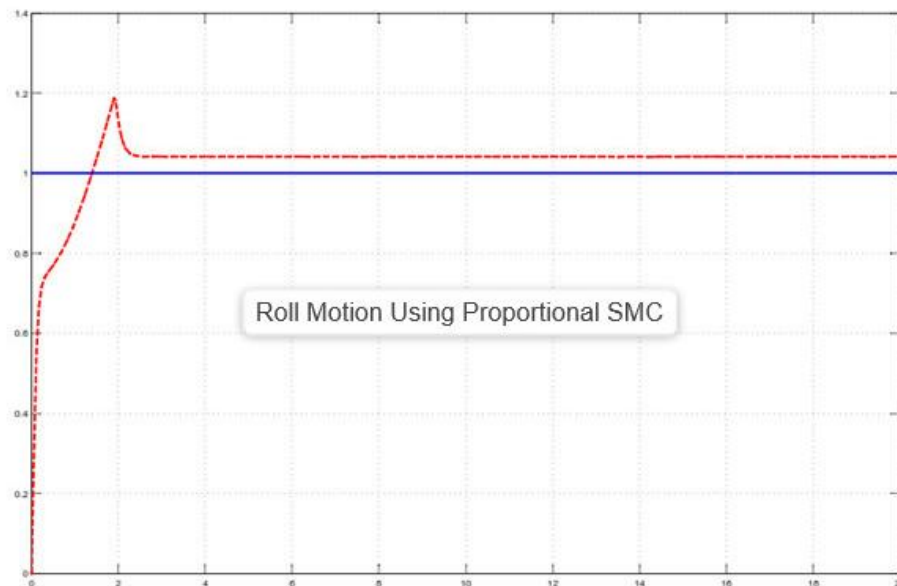

Figure 6. Responses of Roll Motion by Proportional SMC Control System

Figure 5 shows the result of the proportional SMC responses for surge motion. It appears that the surge response is stable at a setpoint of 1 m/s and can reach a settling time of 2 seconds with an error of 0.008% or an accuracy of about 99.992%. Meanwhile, Figure 6 represents the results of the Proportional SMC response

for roll motion. It can be seen that the roll motion response is at a setpoint of 1 rad/s and a settling time of 2.2 seconds with an error of 4.2% or an accuracy of about 95.8%, reaching a maximum overshoot of 1.2 rad/s.

4. CONCLUSION

Based on the simulation results and discussion, it can be concluded that the Proportional SMC method is applicable to the ROV to control its maneuvering motion while underwater, especially the ROV's straight motion with an accuracy of about 99.992% and a settling time of 2 seconds, and an accuracy for roll motion of about 95.8% and a settling time of 2.2 seconds.

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