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

Firman Yudianto¹, Teguh Herlambang²*, Fajar Annas Susanto³, Andy Suryowinoto⁴, Berny Pebo Tomasouw⁵

¹,² Information System Department, FEBTD, Universitas Nahdlatul Ulama Surabaya
Raya Jemursari St., No. 51-57, Surabaya, 60237 Indonesia

⁴ Electrical Engineering Department, Institut Teknologi Adhi Tama Surabaya
Arief Rahman Hakim St., No.100, Surabaya, 60117, Indonesia

³Mathematics Department, Universitas Pattimura
Ir. M. Putuhena St., Poka, Ambon, 97233, Indonesia

*Corresponding author’s e-mail: *teguh@unusa.ac.id

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

Article info:
Submitted: 4th July 2022 Accepted: 29th August 2022

How to cite this article:
F. Yudianto, T. Herlambang, F. A. Susanto, A. Suryowinoto and B. P. Tomasouw, “DESIGN OF ROV STRAIGHT MOTION CONTROL USING PROPORTIONAL SLIDING MODE CONTROL METHOD”, BAREKENG: J. Math. & App., vol. 16, no. 3, pp. 1051-1058, September, 2022.
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:

\[
\ddot{u} = \frac{X_{\text{ROV, res}} + X_{|u|}u + X_{\text{prop}}}{m - X_a}
\]

\[
\ddot{p} = \frac{K_{\text{ROV, res}} + K_{plp}p + K_{\text{prop}}}{t_s - K_p}
\]

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

| Specification          | Details                                      |
|------------------------|----------------------------------------------|
| 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:
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:

\[ \tilde{u} = u - u_d \quad u_d=\text{constant} \]

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:

\[ \dot{S}(u, t) = \dot{\tilde{u}} - \tilde{u}_d \quad \text{(3)} \]

Since \( u_d=\text{constant} \), 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||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u||u|
\[ \dot{X}_{\text{prop}} = -(X_{\text{ROV, res}} + X_{|u|u|u|}) \]  

(6)

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

\[ X_{\text{prop}} = \dot{X}_{\text{prop}} - K_1 \text{sgn} (S) \]  

(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:

\[ \ddot{p} = p - p_d \quad p_d=\text{constant} \]

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

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

\[ S(p, t) = \left( \frac{d}{dt} \right)^{1-1} \ddot{p} \]

\[ S(p, t) = \ddot{p} = p - p_d \]

Whereas the derivative of S is as below:

\[ \dot{S}(p, t) = \dot{\ddot{p}} - \dot{p}_d \]  

(8)

Since \( p_d=\text{constant} \), then \( \ddot{p}_d = 0 \)

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

\[ \dot{S}(p, t) = \frac{K_{\text{ROV, res}} + K_{\text{pl}}|p| + K_{\text{prop}}}{I_x - K_p} \]  

(9)

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

\[ \frac{K_{\text{ROV, res}} + K_{\text{pl}}|p| + K_{\text{prop}}}{I_x - K_p} = 0 \]  

(10)

Thus, the obtained value of \( \dot{R}_{\text{prop}} \) is

\[ \dot{R}_{\text{prop}} = k - \left( K_{\text{ROV, res}} + K_{\text{pl}}|p| \right) \]  

(11)

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

\[ K_{\text{prop}} = \dot{R}_{\text{prop}} - K \text{sgn} (S) \]  

(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.
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 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.

AKNOWLEDGEMENT

This research was supported by LPPM – Nahdlatul Ulama Surabaya of University (UNUSA)

REFERENCES

[1] T. Herlambang, H. Nurhadi and S. Subchan, "Preliminary Numerical Study on Designing Navigation and Stability Control Systems for ITS AUV," Applied Mechanics, vol. 493, pp. 420-425, 2014.
[2] T. Herlambang, E. B. Djatmiko and H. Nurhadi, "Navigation and Guidance Control System of AUV with Trajectory Estimation of Linear Modelling," in International Conference on Advance Mechatronics, Intelligent Manufacture, and Industrial Automation, Surabaya Indonesia, 2015.
[3] S. Subchan, T. Herlambang and H. Nurhadi, "UNUSAITS AUV Navigation and Guidance System with Nonlinear Modeling Motion using Ensemble Kalman Filter," in International Conference on Advance Mechatronics, Intelligent Manufacture, and Industrial Automation, (ICAMIMIA), Malang-Indonesia, 2019.
[4] T. Herlambang, E. B. Djatmiko and H. Nurhadi, "Ensemble Kalman Filter with a Square Root Scheme (EnKF-SR) for Trajectory Estimation of AUV SEGORGENI ITS," International Review of Mechanical Engineering, vol. 9, no. 6, pp. 553-560, 2015.
[5] T. Herlambang, D. Rahmalia, H. Nurhadi, A. Suryowinoto and A. Muhith, "Estimation of Remote Operated Vehicle Motion in XY Plane using Unscented Kalman," in The 1st International Conference on Neuroscience and Learning Technology, Jember, Indonesia, 2021.
[6] Z. Ermayanti, E. Apriliani, H. Nurhadi and T. Herlambang, "Estimate and Control Position Autonomous Underwater Vehicle Based on Determined Trajectory using Fuzzy Kalman Filter Method," in International Conference on Advance Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), Surabaya-Indonesia, 2015.
[7] T. Herlambang, S. Subchan and H. Nurhadi, "Navigation and Guidance Control System of UNUSAITS AUV Based on Dynamical System Using Ensemble Kalman Filter Square Root," in The Third International Conference on Combinatorics, Graph Theory and Network Topology, Jembr, Indonesia, 2019.
[8] H. Nurhadi, T. Herlambang and D. Adzkiya, "Position Estimation of Touristant ASV Using Ensemble Kalman Filter," in International Conference on Mechanical, Yogyakarta, Indonesia, 2019.
[9] T. Herlambang, E. Apriliani, H. Cordova and M. Mardlijah, "Desain Pengendalian Ketinggian Air dan Temperatur Uap pada Sistem Steam Drum Boiler dengan menggunakan Sliding Mode Control (SMC)," in Seminar Nasional Penelitian, Pendidikan, dan Penerapan MIPA, Yogyakarta., 2011.
[10] T. Herlambang, "Desain Sistem Kendali Gerak Surge, Sway Dan Yaw Pada Autonomous Underwater Vehicle Dengan Metode Sliding Mode Control (SMC)," LIMITS, Journal Math and its application., vol. 14, no. 1, pp. 53-60, 2017.
[11] K. Oktafianto, T. Herlambang, M. Mardlijah and H. Nurhadi, "Design of Autonomous Underwater Vehicle Motion Control Using Sliding Mode Control Method," in International Conference on Advance Mechatronics, Intelligent Manufacture, and Industrial Automation, Surabaya, Indonesia, 2015.
[12] D. Adzkiya, H. Nurhadi and T. Herlambang, "Design of Sliding Mode Control for Linearized Touristant ASV Model," in International Conference on Advance Mechatronics, Intelligent Manufacture, and Industrial Automation, Malang, Indonesia, 2019.
[13] H. Nurhadi, E. Apriliani, T. Herlambang and D. Adzkiya, "Sliding Mode Control Design for Autonomous Underwater Vehicle motion under The Influence of Environmental Factor," International Journal of Electrical and Computer Engineering, vol. 10, no. 5, pp. 4789-4797, 2020.
[14] T. Herlambang, T. Rahmalia and T. Yulianto, “Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for Optimizing PID Parameters on Autonomous Underwater Vehicle (AUV) Control System,” in *The Second International Conference on Combinatorics, Graph Theory and Network Topology*, Jember, 2018.

[15] T. Herlambang, S. Subchan and H. Nurhadi, "Design of Motion Control Using Proportional Integral Derivative for UNUSAITS AUV," *International Review of Mechanical Engineering I*, vol. 12, no. 11, pp. 928-938, 2018.

[16] T. Herlambang and H. Nurhadi, "Design of a Sliding PID Controller for The Surge and Roll Motion Control of UNUSAITS AUV," *International Journal of Computing Science and Applied Mathematics*, vol. 3, no. 2, pp. 61-64, 2017.