TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 3, June 2020, pp. 1505~1513
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i3.14781

Velocity control of ROV using modified integral SMC with optimization tuning based on Lyapunov analysis

Syadza Atika Rahmah[1], Eko Henfri Binugroho[2], Raden Sanggar Dewanto[3], Dadet Pramadihanto[4]
[1,3]Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
[2]Department of Mechanical and Energy Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
[4]Department of Information Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia
[1,2,3,4]Robotics and Intelligent System Center, Politeknik Elektronika Negeri Surabaya, Indonesia

Article Info

Article history:

Received Sep 1, 2019
Revised Jan 20, 2020
Accepted Feb 21, 2020

Keywords:

Dynamics control
Remotely operated vehicle
Sliding mode control
Tuning optimization

ABSTRACT

Remotely Operated Vehicle also known as ROV is a vehicle with high nonlinearity and uncertainty parameters that requires a robust control system to maintain stability. The nonlinearity and uncertainty of ROV are caused by underwater environmental conditions and by the movement of the vehicle. SMC is one of the control systems that can overcome nonlinearity and uncertainty with the given robust system. This work aims to control velocity of the vehicle with proposes the use of modified integral SMC compensate error in ROV and the use of particle swarm optimization (PSO) to optimize the adjustment of SMC parameters. The ROV used in this paper has a configuration of six thrusters with five DoF movements that can be controlled. Modified integral sliding mode is used to control all force direction to increase the convergence of speed error. Adjustment optimization techniques with PSO are used to determine four values of sliding control parameters for five DoF. Using Lyapunov stability approach control law of sliding mode is derived and its global stability proved mathematically. Simulation results are conducted to evaluate the effectiveness of Modified Integral SMC and compared with nonlinear control.

Corresponding Author:

Syadza Atika Rahmah,
Department of Electrical Engineering,
Politeknik Elektronika Negeri Surabaya,
Surabaya City, Indonesia.
Email: sar.syadza@gmail.com

1. INTRODUCTION

Remotely Operated Vehicle is an underwater robot controlled by an operator for various applications such as underwater mapping, monitoring, exploration, etc. However, it is still difficult to operate the ROV as there are uncertainties either in its dynamic models or in the navigation and control systems [1]. These uncertainties include nonlinear characteristic systems [2-5] and unpredictable disturbances, such as seawater currents and ocean waves. Nonlinear control for the underwater robot has been studied from different research. For example, Smah Riache et al, introduced a hybrid non-singular terminal sliding-mode control and super-twisting controller with the convergence of minimum chattering of tracking error effects without a singularity problem [6]. Stephen C. et al, comparing the results of the 6DoF coupled nonlinear model with better performance results with a comparison using OLS (ordinary least square), TLS (total least square), and undetermined TLS [7] and also in other research on model-based nonlinear speed control fully coupled 3DoF on dynamic plans shows that nonlinear model-based controller error tracking is lower than excast linearizing model-based [8]. Yanhui Wei et al, controllers can overcome and estimate factors such as external disturbance and uncertain models [9]. For the chattering phenomenon several research have been carried out. Duc Ha Vu et al, achieve high stability and durability and eliminate chattering signals for under-actuated systems with mismatched uncertainties [10]. Bing Sun and Daqi Zhu, controllers removes the chattering phenomenon and compensate disturbance and nonlinear uncertainties in dynamic systems by replacing a switching term with a model based adaptive SMC continuous term [11]. Ding N et al, proposed robust adaptive motion control with velocity constraints [12]. Hosseini M et al, introduced improvement horizontal plane ROV using the adaptive method [13]. Liu H et al, proposed distribution thrust control using adaptive back-stepping controller [14] and also in research on other Sliding Control Modes in ROV [15-18].

In addition, SMC is used because it is robust for controlling the depth of ROV in uncertainty modeling [19]. To find the best value of SMC parameters, the optimization technique is needed. Several combination SMC and optimizations methods have been studied from different views. Cheng Siong et al, introduced a method to deal with linearity and uncertainty of interference by computational fluid dynamics [1]. Zhenzhong et al, Immeasurable condition estimation is used adaptively on sliding-mode terminals that are observing based on local RNN so as to guarantee the limited time convergence of tracking error [2]. Hernandez-Alvarando R. et al, proposed tuning parameter using backpropagation Neural Networks for underwater vehicles [20]. But those optimizations need more delay because of complexity. One of the optimizations that need less delay is PSO [21, 22]. Bordoloi N et al, PD-SMC parameters are optimized with PSO to solve high-frequency chat problems and track desired trajectories in a faster way [21]. Dehdarinejad M et al, the phase-shifted full-bridge (PSFB) SMC parameters optimized with PSO show robust results and to improve system speed and accuracy [22]. Therefore, it is necessary to optimize the SMC with the PSO to control speed movement and error response converges to zero for ROV.

This paper proposes the optimization tuning technique Modified Integral Sliding Mode Control with PSO in ROV. The parameters of the Modified Integral sliding mode control consist of four parameters, namely γ, λ, α, and β for each of the DoFs. Modification of the SMC is the planning of different control inputs according to the movement attitudes of the 5 DoFs in one controlled vehicle. Then the total optimized tuning parameters are twenty tuned parameters for the five controlled DoFs with six thrusters configuration. The best parameter selection is done by achieving the best fitness value. Stability Theory of Lyapunov is calculated to prove in theory about the results of parameter values that must be obtained. The simulation results are compared with the PID method. This comparison is seen from the achievement of the expected error value and ROV speed. Furthermore, an analysis is carried out to prove the ability of the robustness in the proposed method with the given parameter uncertainty values starting at 10% until the system cannot handle it. Simulation results are given to provide an illustration of the performance of the controller in dynamic system control in the ROV.

2. RESEARCH METHOD

ER2C ROV design as shown in Figure 1 [23]. E-ROV has 6 units thrusters with each configuration. Four horizontal thrusters mounted in the opposite direction by having the same azimuth angle and parallel position. And on two vertical thrusters that are mounted parallel to the same facing position, but with different force vector. For Surge, Sway, and Yaw motion using thrusters number 1, 2, 3, and 4 with changes of direction rotation. For Heave and Pitch motion using vertical thrusters numbers 5 and 6. The ROV's pitch and yaw motion are actively controlled whilst the roll motion is naturally depending on the Buoyancy effect.

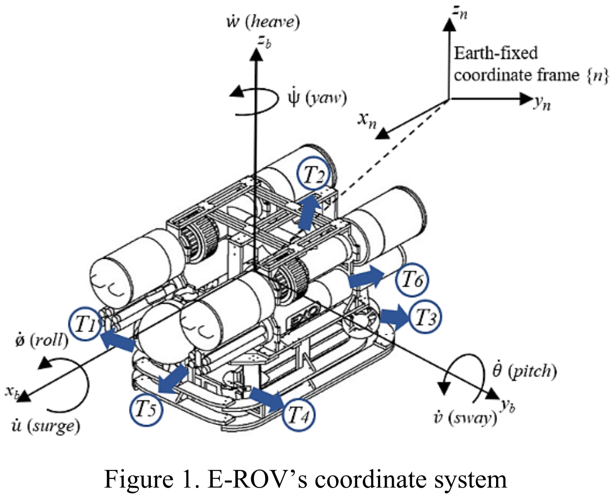


Figure 1. E-ROV's coordinate system

The effect is mostly generated by the upper side hulls, as can be seen in Figure 1 that the roll movement will naturally be neutralized. There are two reference frame that was used in this work i.e. world-fixed reference frame (W) and body-fixed reference frame (B). For frame-W it is a combination of directions in the world, where the x-axis points north, the y-axis points to the east, and the z-axis leads to the midpoint of the earth. Whereas for B-frame is conditioning on the body of the E-ROV vehicle itself, where the x-axis leads to the forward direction of the vehicle, the y-axis leads to the right direction of the vehicle, and the z-axis leads to the vertical axis below the vehicle. The following is a description of the frame used in the E-ROV. All degrees of freedom in this study can be demonstrated with the state space as:

$$\dot{\boldsymbol{v}} = \boldsymbol{f}(v) + \boldsymbol{g}(\eta) + \boldsymbol{u} \quad (1)$$

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \\ \ddot{\emptyset} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} \frac{X_u+X_{u|u|}|u|}{m+X_{\dot{u}}} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{Y_v+Y_{v|v|}|v|}{m+Y_{\dot{v}}} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{Z_w+Z_{w|w|}|w|}{m+Z_{\dot{w}}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{K_p+K_{p|p|}|p|}{I_X+K_{\dot{p}}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{M_q+M_{q|q|}|q|}{I_y+M_{\dot{q}}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{N_r+N_{r|r|}|r|}{I_z+N_{\dot{r}}} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{\emptyset} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} + \begin{bmatrix} \frac{(W-B)\sin(\theta)}{m+X_{\dot{u}}} \\ 0 \\ \frac{-(W-B)\cos(\theta)\cos(\emptyset)}{m+Z_{\dot{w}}} \\ 0 \\ \frac{(-z_B B)\sin(\theta)}{I_y+M_{\dot{q}}} \\ 0 \end{bmatrix} + \begin{bmatrix} \frac{0,707(-F_1+F_2+F_3-F_4)}{m+X_{\dot{u}}} \\ \frac{0,707(F_1+F_2-F_3-F_4)}{m+Y_{\dot{u}}} \\ \frac{F_5-F_6}{m+Z_{\dot{w}}} \\ \frac{0}{I_X+K_{\dot{p}}} \\ \frac{0,03(F_1-F_2-F_3+F_4)+0,199F_5+0,303F_6}{I_y+M_{\dot{q}}} \\ \frac{0,291(-F_1+F_4)+0,245(F_2+F_3)}{I_z+N_{\dot{r}}} \end{bmatrix} \quad (2)$$

Where $\boldsymbol{f}(v)$ is a function consisting of adding linear effects and nonlinear attenuation divided by mass, $\boldsymbol{g}(\eta)$ is the effect of hydrostatic, and u is the input control force thrusters. Input is obtained from the sliding mode control design control. Sliding Mode Control is one of the simplest control forms on robust controlling approaches. Settlement using SMC by simplifying the formulation means that it replaces the problem with the high order value (nth) with the problem of stability on the 1st order [24]. Based on tracking error vectors and derivatives in translational and rotational speeds, namely:

$$\xi = \boldsymbol{v}_d - \boldsymbol{v} \quad (3)$$

$$\dot{\xi} = \dot{\boldsymbol{v}}_d - \dot{\boldsymbol{v}} \quad (4)$$

where $v_d = [\dot{x}_d, \dot{y}_d, \dot{z}_d, \dot{\phi}_d, \dot{\theta}_d, \dot{\psi}_d]^T$ is the position vector and the setpoint or desired attitude of E-ROV and $\boldsymbol{v}$ is the result of the E-ROV system. Because the dynamic system on E-ROV is a first-order system for controlling the speed of movement of E-ROV, then the sliding surface for each DoF can be designed as follows:

$$s_i = \lambda_i \boldsymbol{\xi}_{vi} + \gamma_i \int \boldsymbol{\xi}_{vi} \quad (5)$$

for $\boldsymbol{\xi}_{vi}$ is a tracking error vector, λ_i is positive reinforcement and to compensate the effect of an integrator, γi as the integrators, and s_i is a vector of sliding surfaces. γi parameter addition has a function as an integrator for optimizing error to be zero. Input control is done by reducing the error value in (4), the dynamic control system in sliding mode becomes $\dot{s}_i$ and its derivate values become:

$$\dot{s}_i = \lambda_i \dot{\xi}_v + \gamma_i \xi_{vi} \quad (6)$$

substituting (4) and (1) the dynamic results can be written as:

$$\dot{s}_i = \lambda_i\left(\dot{\boldsymbol{v}}_d - \left(\boldsymbol{f}_i(v) + \boldsymbol{g}_i(\eta) + \boldsymbol{u}_i\right)\right) + \gamma_i \xi v_i \quad (7)$$

The input value is needed to cancel the new dynamic effect called u_{eq} and the sliding controller input mode named u_{smc}, the sum of the two inputs can be formulated as a control input. In this paper, we propose the u_{smc} modification by combining the discontinuous function sign(s) and sat(s) according to the behavior of each DoF movement. With control input as follows:

$$u_{(\dot{x})} = (\ddot{x}_d - f_1(\dot{x}) - g_1(x) + \gamma_x e_{vx})\frac{1}{\lambda_x} + \alpha_x s_x + \beta_x \, sat(s_x) \tag{8}$$

$$u_{(\dot{y})} = (\ddot{y}_d - f_2(\dot{y}) - g_2(y) + \gamma_y e_{vy})\frac{1}{\lambda_y} + \alpha_y s_y + \beta_y \, sign(s_y) \tag{9}$$

$$u_{(\dot{z})} = (\ddot{z}_d - f_3(\dot{z}) - g_3(z) + \gamma_z e_{vz})\frac{1}{\lambda_z} + \alpha_z s_z + \beta_z \, sat(s_z) \tag{10}$$

$$u_{(\dot{\phi})} = (\ddot{\phi}_d - f_4(\dot{\phi}) - g_4(\phi) + \gamma_\phi e_{v\phi})\frac{1}{\lambda_\phi} + \alpha_\phi s_\phi + \beta_\phi \, sign(s_\phi) \tag{11}$$

$$u_{(\dot{\theta})} = (\ddot{\theta}_d - f_5(\dot{\theta}) - g_5(\theta) + \gamma_\theta e_{v\theta})\frac{1}{\lambda_\theta} + \alpha_\theta s_\theta + \beta_\theta \, sign(s_\theta) \tag{12}$$

$$u_{(\dot{\psi})} = (\ddot{\psi}_d - f_5(\dot{\psi}) - g_5(\psi) + \gamma_\psi e_{v\psi})\frac{1}{\lambda_\psi} + \alpha_\psi s_\psi + \beta_\psi \, sign(s_\psi) \tag{13}$$

α and β are gain and discontinue gain to reach the sliding manifold. *sat(s_i)* function can help minimization chattering phenomenon [25] with function as follows:

$$Sat\ (S) = \frac{S}{|S| + \varepsilon} \tag{14}$$

where ε is a positive value. In this paper, in addition to the modification of the SMC input control, it also carried out the optimization of the four parameters of each DoF with particle swarm optimization (PSO). PSO has a robust ability for nonlinearity problems [26] with velocity values and positions of each parameter. And the renewal function on each parameter, i.e.:

$$\boldsymbol{\delta}_{i,d}^{m+1} = w.\boldsymbol{\delta}_{i,d}^{m} + c_1.r_1.(Pb_{i,d} - \rho_{i,d}^{m}) + c_2.r_2.(gb_d - \rho_{i,d}^{m}) \tag{15}$$

$$\rho_{i,d}^{m+1} = \rho_{i,d}^{m} + \boldsymbol{\delta}_{i,d}^{m+1} \tag{16}$$

where $\boldsymbol{\delta}$ and ρ are velocity and position update of parameter $\gamma_i, \lambda_i, \alpha_i, dan\ \beta_\psi$, c1 and c2 are two positive constants, r_1 and r_2 are random functions in the range {0,1}, $Pb_{i,d}$ is the best position for a particle (i) based on its own position, and g_{bd} is the best position achieved by all particles in the swarm. The addition of inertia weight (w) has an effect on the chance to find a bigger global position with a reasonable iteration to improve PSO performance. That is a combination of several local soul-based methods based on intuition or empirical rules to obtain the best solution in a relatively short time. The use of SMC with parameter optimization using PSO is illustrated in the block diagram as Figure 2.

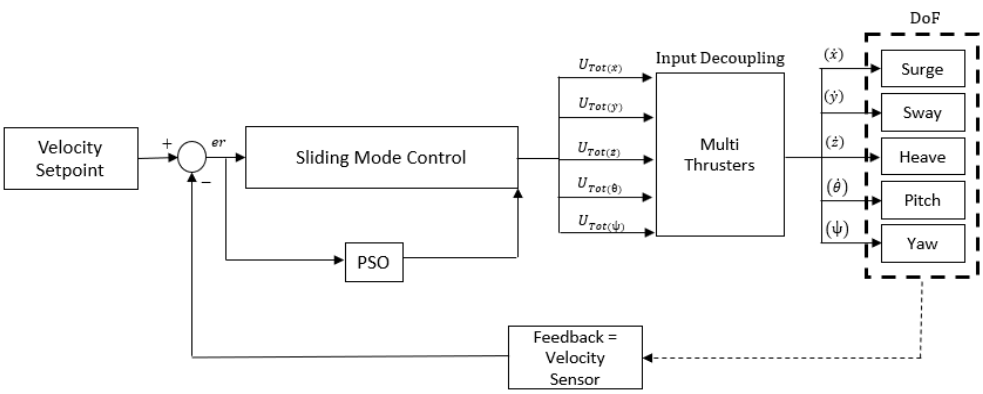


Figure 2. Control system diagram blok

2.1. Stability analysis

The stability of the proposed control input $u_{(i)}$ can be analyzed using Lyapunov function. Lyapunov function as follow:

$$V_i = \frac{1}{2} S{v_i}^2 \tag{17}$$

with i for the 5 DoF in the E-ROV responses. The value of the derivative Lyapunov function is used to analyze the stability of 5 DoF system. For Surge and Heave movement, the analysis becomes:

$$\dot{V}_i = S_i(-\lambda_i\alpha_i S_i - \lambda_i\beta_i sat(S_i)) \tag{18}$$

and for the other DoF the analysis becomes:

$$\dot{V}_i = S_i(-\lambda_i\alpha_i S_i - \lambda_i\beta_i sign(S_i)) \tag{19}$$

$$\dot{V}_i = -\lambda_i\alpha_i {S_i}^2 - \lambda_i\beta_i |S_i| \tag{20}$$

from (18) and (19) can be analyzed that the system for 5 DoF is globally stable with the SMC parameters are:

$$\lambda_i\alpha_i > 0 \tag{21}$$

$$\lambda_i\beta_i > 0 \tag{22}$$

3. RESULTS AND ANALYSIS

The purpose of the simulation is to find out and prove the implementation of the control system that has been formulated to be applied. The simulation consisted of two tests, namely speed and robust response. Two simulations are done by comparing the results of observations of tracking responses and sliding surfaces between the PID controller and proposed method. Predetermined parameters are obtained from measurement, there are the weight of the vehicle on the air is 28.9 kg, total volume at 29.3 liters, the center of gravity of ROV $r_g=[0,0,0]^T$, and center of buoyancy $r_b=[0,0,-54.697mm]^T$. And the SMC-PSO-MODIF parameter tuning results obtained the best fitness value that is 0.6485 with the convergence of parameters as shown in the following Figure 3.

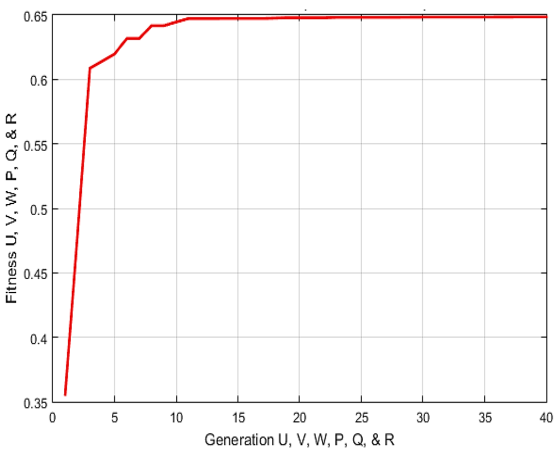
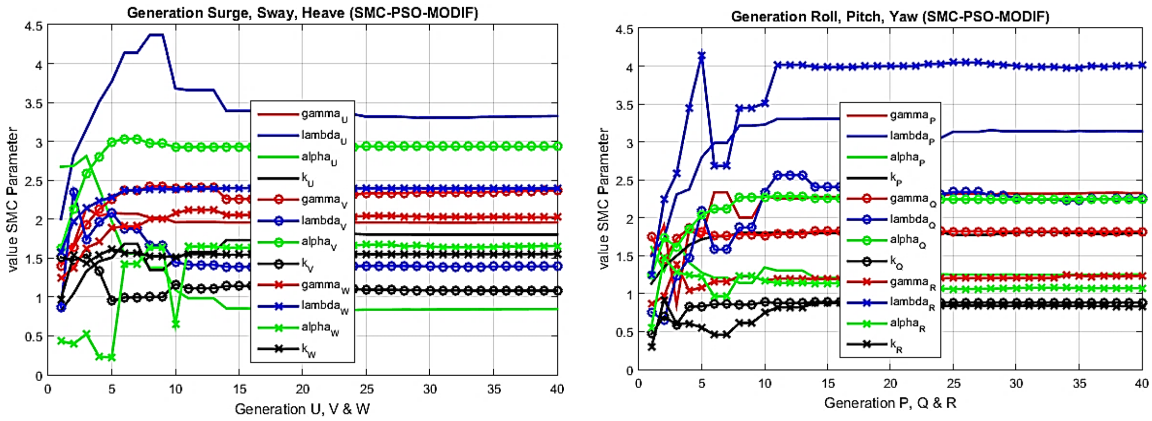


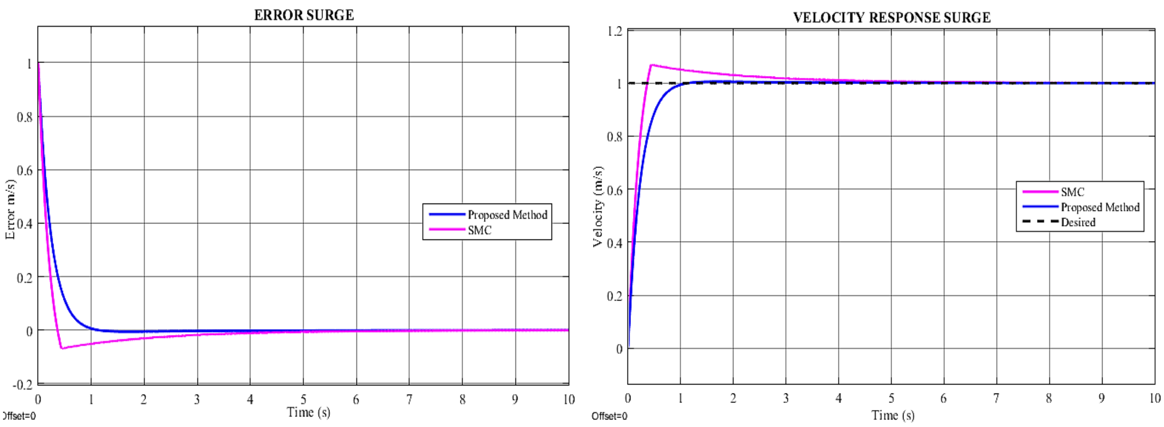
Figure 3. Fitness generation (SMC-PSO-MODIF)

Figure 4 (a) shows that the selection of the best parameters for Surge, Sway, and Heave movement and Figure 4 (b) for Roll, Pitch, and Yaw movement has been successful based on the convergence value which is also evidenced by the convergence value of the fitness generation in Figure 3. And to compare the input capability of the proposed method, the tuning of the parameter value is compared with the conventional SMC.



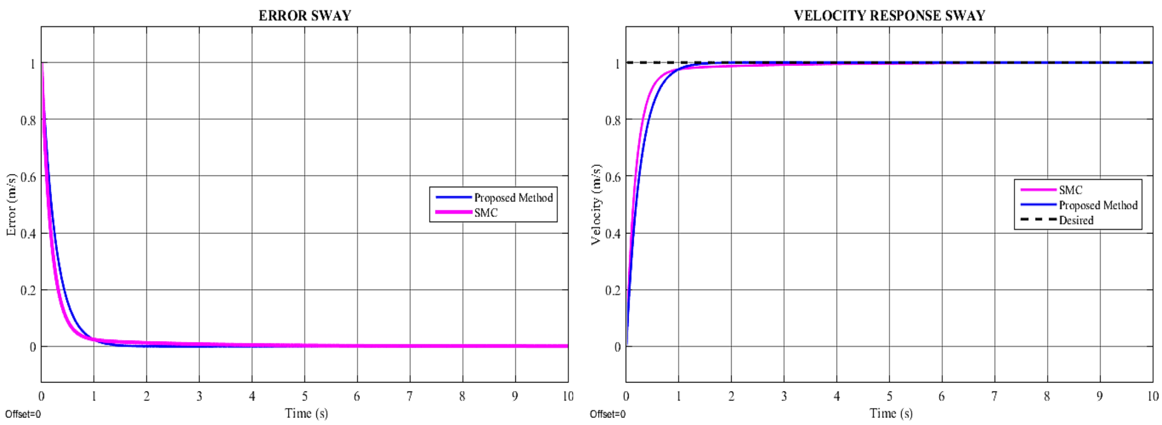
(a) (b)

Figure 4. Update generation (SMC-PSO-MODIF); (a) surge, sway, heave (b) roll, pitch, yaw



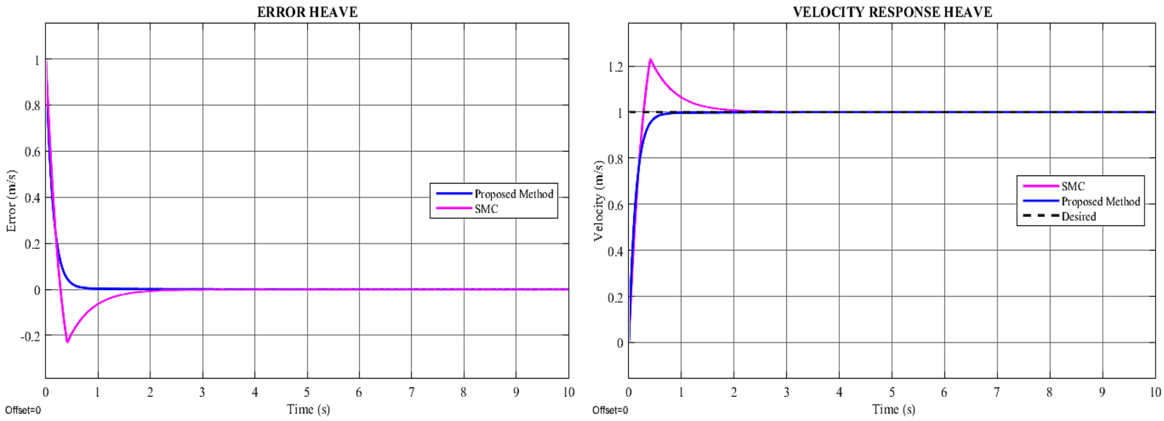
(a) (b)

Figure 5. Response of surge movement; (a) error (b) velocity



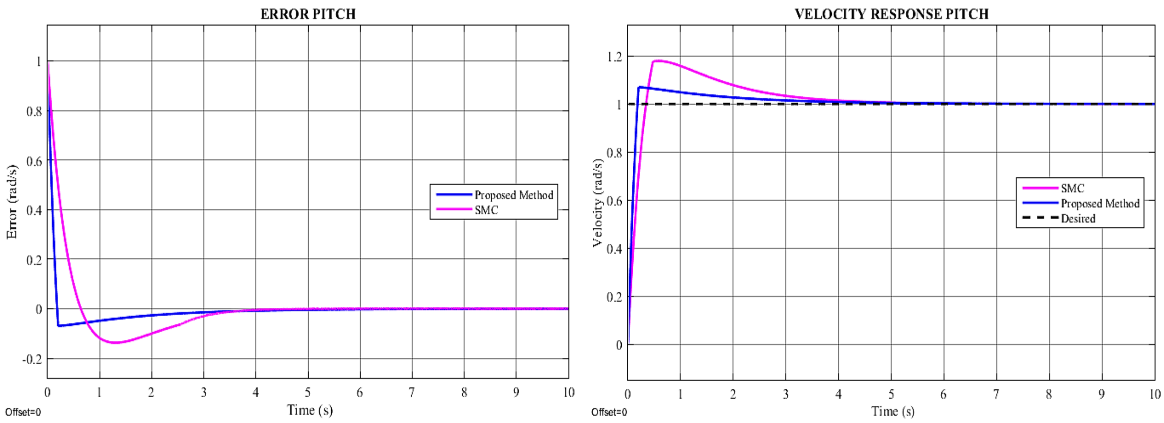
(a) (b)

Figure 6. Response of sway movement; (a) error (b) velocity



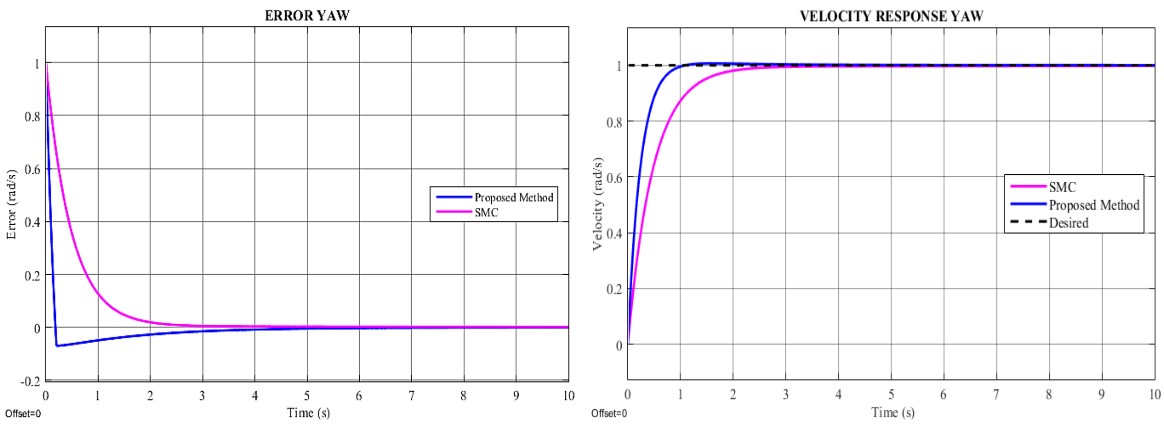
(a) (b)

Figure 7. Response of heave movement; (a) error (b) velocity



(a) (b)

Figure 8. Response of pitch movement; (a) error (b) velocity



(a) (b)

Figure 9. Response of yaw movement; (a) error (b) velocity

For the surge response in Figure 5 and heave response in Figure 7 the chattering phenomenon in conventional SMC can be resolved by modifying the SMC-PSO and has a better response than the proportional SMC. For responses to sway, pitch, and heave response in Figure 6, Figure 8, and Figure 9 the proposed method can improve the response of conventional SMC by achieving a better setpoint. In contrast to conventional SMC which still has greater overshoot and error values. This can be proven by calculating the number and mean of absolute error. For the comparison value of the error value of each movement in Table 1 can be analyzed that the proposed method has an increase in the mean absolute error value. In surge increased 0.0008 m/s, for sway increased 0.0044 m/s, sway had an increase of 0.0129 m/s, pitch had an increase of 0.0304 rad/s, and in yaw it had an increase of 0.0373 rad/s. Proof of Lyapunov stability analysis, parameter values obtained from the PSO tuning are in Table 2.

Table 1. Compare of tracking error

DoF	Sum Absolute Error		Mean Absolute Error	
	SMC	Proposed Method	SMC	Proposed Method
Surge (m/s)	167.0452	164.7218	0.0570	0.0562
Sway (m/s)	161.3301	174.2008	0.0594	0.055
Heave (m/s)	162.9408	125.2657	0.0556	0.0427
Pitch (rad/s)	230.9396	141.9494	0.0788	0.0484
Yaw (rad/s)	251.0972	141.9494	0.0857	0.0484

Table 2. Value of SMC and modified SMC-PSO

DoF	SMC Parameters				Modified Integral SMC-PSO			
	γ	λ	α	B	γ	λ	α	B
Surge	1.0659	2.5797	1.5529	1.0314	1.9582	3.3255	0.8453	1.8029
Sway	1.8361	2.4995	1.7096	1.4783	2.3709	1.3932	2.9328	1.0810
Heave	2.9795	1.2858	2.1891	1.5468	2.0231	2.3954	1.6554	1.5504
Pitch	3.1552	2.3245	2.8270	0.9028	1.8190	2.2536	2.2444	0.8809
Yaw	1.5822	3.5552	0.3306	1.1518	1.2332	4.0079	1.0725	0.8315

This is based on Lyapunov's stability analysis, that the system will be stable if it conforms to the conditions (21) and (22). In Table 2 it can be analyzed that the result of the parameter value is greater than zero. Values that conform to the requirements make the system stable with different stability values based on the accuracy of the parameter selection. And the parameter adjustment with optimal tuning PSO has more optimal results compared to conventional SMC without optimal tuning.

4. CONCLUSION

In this paper, the Modified Integral Sliding Control with tuning optimization parameters with PSO is utilized for controlling the E-ROV's speed. The aim of this work has been achieved. The speed of the vehicle can be resolved according to the setpoint by improving tracking error compared to conventional SMC. This method can make the error and sliding surface decrease or converges to zero according to the purpose of the initial control design compared to the SMC conventional. Compare with SMC conventional, proposed method improve tracking error for surge, sway, heave, pitch, and yaw are 0.0008 m/, 0.0044 m/s, 0.0129 m/s, 0.0304 rad/s, and 0.0373 rad/s.

REFERENCES

[1] C. S. Chin and W. P. Lin, "Robust Genetic Algorithm and Fuzzy Inference Mechanism Embedded in Sliding -Mode Controller for Uncertain Underwater Robot," *IEEE/ASME Transaction on Mechatronics*, vol. 23, no. 2, pp. 655-666, 2018.

[2] Z. Chu, D. Zhu, and S. X. Yang, "Observer-Based Adaptive Neural Network Trajectory Tracking Control for Remotely Operated Vehicle," *IEEE Transaction on Neural Networks and Learning Systems*, vol. 28, no. 7, pp. 1633-1645, 2016.

[3] C. D. Makavita, et al, "Experimental Study of Command Governor Adaptive Control for Unmanned Underwater Vehicles," *IEEE Trans. On Control Systems Technology*, vol. 27, no. 1, pp. 332-345, 2017.

[4] Z. Qingjun, *et al.* "Research on Dynamic Positioning of Model-Converted ROV Anti-waves Based on Micro Inertial Navigation Sensors," *10th Int. Conf. on Sensing Technology (ICST),* pp. 1-6, 2016.

[5] A. R. Marzbanrad, M. Eghtesad and R. Kamali, "A robust adaptive fuzzy sliding mode controller for trajectory tracking of ROVs," *50th IEEE Conf. on Decision and Control and European Control Conference*, pp. 2863-2870, 2011.

[6] S. Riache, M. Kidouche and A. Rezoug," Adaptive robust nonsingular terminal sliding mode design controller for quadrotor aerial manipulator," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 3, pp. 1501-1512, 2019.

[7] S. C. Martin and L. L. Whitcomb, "Experimental Identification of Six-Degree-of-Freedom Coupled Dynamic Plant Models for Underwater Robot Vehicles," *IEEE Journal of Oceanic Engineering*, vol. 39, no. 4, pp. 662-671, 2013.

[8] S. C. Martin and L. L. Whitcomb, "Nonlinear Model-Based Tracking Control of Underwater Vehicles With Three Degree-of-Freedom Fully Coupled Dynamical Plant Models: Theory and Experimental Evaluation," *IEEE Transactions on Control Systems Technology*, vol. 26, no. 2, pp. 404-414, 2017.

[9] Y. Wei, et al., "Adaptive Integral Back-Stepping Controller Design for ROV with Disturbance Observer," *International Conference on Mechatronics and Automation*, pp. 1106-1110, Aug 2015.

[10] D. H. Vu, S. Huang, and T. D Tran "Hierarchical robust fuzzy sliding mode control for a class of simo under-actuated systems with mismatched uncertainties," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol 17, no. 6, pp. 3027-3043, 2019.

[11] B. Sun and D. Zhu, "A chattering-free sliding-mode control design and simulation of remotely operated vehicles," *2011 Chinese Control and Decision Conference (CCDC),* pp. 4173-4178, 2011.

[12] N. Ding, et al, "Robust adaptive motion control for Remotely Operated Vehicles with velocity constraints," *IEEE International Conference on Robotics and Biomimetics,* pp. 932-937, 2010.

[13] M. Hosseini and S.Seyedtabaii, "Improvement in ROV horizontal plane cruising using adaptive method," *24th Iranian Conference on Electrical Engineering (ICEE)*, pp. 1892-1896, 2016.

[14] H. Liu, et al, "Operated ROV thrust distribution control system based on adaptive back-stepping controller," *35th Chinese Control Conference (CCC), pp. 4633-439, 2016.*

[15] M. U. Khalid, et al, "Modeling and Trajectory Tracking of Remotely Operated Underwater Vehicle using Higher Order Sliding Mode Control," *2019 16th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, pp. 855-860, 2019.

[16] M. Alibani, C. Ferrara and L. Pollini, "Super Twisting Sliding Mode Control for Precise Control of Intervention Autonomous Underwater Vehicles," *OCEANS 2018 MTS/IEEE Charleston*. Charleston, pp. 1-7, 2018.

[17] T. Q. Vo, H. S. Kim and B. R. Lee,"A Study on Turning Motion Control of a 3-Joint Fish Robot Using Sliding Mode Based Controllers," *ICCAS 2010*, pp. 1556-1561, 2010.

[18] J. Wang, *et al,* "Modelling, Parameters Identification and Sliding Mode Control for the Pitch Control System of an Remotely Operated Vehicle," *35th Chinese Control Conference (CCC),* pp. 2146-2150, 2016.

[19] Y. Wang, et al. "Depth control of remotely operated vehicles using nonsingular fast terminal sliding mode control method," *2013 OCEANS* – San Diego, pp. 1-6, 2013.

[20] R. Hernandez-Alvarado, *et al*., "Self-tuned PID control based on backpropagation Neural Networks for underwater vehicles," *OCEANS 2016 MTS/IEEE Monterey*, pp. 1-5, 2016.

[21] N. Bordoloi and M. Buragohain,"Bacteria foraging optimized and modified PSO optimized PD-SMC and PID-SMC controller for inverted pendulum system," *2017 International Conference on Smart grids, Power and Advanced Control Engineering (ICSPACE),* pp. 171-176, 2017.

[22] M. Dehdarinejad, et al, "Optimization of SMC parameters using PSO in a Full-Bridge DC-DC converter with inductive load," *2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE),* pp. 1-6, 2013.

[23] E. H. Binugroho, R. S. Dewanto, and D. Pramadihanto, "eROV: Preliminary Design of 5 DOF ROV using 6 Thrusters Configuration," *2018 International Electronics Symposium on Engineering Technology and Applications (IES-ETA)*, pp. 281-287, 2018.

[24] Slotine JJE, Li W. "Applied Nonlinear Control." New Jersey: *Prentice*, vol. 199, no. 1, 1991.

[25] A. Farrage and N. Uchiyama, "Design and Experimental Verification of Adaptive Sliding Mode Control for Motion Accuracy and Energy Saving in Indstrial Feed Drive System," *America Control Conference (ACC),* pp. 1724-1729, 2019.

[26] G. A. F. Alfarisy, W.F.Mahmudy and M. H. Natsir, "Optimizing Laying Hen Diet using Multi-swarm Particle Swarm Optimization," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 16, no. 4, pp. 1712-1723, 2018.