Steering control design and simulation of hybrid underwater glider

A Latifah¹,*, D D S Fatimah¹, B L Hakim² and Y Mauluddin²

¹ Department of Informatics, Sekolah Tinggi Teknologi Garut, Jalan Mayor Syamsu 1, Garut 44151, Indonesia
² Department of Civil Engineering, Sekolah Tinggi Teknologi Garut, Jalan Mayor Syamsu 1, Garut 44151, Indonesia

*ayulatifah@sttgarut.ac.id

Abstract. A new class of autonomous underwater vehicle (AUV) is a hybrid underwater glider (HUG) that integrates buoyancy engine and propeller as the main actuator. This kind of vehicle has multi-mode to act that is glider and AUV mode that derive to the mathematical model for the longitudinal and lateral plane. To design steer control of HUG, the mathematical model derives to a linear equation, and the variable controller is rudder for yaw control and main thruster for speed control of HUG. The method of control design is Proportional, Integral and Derivative (PID), there is PD for yaw controller and P for speed controller that are simulated using MATLAB/Simulink to get a response so that we can verify the dynamic model for steering control using waypoint desire. The results demonstrate dynamic response for the lateral plane over waypoint on the surfaces of water.

1. Introduction

Recently, the interest in marine resources has been increased, and for marine equipment, there also has been a growing need. Among various marine equipment, the underwater robot is essential equipment for resource development and ocean exploration. Thus nowadays underwater robot field is rapidly growing due to the exploration, investigation and the activities of research in underwater [1,2]. Autonomous underwater vehicle (AUV) is one of the underwater robot kind, this kind of vehicle can cruise in the sea with high maneuverability movement with its power supply, generally using batteries to perform the mission.

In another hand, there is another kind of underwater robot called Autonomous underwater glider (AUG) that has been used for underwater exploration because of its high endurance, low power consumption and long range compared to another kind such as a Remotely operated vehicle (ROV) [3,4]. But for AUG the movement is very slow and has low maneuverability, the same case for AUV has weak endurance so that can’t be used for long term mission. Because of this problem, Hybrid underwater glider (HUG) with concept design to combines the advantages of AUV and AUG so that the vehicle has high endurance and high manoeuvrability [5–7].
HUG is one of object research in Bandung Institute of Technology that can perform the long-term bathymetric mission with a waypoint tracking system. The platform of the vehicle is shown in figure 1, with the shape of a torpedo. To support the vehicle function, control systems are needed which has responsibility for attitude control and the movement mechanism.

There are two kind controllers that will be used in this vehicle that is depth control and steering control. The main object research in this paper will explain the overview of design and development steering control in the HUG. This controller system is simulated on MATLAB/Simulink for SILS (software in the loop simulation) process for the research.

2. Vehicle description

The platform for this research that designed base on vehicle missions for oceanographic research has been equipped with buoyancy engine, its typical actuator for an underwater robot. The motion control of the vehicle is 6 DOF which is surge, sway, heave, roll, pitch and yaw [8,9]. There are several subsystems that being used in this vehicle such as control system, guidance and navigation system, and communication system. Table 1 presents the main technical of the vehicle.

There are 6 actuators to do missions for ocean exploration, there is buoyancy engine for heave motion, propeller for surge motion, bow and stern thruster for sway motion, moving mass for roll and pitch motion, rudder and elevator for yaw and pitch motion base on the vehicle has initial condition (not zero) (fig. 2) [10–14]. Table 2 described part of vehicle from figure 2.

Table 1. The main technical specification of HUG.

| Body Type             | Torpedo |
|-----------------------|---------|
| Dry Weight (kg)       | 76      |
| Buoyancy Displacement (L) | 2,5    |
| Length (m)            | 2,3     |
| Diameter (m)          | 0,24    |
| Max. Depth (m/s)      | 50      |
| Max. Surge Speed (m/s)| 2       |

Figure 1. Hybrid underwater glider in ITB.

Figure 2. The part of hybrid underwater glider.
3. Methodology
For steering control, there is three variables that affected: yaw velocities (v), yaw angular rate (r), and yaw angle (ψ). Controlled variable are rudder deflection (δ_r) and main thruster (propeller) [15,16].

\[
G(s)_{\text{Rudder}} = \frac{8.871s + 1495}{s^2 + 48.21s + 1593}
\]

\[
G(s)_{\text{Thruster}} = \frac{0.618s + 75.55}{s + 7.34}
\]

To represent vehicle design, there is a mathematical model in nonlinear equations that derive from physical theory, and for controller problem, the nonlinear equations are linearized at an equilibrium point and assume another parameter that are not used zero:

\[ u = \text{constant}, \ \psi = v = r = 0 \]

Equation 3 shown linearized the vehicle mathematical model in the lateral plane and Equation 4 shown the matrix form of the linearized mathematical model. Block diagram for the simulation process are shown in figure 4.

\[
249|v|v = -0.00013v_B^2
\]

\[
L_z\dot{r} + 1.9|v|v = -0.6v_B^2
\]

\[
\begin{bmatrix}
 m & 0 & 0 \\
 0 & L_z & 0 \\
 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
 \dot{v} \\
 \dot{r} \\
 \dot{\psi}
\end{bmatrix}
- \begin{bmatrix}
 -249|v| & 0 & 0 \\
 -1.9|v| & 0 & 0 \\
 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
 v \\
 r \\
 \psi
\end{bmatrix}
= \begin{bmatrix}
 -0.00013v_B^2 \\
 -0.00013v_B^2 \\
 0
\end{bmatrix}
\begin{bmatrix}
 \delta_r
\end{bmatrix}
\]
4. Result and discussion

For steering control, the desired position has to set first for some waypoint, and the initial position of the vehicle are set to zero for x-axes and y-axes. The next condition where vehicle comes closer to the desired waypoint, vehicle speed will be reduced. The simulation result is waypoint tracking on surfaces plane that are shown in figure 5.

Figure 5. Waypoint tracking for steering control.

The result shows that simulation of the vehicle can reach the desired waypoint based on the distance with a radius of acceptance that will reduce the vehicle speed when the distance is two times larger than the length of the vehicle. This method is obtained from guidance system using LoS (Line of sight) that already designed for this vehicle. On another hand, there is a greater deviation for shorter distances between the desired waypoint as shown in Figure 5. The vehicle response characterized show there is overshoot especially for short distance that is larger than long distance. PID controller for rudder and main thruster actuator are:

4.1. Controlled rudder actuator

The result of the simulation for steering control on the rudder actuator obtained controller PD value: $K_p = -1,1178$ and $K_d = -54,65$.

Then the transfer function equation of this actuator with a PD controller is shown in Equation 5.

$$G(s)_{\text{Rudder}} = \frac{-484,8s^2 - 81711,67s - 1671,1}{s^2 + 48,21s + 1593}$$

Equation 5
4.2. **Controlled main thruster actuator**

The result of the simulation for steering control on the main thruster actuator obtained controller P-value: $K_P = 10$.

Then the transfer function equation for the main thruster actuator with a PD controller is derived and shown in Equation 6.

$$K_P G(s)_{\text{Thruster}} = 10 \times \frac{0.618s + 75.55}{s + 7.34}$$

$$G(s)_{\text{Thruster}} = \frac{6.18s + 755.5}{s + 7.34}$$

(6)

5. **Conclusions**

On waypoint, tracking result shown there is a larger deviation for a shorter distance between the desired waypoint, it affected the power consumption of the vehicle. The larger deviation means the larger overshoot of this system, and the power consumption for the vehicle less efficient. To avoid this problem, the desired waypoint given to each destination point is better three times greater than the length of the vehicle.

5. **References**

[1] Kim S-G, Song S-H, Chang C-H, Kim D-H, Heu S and Kim J 2009 Design and Implementation of an Operational Flight Program for an Unmanned Helicopter FCC Based on the TMO Scheme *FIP International Workshop on Software Technologies for Embedded and Ubiquitous Systems* 1–11

[2] Kim M J, Baek W K, Ha K N and Joo M G 2015 Way-point tracking for a hovering AUV by PID controller In *2015 15th International Conference on Control, Automation and Systems (ICCAS)* 744-746

[3] Latifa U, Putri T W O, Trilaksono B R and Hidayat E M I 2017 Modelling, identification, and simulation of autonomous underwater glider in longitudinal plane for control purpose In *2017 2nd International Conference on Control and Robotics Engineering (ICCRE)* 140-144

[4] Ge Z, Luo Q, Jin C and Liang G 2016 Modeling and diving control of a vector propulsion AUV 2016 *IEEE International Conference on Robotics and Biomimetics (ROBIO)* (IEEE) 1–6

[5] Isa K, Arshad M R and Ishak S 2014 A hybrid-driven underwater glider model, hydrodynamics estimation, and an analysis of the motion control *Ocean Eng.* 81 111–29

[6] Liu F, Wang Y, Wu Z and Wang S 2017 Motion analysis and trials of the deep sea hybrid underwater glider Petrel-II China *Ocean Eng.* 31 55–62

[7] Claus B and Bachmayer R 2016 Energy optimal depth control for long range underwater vehicles with applications to a hybrid underwater glider *Auton Robots* 40 1307–20

[8] Xu J, Wang M and Qiao L 2015 Dynamical sliding mode control for the trajectory tracking of underactuated unmanned underwater vehicles *Ocean Eng.* 105 54–63

[9] Liang X, Wan L, Blake J J R, Shenoi R A and Townsend N 2016 Path following of an Underactuated AUV Based on Fuzzy Backstepping Sliding Mode Control *Int. J. Adv. Robot. Syst.* 13 122

[10] Khodayari M H and Balochian S 2015 Modeling and control of autonomous underwater vehicle (AUV) in heading and depth attitude via self-adaptive fuzzy PID controller *J. Mar. Sci. Technol.* 20 559–78

[11] Yuan C, Licht S and He H 2018 Formation Learning Control of Multiple Autonomous Underwater Vehicles With Heterogeneous Nonlinear Uncertain Dynamics *IEEE Trans. Cybern.* 48 2920–34

[12] Liu F, Wang Y, Niu W, Ma Z and Liu Y 2014 Hydrodynamic performance analysis and experiments of a hybrid underwater glider with different layout of wings *OCEANS 2014 -
TAIPEI (IEEE) 1–5

[13] Rezazadegan F, Shojaei K, Sheikholeslam F and Chatraei A 2015 A novel approach to 6-DOF adaptive trajectory tracking control of an AUV in the presence of parameter uncertainties *Ocean Eng.* **107** 246–58

[14] Allotta B, Caiti A, Costanzi R, Fanelli F, Fenucci D, Meli E and Ridolfi A 2016 A new AUV navigation system exploiting unscented Kalman filter *Ocean Eng.* **113** 121–32

[15] Geranmehr B and Nekoo S R 2015 Nonlinear suboptimal control of fully coupled non-affine six-DOF autonomous underwater vehicle using the state-dependent Riccati equation *Ocean Eng.* **96** 248–57

[16] Batmani Y, Davoodi M and Meskin N 2017 Nonlinear Suboptimal Tracking Controller Design Using State-Dependent Riccati Equation Technique *IEEE Trans. Control Syst. Technol.* **25** 1833–9