Depth control design and simulation of hybrid underwater glider

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Abstract. The hybrid underwater glider is a class from the autonomous underwater vehicle (AUV) that the concept of a buoyancy-engine to drive the vehicle sinking or to float are integrated and propeller propulsion systems for variable motion. This kind of vehicle has multifunctionality that enables to maneuver with glider and AUV mode so that it is an effective tool for oceanographic research. To represent the vehicle dynamic, the mathematical model base on the Newton–Euler approach is designed as a nonlinear equation that derives from forces and moment that acting from the vehicle design. For glider motion, buoyancy-engine and moving mass are coupled for working as an input controller actuator, and there is controlling need to make the vehicle go to mission point in some depth for a mission. In this paper, the depth controller will be designed to make the vehicle stay on depth condition. PID controller is used for controller design, that the mathematical model is derived to linear model. Simulation on MATLAB/Simulink is used to design the model and get dynamic vehicle response. With vehicle characteristic for glider motion, desired waypoint obtained with PD control for moving mass in x-axes and P controller for buoyancy engine.

1. Introduction

The valuable and abundant resources of oceanic have inspired explored of the ocean and marine environment for the mankind benefits. The resources of ocean are critical to our life, but there is a natural disaster involving the ocean such as earth-quakes of underwater and tsunamis that can be threatening and change our lives. Thus, monitoring system is needs for oceanic activities continously so that can minimize the damage caused by the disaster. Because of this case, an efficient underwater vehicle such as Hybrid Underwater Glider (HUG) is needs to be developed for the ocean’s resources exploration and the oceans activities to be monitored [1].

HUG is one class of Autonomous Underwater Vehicle (AUV) that has been used in many underwater explorations because of its long rage, high endurance and low power consumption that compared to the other kinds of AUV. For purposes of oceanographic research, HUG provides more high quality and precise data exploration than human diver [2].
The typical design of the underwater glider is a buoyancy engine that has a significant influence on HUG’s motion. The estimated values of buoyancy engine deviation are caused by variation pressure of the vehicle when drive-in underwater and variation of the water density, depending on its salinity and temperature and from the submergence depth [3].

To reduce the energy consumption of HUG, there is an effective way while the vehicle is moving for missions with a variation of the buoyancy system. This system is widespread in gliders and autonomous buoyancy [4]. The scenario of effective power and depth control has a special interest during oceanographic research, the impact of buoyancy change for HUG moving and depth control by this variation of buoyancy system without propulsion system are described in detail in the book [6] and papers [5,6].

The vehicle equipped by buoyancy engine, propulsion system, moving mass, controllable rudder and elevator to provides control of 6 Degree of Freedom (DOF). The object study of this paper is analyzing the transition process of depth control for HUG with buoyancy engine variation system, the mathematical model is used for simulation on MATLAB that represent the buoyancy engine for control design of the vehicle. The proposed algorithm will be implemented on HUG that was designed and implemented in Bandung Institute of Technology (Indonesia, Bandung city) as shown in figure 1. This system is one of the main actuator that is used in the vehicle that consists of oil bladder, it can be changed independently to provide heave movement and static pitch.

2. Vehicle description

The platform for this research has been equipped with built-in buoyancy engine that designed base on vehicle missions for oceanographic research, this vehicle is an unmanned AUV that combines the movement mechanism of AUV and Autonomous Underwater Glider (AUG) that has advantages of high endurance and high maneuverability. This vehicle can control the motion of 6 DOF which is surge, sway, heave, roll, pitch, and yaw [7–9]. Table 1 presents the main technical of the vehicle. The motion of vehicle can move in 6 DOF that usually means in typical case the actuator and DOF of vehicle is always having the same number so that this HUG has 6 actuators to do missions for ocean exploration, there is buoyancy engine, propeller, bow, and stern thruster, moving mass, rudder and elevator (Figure 2) [10–13]. Table 2 described part of the 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. Depth Speed (m/s)        | 0,125       |

Figure 1. Hybrid Underwater Glider in ITB.
Figure 2. The part of hybrid underwater glider.

For underwater vehicle application, there are so many buoyancy engine types, all of them were compared and the compromise choice has been made for the required specifications. The buoyancy engine mechanism of this HUG generally adopted from oil bidirectional pump — the detail of the schematic buoyancy engine described in figure 3. Table 2 shows the main specifications of the buoyancy engine.

Table 2. The main specification of buoyancy engine.

| Specification                              | Value |
|--------------------------------------------|-------|
| Volume per pump revolution (L/min.)        | 0.4   |
| Max pump speed (rpm)                       | 1800  |
| Max. the volume of the bladder (L)         | 5     |

Figure 3. The detail of schematic buoyancy engine.

3. Methodology

For depth control, there is four affected parameters: heave velocities (v), angular pitch rate (θ) and heave position (z). The controller variable is moving mass displacement on x-axes and buoyancy engine \([14–16]\). On the other hand, the controller variable is obtained from PID tuning from the tool of MATLAB/Simulink.

Figure 4. Diagram block for depth control.
There is a mathematical model derivation that is used for this research obtained using MATLAB/identification tool. Transfer function for moving a mass (equation 1) and buoyancy engine (equation 2) control variable are obtained so that the vehicle can go to the desired waypoint on x-axes and z-axes.

\[
G(s)_{\text{Moving Mass}} = \frac{0.1256s + 0.9712}{s^2 + 1.473s + 0.9776}
\]

\[
G(s)_{\text{Buoyancy Engine}} = \frac{0.2667s - 1.716 \times 10^{-16}}{s^2 + 1.548 \times 10^{-31}s + 3.204 \times 10^{-1}}
\]

To simplified the controller, a nonlinear equation that represents the vehicle are linearized on equilibrium point as, \( u = \text{constant}, \psi = v = r = 0 \) and assume other parameters that is not used are zero. From linearized, equation 3 is obtained with the form of a matrix on equation 4. Figure 5 shows the simulation block that is used for simulation the vehicle model on depth control.

\[
m\dot{w} + 307|w|w - mUq = -0.34V_B^2 \delta_e
\]

\[
l_{yy}\dot{q} + 23|w|w - mq \theta = -0.248V_B^2 \delta_e
\]

\[
\begin{bmatrix}
m & 0 & 0 & 0 & w \\
0 & l_{yy} & 0 & 0 & q \\
0 & 0 & 1 & 0 & z \\
0 & 0 & 0 & 1 & \theta
\end{bmatrix}
\begin{bmatrix}
-307|w| \\
-23|w| \\
1 \\
0
\end{bmatrix}
\begin{bmatrix}
mU & 0 & 0 & 0 & w \\
0 & 0 & -Mq & q \\
1 & 0 & 0 & -u & z \\
0 & 1 & 0 & 0 & \theta
\end{bmatrix}
\begin{bmatrix}
-0.34V_B^2 \\
-0.248V_B^2 \\
0 \\
0
\end{bmatrix}
\]

**Figure 5.** Simulation block HUG depth control.

### 4. Result and discussion

The desired position of z-axes (depth) is set to 125 m with initial condition of the vehicle are zero at all axes, the next condition will be setting when closed to waypoint the vehicle speed will be reduced until it stops. Figure 5 shows the response from a simulation with the desired waypoint.
Figure 6. The result of the desired waypoint.

From the simulation, there is a small overshoot for the variable controller, and the response is good enough that the vehicle stop close to the desired waypoint. The vehicle speed is 0.8 m/s with 45° pitch angle. On simulation result, from controller characteristic shows that the overshoot are 9.24% and this will affect the vehicle power consumption. Here is the controller variable that obtained:

4.1. Moving the mass controlled actuator
From the simulation, for moving mass controller actuator obtained PD controller value: $K_P=-0.28$ and $K_d=-27.39$.
Then the transfer function equation of this actuator with PD controller is shown in Equation 5.

$$
(K_P(r_d s + 1))G(s)_{\text{Moving Mass}} = (-27.39 s - 0.28) \cdot \frac{0.1256s + 0.9712}{s^2 + 1.473s + 0.9776}
$$

Equation 5

$$
G(s)_{\text{Moving Mass}} = \frac{-3.44s^2 - 26.604s - 10.272}{s^4 + 48.21s + 1593}
$$

4.2. Buoyancy engine controlled actuator
The same thing for this controlled actuator obtained a P controller with a different value: $K_P=20$.
Then the transfer function equation of this actuator with the P controller is shown in Equation 6.

$$
K_P \cdot G(s)_{\text{Buoyancy Engine}} = 20 \cdot \frac{0.2667s - 1.716 \cdot 10^{-16}}{s^2 + 1.548 \cdot 10^{-31}s + 3.204 \cdot 10^{-1}}
$$

Equation 6

$$
G(s)_{\text{Buoyancy Engine}} = \frac{5.334s - 34.32 \cdot 10^{-16}}{s^2 + 1.548 \cdot 10^{-31}s + 3.204 \cdot 10^{-1}}
$$

5. Conclusions
The result of this research obtained small enough overshoot, but it still not effective for vehicle power consumption. This case is because of the controller variable are less optimal. The transfer function of the controller variable that obtained will be applied on the nonlinear equation of mathematical model that represents the vehicle.

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