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Design, Development, Fabrication, and Testing of Unmanned Surface Vehicle for Environmental Monitoring Mission in Indonesia

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Abstract— In this paper, the design, development, fabrication and tests of an unmanned surface vehicle (USV) are discussed. The USV is designed to accommodate a path following mechanism. Thus, an automated control system is enabled. The USV is designed and prepared for carrying out environmental monitoring operation which is an important mission to support the sustainability agenda of archipelagic state like Indonesia. Preliminary trajectory tests were conducted in open water environments with enclosed region, i.e., dam reservoirs. Insight from the tests was used to optimize the USV's automated path following control system. Results of bathymetric survey are also shown in some details. Based on the tests, the USV is proven to have a functioning capability for automated environment's mapping.

Keywords— unmanned surface vehicle (USV); environmental mission; fully autonomous; path following; trajectory test; bathymetric survey

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I. INTRODUCTION

THE advancement of technologies in USV, however, still face many challenges. Mostly, USVs are operated semi-autonomous rather than fully autonomous USVs (Liu et al., 2016). Even the operation of Yara Birkeland currently still require remote control to support its autonomous system (Yara, 2022). Automation and intelligent levels of USVs could be classified from remotely controlled path, the ability of path tracking to the ability of optimum path planning under dynamic obstacles and complex environment, i.e., wave, current, wind (Zhou et el., 2020). In this paper, the development of a USV with fully autonomous system and ability of path following is discussed.

Indonesia as a maritime country has large economic, social and security activities on open water, coastal and ocean. From the environmental perspective, as one of the countries with the largest biodiversity (USAID, 2019), Indonesia is also important in the share of global sustainability. With very large oceanic and coastal areas, its national security is significantly dependant on the monitoring and surveillance by maritime patrol boats (Budiyanto et al., 2024) and aircrafts (Iqbal et al., 2017).. Up to this date, most of marine activities in Indonesia are still using manned vehicles. Despite this fact, in the last decade, Indonesian industries have shown growing capabilities to develop and produce unmanned marine vehicles (Robo Marine Indonesia, 2016).

In the present work, national academic and research institutions collaborate with an ROV manufacturer company in Indonesia to develop a USV for environmental missions, i.e., monitoring on water quality, waste and radiation. To the authors' knowledge there is only a few published articles which elaborate detailed design and development process for an actually built USV. The articles by Peng et al. (2017) and Ryu (2022) are amongst those few. Therefore, this paper presents an effort to discuss the design process of a USV development. In this preliminary stage of the development, the project encompasses several defined objectives and the USV technology is designed and evaluated as a monitoring platform. The basis of design, manufacturing process and operation tests of the ROV are explained in some details in this paper.

II. BASIS OF DESIGN

The present USV is mainly designed as a survey boat for various needs in open water locations, i.e., bathymetric survey, lake/ river bottom survey, water and mud volume survey. The autonomous control system enables it to be programmed to move on a particular set of way points. Table 1 depicts the general specification of the present USV.

The communication system of the present USV allows the survey range for up to 1 km (3500 ft). The USV sensors and GNSS antenna are integrated with radio transmission system to provide real time tracking to the ground station. The structure of the USV hull is designed to be lightweight, made of carbon fibre; thus enabling ease of handling and deployment. The weight of the USV mostly comprises of the battery, motor and

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propulsion system and its payload. Compatible payload includes but not limited to video camera gimbals, transmitter module, inertial measurement unit (IMU), GNSS positioning system and radiation sensor. Figure 1 shows the general configuration of the present USV.

Table 1 General specifications of the designed USV

Length	1.5 meters
Width	1 meters
Weight	50 kg
Velocity	0 – 5 knots
Propulsion	Dual Electric Propulsion
Engine	Electric Motor 2 × 1 Hp
Fuel	Battery
Payload Capacity	Up to 10 kg
Communication	Real time range up to 1km

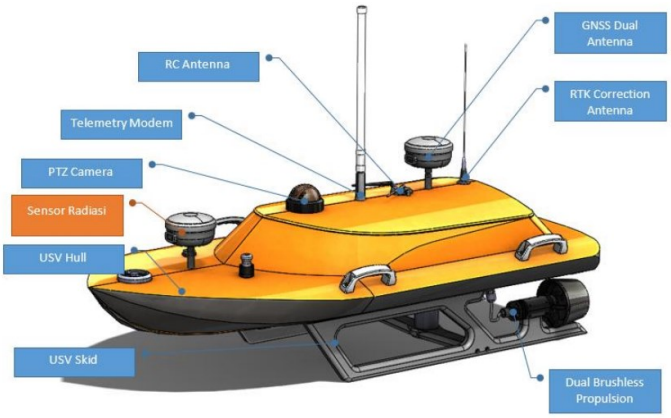


Figure 1 General Configuration of the designed USV

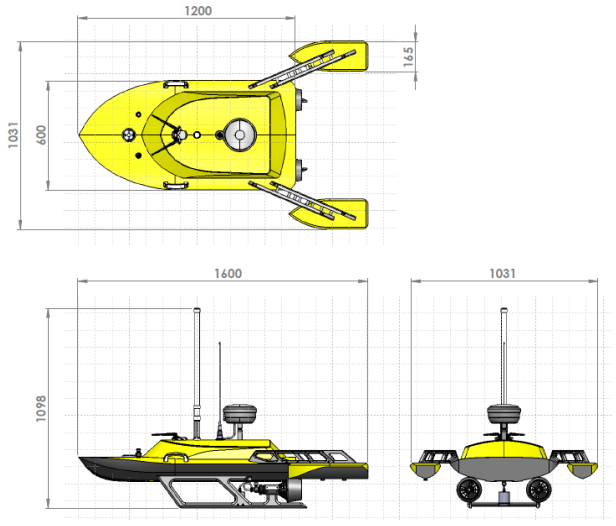


Figure 2 General dimensions of The Present USV with stabilization pontoon (unit in mm)

The aerodynamics/ hydrodynamics components of the USV are mainly the hull and propeller. Figure 3 displays the 3D model of the hull. Computational fluid dynamics (CFD) analysis was conducted to estimate the resistance forces acting on the hull. Multiphase domain for an open channel domain (air and water) was considered for the CFD analysis.

In the present case, a fixed pitch screw propeller is chosen due to design and manufacturing constraints. A graphical design method was used to obtain initial sizing of the shape and dimension of the propeller blade(s). Similarly, the propeller performance was also estimated via CFD analysis. In this case, fluid (water) domain with rotating part was evaluated. These thrust and torque data as a function of propeller's rotational speed were used to evaluate the thrust coefficient, torque coefficient, blade efficiency, propeller loading and pitch-diameter ratio.

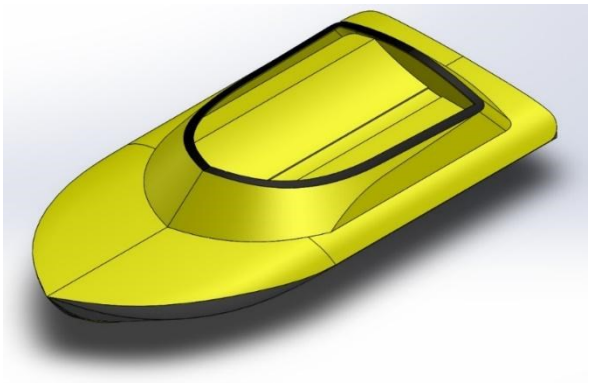


Figure 3 3D Model of The Present USV Hull

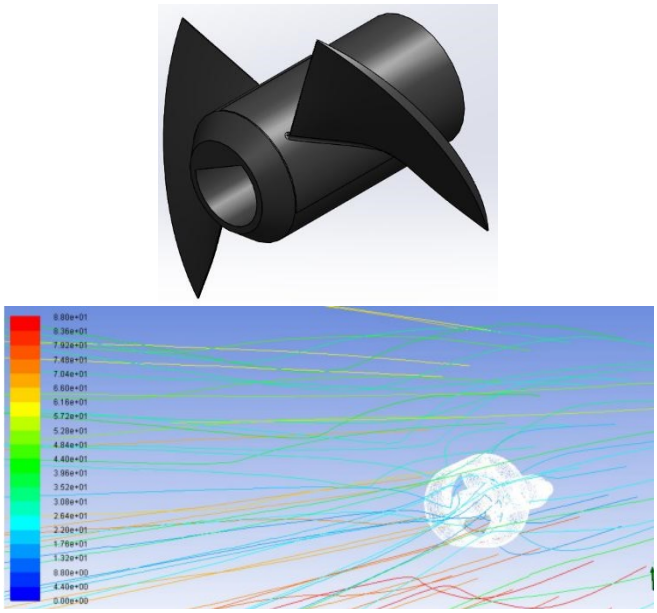


Figure 4 3D Model and CFD Analysis of The USV Propeller

Stability analysis for small unmanned vehicles such as USV are crucial, especially when operated in challenging marine terrains. In the present USV design, a self-righting method has been developed. The self-righting method allows the vessel to return to an upright condition when subjected to spontaneous disturbances.

Generally, there are three methods that are used in self-righting vessel: inherent self-righting, inflatable bags, and

movable ballast. The method that is used in the present USV is the passive method (inherent self-righting). To develop the inherent self-righting mechanism, a thorough consideration of weight distribution and lift forces are to be analyzed.

To calculate the stability characteristics of the USV, the weight distribution of the USV is based on actual weighing of the components and calculation of the center of gravity (CG) is done in a 3D modelling software. This method is carried out to estimate the ballast configuration and optimal component placement that enables the vehicle to be stable. The expected output is to find the optimal position of the CG with respect to the center of buoyancy (CB) and meta-center to create a positive stability, allowing it to return to its stable position both in static and dynamic condition. Figure 5 and Table 2 shows the position and coordinate of the USV's CG.

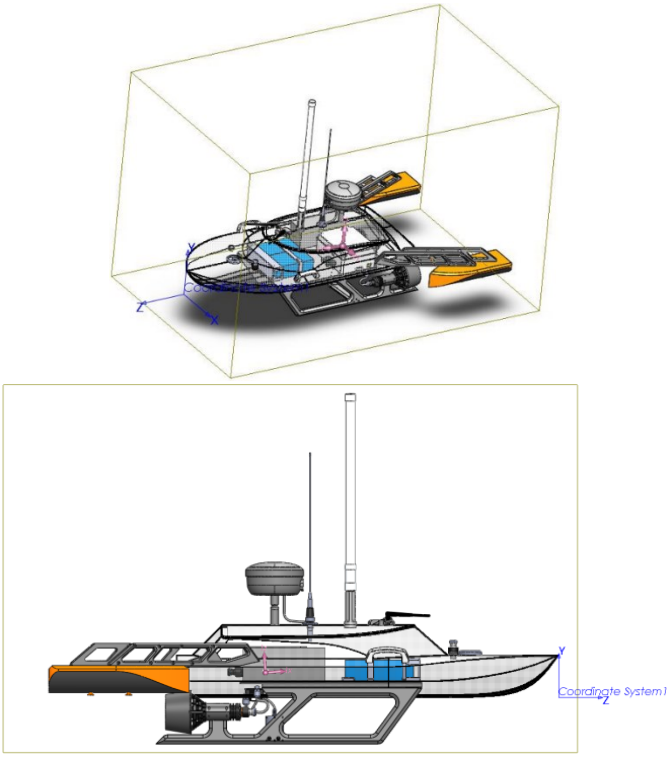


Figure 5 CG Position of The Present USV

Table 2 General specifications of the designed USV

mass	50	kg
x_{CG}	-3.65	mm
y_{CG}	78.22	mm
z_{CG}	-920.15	mm

The Vehicle Control Unit (VCU) in the USV is responsible for taking input commands from the control and navigation computer and translate them into signals that actuate the vehicles control systems. Various vital condition data such as vehicle health status, attitude, battery voltage, and sensor data are situated in the VCU. As for the present USV, the VCU consists of (1) electronic system to activate thrusters actuator for USV navigation, (2) ability to read orientation data provided by IMU/ AHRS, (3) ability to read absolute position data provided by GNSS, (4) telemetry access based on long-range TCP/IP WIFI.

An Inertial Measurement Unit (IMU) device is embedded in the USV to read the orientation of the vehicle. IMU sensors comprise of three main sensors: accelerometer, gyroscope, and magnetometer. The accelerometer is used to detect changes in the vehicle orientation relative to the direction of the earth's gravity. It provides information about the tilt of the vehicle, specifically the roll and pitch angles. The magnetometer sensor detects the magnitude of the magnetic field of the north direction, which can be translated into the vehicle's heading data. The combination of the accelerometer and magnetometer results in the simultaneous reading of the Roll, Pitch, and Yaw attitude of the vehicle. On the other hand, the gyroscope is utilized to provide the angular velocity data.

The specification of the IMU sensor that is chosen are (1) data output with 3-axis XYZ (pitch-roll-yaw), (2) temp-compensation MEMS module and military grade magnetometer-compensation chip to ensure high performance in the harsh environment, (3) military-grade inclinometer with high angle measurement accuracy, low-drift angle, automatic data correction and large signal-noise immunity.



Figure 6 BLDC Motor and Electronic Speed Controller (ESC)

The electric propulsion is chosen as the prime mover of the designed USV. The motor used is a BLDC motor equipped with a propeller. The BLDC Motor is driven by an electronic speed controller (ESC) system that gives commands such as rotational speed and direction. The VCU controller will communicate with the ESC by providing speed and direction commands, which are then translated by the ESC into actuating the movement of the BLDC motor. The commands given by the VCU are in the form of PWM signals with pulse width modulations adjusted according to the desired rotational direction and velocity.

III. MANUFACTURING

The fabrication of the USV is done in-house at PT. Robo Marine Indonesia. The USV is divided into 3 main parts, which are (1) the main hull that holds the electronics and systems, (2) the skids to help create clearance and provide protection to the propulsion system, and (3) the thruster components. The manufacturing process includes composite fibre lay-up, various machining practices using the lathe and milling machine and drilling. The documentation of the activities can be seen in Figure 7, Figure 8 and Figure 9.

To assess the performance and implementation of the designed USV, testing of the manufactured specimen is essential. The testing procedure involves a series of test conducted both in a controlled laboratory environments and field trials. The laboratory testing includes:



Figure 7 Lay-up fibre of Main Hull (left) and Final Coating of Hull (right)



Figure 8 Skid Machining and Result

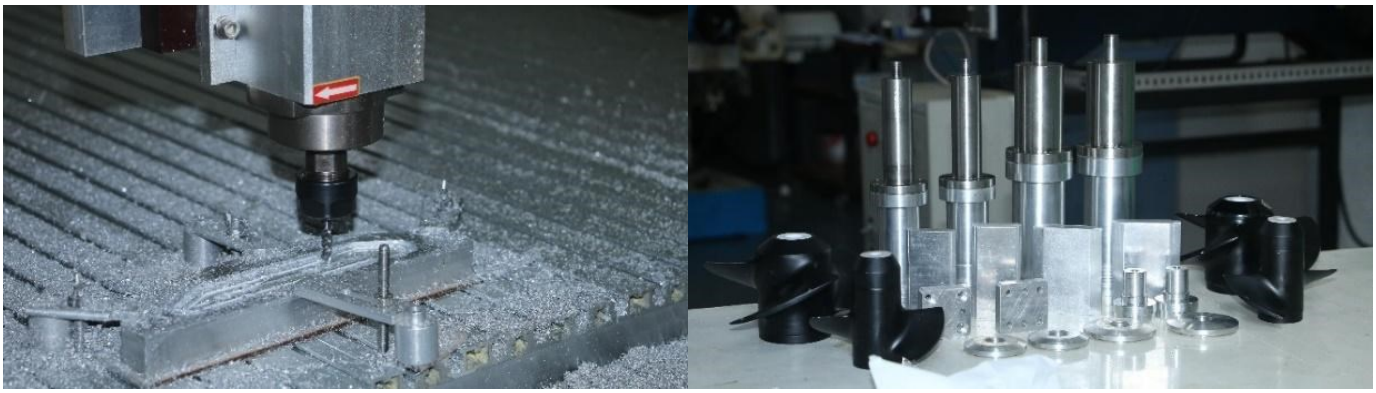


Figure 9 Thruster Machining and Result



Figure 10 Static Thrust Testing in Thrust Stand

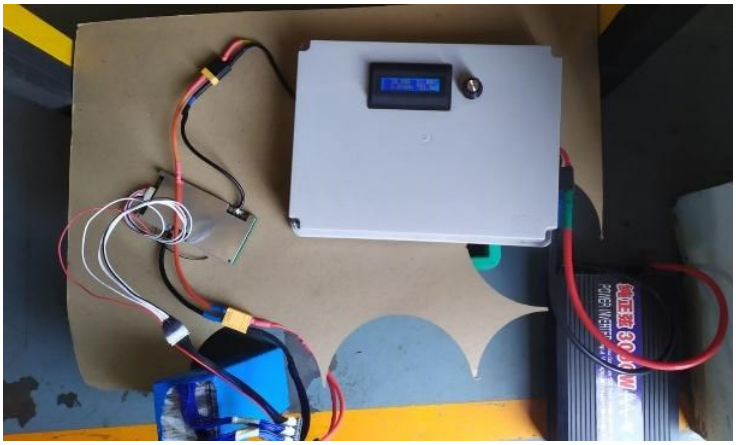


Figure 11 Trajectory Test and Bathymetric Survey

1. Thruster bollards pull test
   Thruster testing was conducted to obtain static thrust forces. This was done in a controlled pool, and the data are collected to assess the performance of the propellers.
2. Battery capability test
   The battery capability test was done primarily to collect the data of the battery real capacity. The test was done by charging the battery to various voltages/capacity, then discharging the battery at a specific discharge rate.
3. Dry test
   Dry tests are also commonly referred to as ground testing, assembling the USV and testing all built subsystems. This testing was conducted before deployment or usage to determine whether all systems can function without interference and to assess the inner workings of the USV as a whole. The purpose of this test was to determine if the USV is ready for deployment. The dry test involves thourough checking on:
   - Turning on and shutting down the USV.
   - Battery health and status indicator reading.
   - GPS reading.
   - IMU: response testing and calibration.
   - Thruster input.
   - Realtime communication connectivity.

IV. Trajectory Test & Bathymetric Survey

The trajectory tests were conducted in an open water environment, a dam reservoir (lake), to evaluate the performance of the USV. Specifically, the functionality of the tracking control system is examined. The trajectories or paths were predefined using waypoints that the USV must navigate through. Different shapes of paths, *i.e.*, straight line, rectangle, and ellipse were used to evaluate the automated path following mechanism of the USV. Figure 12 shows the present USV operating at a dam reservoir with autonomous control.



Figure 12 The Present USV Operating at A Dam Reservoir

Figure 13 and Figure 14 displays the results of trajectory tests for rectangular and elliptic paths. The rectangle path was

created by 4-way points representing its corners. As it can be seen in Figure 13, in general, the USV tried to follow the path, the rectangle shape. However, some discrepancies occurred around the corners of the rectangle. The position and heading of the USV at each corner, could not be changed sharply to a 90-degree position. Thus, around the corner, the USV adjust itself, created a curvy turning path to revise its heading and went back to the reference path. Similar situations could be observed for the elliptic path as depicted in Figure 14. In this case, the elliptic shape was created by more than 10-way points. In comparison to the rectangle shape, there is no corner with sharp 90 degree turning. Therefore, as can be seen in Figure 14, the position and heading adjustment of the USV was much better at each way point.

Academic-industrial joint papers have a significant impact on further modification of the controller and upgrade in GPS module was done to minimize the trajectory error of the USV during the change of position and heading at a way point. Trajectory test and bathymetric surveys were conducted to evaluate the USV operation with upgraded controller and GPS module. The test and survey were conducted at a dam reservoir with different shape, one with a narrowing area and another with a much wider area. The trajectory test results are shown in Figure 15 and Figure 16. The bathymetric survey results are displayed in Figure 17 and Figure 18. Both tests successfully shown the ability of the USV's path following mechanism and survey mission.



Figure 13 USV Trajectory Test – Rectangular Path

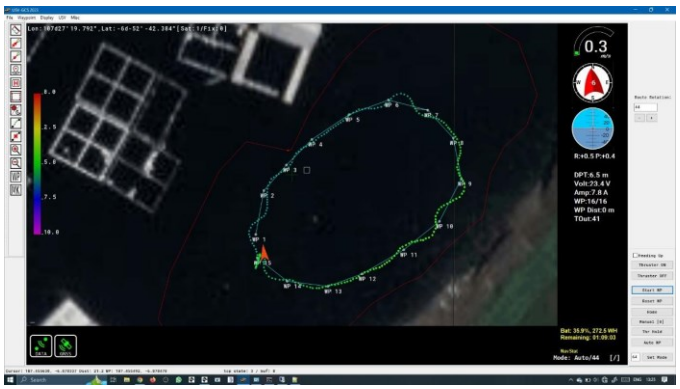


Figure 14 USV Trajectory Test – Elliptic Path

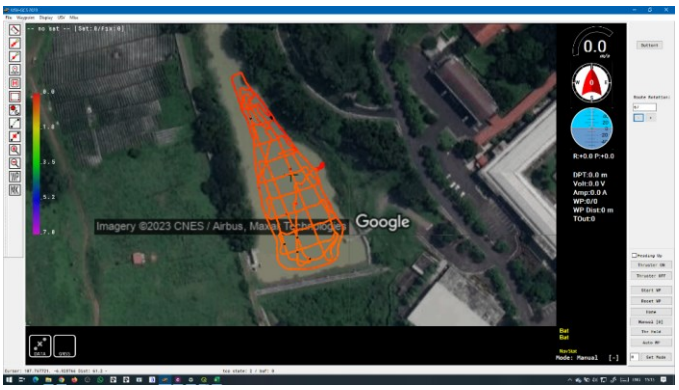


Figure 15 USV Trajectory Test at Lake 1

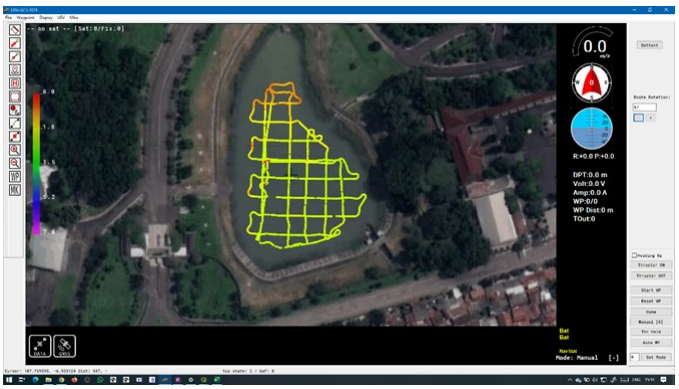


Figure 16 USV Trajectory Test at Lake 2

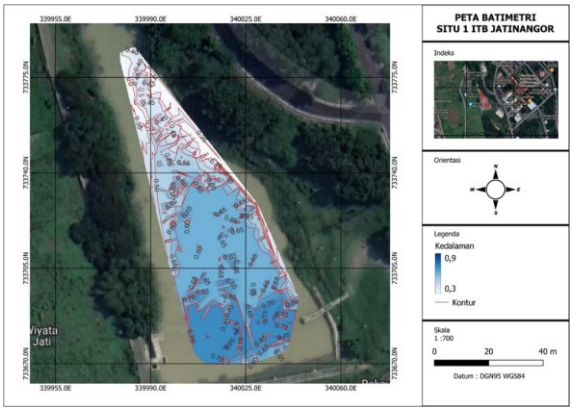


Figure 17 USV Bathymetric Survey Result at Lake 1

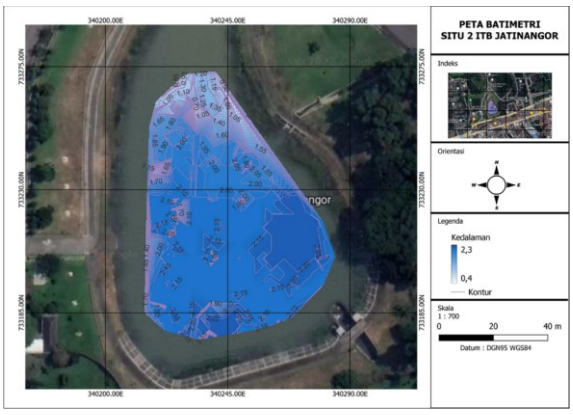


Figure 18 USV Bathymetric Survey Result at Lake 2

V. Conclusion

In the present work, a fully autonomous USV with environmental mission has been designed, developed and manufactured. The present USV has been tested for its path following mechanism via trajectory tests. The USV also has been evaluated for its mission in bathymetric survey. Therefore, a functioning USV platform has been built and tested. This is the first time, collaboration of academic and research institutions with a private company successfully delivered a USV technology in Indonesia. In the future work, the present USV will be upgraded for a much more elaborate mission, i.e., waste and radiation monitoring.

Aknowledgments

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