Unmanned Surface Vehicle (USV) performance test in Bintan Island Waters

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Abstract. An unmanned surface vehicle (USV) is an unmanned vehicle that is operated on the surface of the water for certain purposes, for example, bathymetry measurement, underwater imaging, etc. These unmanned surface vehicles can be used in impassable waters for crewed vessels in dangerous waters. This research measures the movement of the vehicle acceleration and then calculates it as the USV roll and pitch values. The direction of movement and wind speed and the height of the water surface at low tide are also aspects measured in this research. An accelerometer is a sensor that can measure the acceleration of an object, both dynamic and static. Based on the observations, the highest roll value is 6.0° deep while the highest pitch value is 6.5°. The standard deviation value at roll conditions of 2.92 and the standard deviation value at pitch conditions of 1.25. The average frequency of roll conditions is 2.18 and pitch conditions of 1.13. The dominant wind moves from the south to the southwest with a dominant speed ranging from 3.0 to 4.0 m/s. The results of this research indicate that the USV has a good performance so that it is possible to collect data in the water.

Keywords: accelerometer, tides, USV, wind

1. Introduction
Unmanned surface vehicle (USV) is an unmanned vehicle operated on the surface for a specific purpose. USV is also known as the autonomous surface vehicle (ASV) or automatic surface vehicle because it uses a global positioning system (GPS) in determining the direction of the vehicle's movement destination [1-2]. These unmanned surface rides can be used in waters that the ship has difficulty to travel through. The USV can be used for various applications, such as shallow-water surveys, military purposes, and underwater observation purposes in coordination with autonomous underwater vehicles (AUV) and other underwater vehicles [3-5]. Further, the ratio of accuracy rates in automation systems, USVs are much better than AUV due to the availability of GPS on navigation systems [5].

The USV as an observation platform can also be used for research in territorial waters. The maneuverability of the USV in acquiring some physical parameters from the waters is supported by the shape of the USV, the propulsion, and the working system of the USV. The ability of the USV will also be tested by factors that can affect the balance and stability of the USV in conducting the process of observation and data retrieval such as wind factors directly causing waves and tides.

The USV has several sensors for aquatic observation purposes and an accelerometer sensor used for their motion from the ship when retrieving data. The motions recorded by the USV are pitch, roll, and yaw [6-7]. The accelerometer is a sensor that can measure the acceleration of an object, both dynamic
and static acceleration. USV uses accelerometer type with principle 6 DOF (Degree of Freedom) using 3 axes, namely the X axis combined with the Y and Z axes, to increase the accuracy of the motion of an object. Accelerometer data recorded from the USV will be analyzed so that it can be known the level of equilibrium, slope, distance of displacement and also acceleration of the USV. The study aims to test USV performance and conduct an analysis of USV motion from Accelerometer data at a predetermined destination waypoint in the retrieval of water state data. The USV used in this paper is the one developed and supported through research grants from COREMAP-LIPI and PTUPT-Kemenristekdikti to Prof. Dr. Indra Jaya.

2. Materials and methods

2.1. Time and research location

The study was conducted from January 2021 to March 2021. USV performance test research is divided into two, namely the USV performance test site and the data processing site of the USV. USV data processing was conducted at the Ocean Instrumentation and Robotics Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University while the USV performance test was conducted in the Waters of Bintan Island, Riau Islands (Figure 1).

![Figure 1. USV performance test site in Beralas Pasir, Bintan, Riau.](image)

2.2. Data and tools

The tools used in data processing consist of Microsoft Excel, Anaconda, and Spyder software. The materials used are USV recording data, tidal data from BIG, and wind data from the climate datastore website. Materials and sources are presented in Table 1.

| No | Data                      | Data Sources                                           |
|----|---------------------------|--------------------------------------------------------|
| 1  | Wind Data                 | Climate Data Store (https://cds.climate.copernicus.eu) |
| 2  | Tidal Data                | Geodetic and Geodynamic Control Net Center             |
| 3  | Unmanned Surface Vehicle data | (http://tides.big.go.id)                              |
|    |                           | Satria MGA, 2019                                      |

Table 1. Sources of information and data acquisition.
2.3. Data processing and analysis

The research is done in several stages. The first is to extract USV data recording and then analyze and interpret. Both download tidal data from BIG and wind data from climate datastore websites with addresses cds.climate.copernicus.eu to see the water conditions when the USV performance test is conducted. The processing results of these parameters will later affect the rate of the USV when in the waters. The procedure of the data processing research stage is presented in the flowchart (Figure 2) as follows:

![Flowchart of data processing and analysis](image)

**Figure 2.** Steps in data processing and analysis.

The Accelerometer with principle 6 DOF (Degree of Freedom) uses 3 axes, namely the X-axis combined with the Y and Z axes, to increase the accuracy of the motion of an object. Principle 6 DOF (Degree of Freedom) is translational and rotational motion on each three-axis (x, y, z). These movements are surging, swaying, heaving, rolling, pitching, and yawing [8-9]. Data generated by the accelerometer sensor of the USV movement is a data format in the form of .txt. So that it can be processed into other formats. The USV is also equipped with an underwater camera to observe or monitor underwater vegetation, namely seagrass. The data collection was done to produce an image recording of underwater vegetation from the waypoint point traversed. Seagrass data retrieval is done by way of USV rides following a waypoint that adjusts to the collection of seagrass data that is in the form of parallel shapes with three transects with a length of 100 m each with a transect distance of 50 m. so that it is by the rules of data retrieval for seagrass vegetation [10]. The Accelerometer Sensor MPU6050 on module 10 DOF serves as a USV motion acceleration gauge on each axis then calculated into roll and pitch motion values. The roll and pitch value are obtained based on the following formula [1]:

\[
\rho = \arctan \left( \frac{Ax}{\sqrt{Ax^2 + Az^2}} \right)
\]

\[
\Phi = \arctan \left( \frac{Ay}{\sqrt{Ax^2 + Az^2}} \right)
\]

Information:

- \( \rho \) = Pitch (°)  \( Ax = \) Acceleration on the x-axis
- \( \Phi \) = Roll (°)  \( Ay = \) Acceleration on the y-axis
- \( Az = \) Acceleration on the z-axis

The wind is a parameter that has a role to play in the phenomena that occur in the waters. The wind has a significant impact that certainly affects the rate of USV. This wind data is downloaded through CDs. climate.Copernicus.EU. (2021) The data is obtained in real-time to be a helpful factor in the research. Wind data used on September 5 2018, coincided with the USV performance test. Wind data processing is done using Anaconda and Spyder software to see wind movement patterns at water sites during USV performance tests. Wind movement patterns are visualized in the form of wind roses,
making them easier to understand and interpret. USV performance tests are conducted in coastal waters and not far from the coast to be affected by tidal phenomena even though they are not large enough. Tidal parameters are important enough to know the aquatic characteristics of the USV performance test site. Tidal data processing is done using Microsoft Excel 2019 software to generate tidal graphs. The tidal graph is then interpreted to describe the water conditions as the USV performance test takes place. The condition of the waters will certainly significantly affect the vehicle's movement when taking data because it is directly related to the condition and attitude of the USV vehicle. The smaller the waves or waves from the tidal conditions will be the better the data obtained by the USV vehicle.

3. Results and discussion

3.1. Specification of the unmanned surface vehicle (USV)

Unmanned Surface Vehicle (USV) used catamaran type. Catamaran ships are included in multi-hull ships with two hulls or hulls, and the two hulls are connected into a single ship. According to [11], The primary size of the ship with catamaran type consists of several provisions, namely LOA (Length Overall), which is the ship's overall length from the end of the bow to the stern of the stern ship. Then Breadth is the distance between the center lines of the ship at the end of the bow to the stern of the stern ship. Then Breadth of Each Hull, is the maximum width of each hull, and the last is depth, i.e., the height of the ship vertically from the base of the ship to the deck surface of the ship [1].

![Figure 3. USV electronic instrument scheme.](image)

The bottom of the USV has a camera in a waterproof acrylic tube with a Logitech C525 webcam type for underwater vegetation data collection with a resolution of 640 x 480 in the form of video with a framerate of 30 fps. The bottom of the USV also has dual frequency transducers of 50 and 200 kHz for water depth measurement and turbidity sensors. As long as the USV is in motion, a Webcam connected to the Raspberry Pi will automatically record every 15 minutes of recording and is stored in external hard disk storage media. As long as the signal from the ground station is still connected to the GPS antenna and Wi-Fi antenna (Figure 5), the USV will send the latest data during the performance test and the data is the coordinate position of latitude and longitude, roll condition, pitch and direction of the barrier [1].

| Name            | Type               | Function                                      |
|-----------------|--------------------|-----------------------------------------------|
| Microprocessor  | Raspberry Pi 3 B+  | USV Center Controller                         |
| Microcontroller | Arduino Mega 2560  | USV Sensor Controller                         |
| Sensor 10 DOF   | GY-87              | USV Motion Recording                          |
| Camera          | Webcam Logitech C525 | Underwater Video Recording                   |
| Transducer + GPS| Garmin GPSMap 585 | Water Depth Gauge and USV Vehicle Coordinate Data Retrieval |
| Motor Electric  | Intex 0.2 hp Transform | USV Propeller Drive                         |
3.2. **USV tracking result**

The USV performance tests are conducted for the ability of the USV in retrieving underwater biota data and the spacecraft’s body movements by following a parallel path-shaped waypoint autonomously (unmanned) that has been prepared. The movement of the USV vehicle relies on the Wi-Fi signal emitted from the ground station and received by the USV to follow a predetermined waypoint. USV’s limitations in operating an autonomous system depend on the furthest distance of the Wi-Fi signal that a USV vehicle can receive. The results of tracking the USV movement (Figure 5) during the performance test show that the USV vehicle began to move horizontally from the West towards the coast following the waypoint then turned 90° towards the south, moving vertically parallel the beach. When turning, the USV experiences interference from both the waves and the wind, so it cannot turn sharply. Furthermore, the USV vehicle turned 90° westward away from the beach. The USV vehicle during the performance test was conducted 4 times moving closer to the beach horizontally, 6 times moving parallel to the beach, and 3 times moving away from the beach. The USV spacecraft successfully followed the given waypoint, thus forming a parallel trajectory on data retrieval. This shows that the USV can be used to conduct surveys or data collection of waters well. The travel time of the USV ride on the performance test is approximately 19 minutes, with a tracking length of 811 m.

3.3. **Interpretation of USV roll and pitch values**

The ability of USV rides to maintain stable conditions during data retrieval can be seen from the pitch and roll value produced. Aside from the characteristics and dimensions of the USV vehicle, external factors certainly significantly affect the movement and stability of the USV. These factors include wind, ocean waves generated by wind, and waves from tides. When the USV is experiencing significant pitching and rolling, the stability level of the ship is getting smaller because of the possibility of the ship rolling or capsizing largely. Observations from USV using underwater cameras will produce less clear images, so they cannot be used for data retrieval. Roll value (Figure 6) and pitch value (Figure 7) of USV rides during performance tests. The condition of the roll (blue) and pitch (red) has almost the same value, but the value of the roll (blue) has a greater value. Based on the observations, the highest roll (blue) value is only 6.0° and only for a moment, while the highest pitch (red) value is 6.5° although very short.

**Figure 4.** Shape and Parts of USV [1].

**Information:**

a. LOA (*Length Overall*)
   
   \[= 2.04 \text{ m}\]

b. B (*Breadth*) = 0.6m

c. D (*Depth*) = 0.31m

d. Bhull (*Breadth Each Hull*) = 0.3m

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**Figure 6.** Roll value of USV

**Figure 7.** Pitch value of USV
Figure 5. USV tracking result.

Figure 6. USV pitch graphic condition.
Figure 7. USV roll graphic condition.

Figure 8 displays a sample of fluctuation profiles of pitch and roll values filtered on data processing. Based on the results obtained the standard deviation value at the roll condition of 2.92 and the standard deviation value at the pitch condition of 1.25 according to the graph of fluctuations in Figure 8. The average frequency value of the roll condition is 2.18 and for pitch conditions of 1.13. External factors certainly influence the figure in the waters and the characteristics of the USV. Overall, with the observations' results, USV has a fairly stable ability because the rolling and pitching value is still below 6 ° and meets the criteria of seakeeping. As long as the USV moves in following the waypoint, there are several points or locations where the USV is less stable so it records a roll and pitch value that is greater than other locations and this proves that external factors certainly significantly affect the condition of the vehicle in taking data.

Figure 8. USV roll and pitch graphic condition.
3.4. Wind data interpretation

The characteristics of ocean waves generated by wind have three main factors: the length of wind blow, the speed of the wind blow, and the distance traveled by the wind from the direction of the rise of the wave (fetch). The presence of wind factors causes external factors that affect the USV vehicle.

Figure 10 displays the wind speed value on the day and time the USV vehicle is operated. Ocean waves in the waters are generated by winds with speeds ranging from 2.0 m/s to 6.0 m/s. The USV trial was conducted from 17.31 PM to 17.50 PM based on information obtained by the wind that blew on average at a speed of 3.0 m/s to 4.0 m/s. In these conditions, use rides can survive the movement of wind and waves that take place to take data.

![Figure 9. Graph of wind speed conditions (blue) and USV data retrieval time (red).](image1)

![Figure 10. Overlay USV Tracking Results with Wind Direction. Red dots on the left side of the figure represent the direction of the USV is perpendicular to the coastline, while the yellow dots are parallel to the coastline.](image2)
Figure 10 is the overlay USV tracking result with wind direction that blows on the operation of the USV. Wind direction varies from 45° Northwest to 135° Southwest. The dominant wind moves from the northeast 315° towards the southwest 135° with speeds varying from 3.0 m/s-4.0 m/s. Wind gusts as the USV approach the coast affect the pitch value as it causes waves perpendicular to the coast in the direction of the USV path. At the USV position parallel to the coast and towards the south, wind gusts and waves will affect the value of the USV roll. At the USV position away from the coast (to the West), the direction of the wind and waves opposite the direction of the coming USV, thus affecting the pitch value of the USV. The greater the recorded pitch and roll values, the less stable the USV condition is because it is influenced by these external factors and the USV vehicle's characteristics.

3.5. Tidal data interpretation
The tides are a phenomenon that generally occurs in coastal waters. USV rides are operated in relatively shallow waters to identify underwater biota properly so that it is closely related to tidal conditions as one of the external factors that affect the motion and sway of the USV. Tidal data is obtained from the Spatial Information Agency (BIG) for daily tidal data for the USV operated area. USV operations need to pay attention to the type of tide and the right time to carry out USV performance tests. The right conditions are where the surface waters are calm, with few currents, wind, and clear enough to get relevant results. This condition can be achieved when the waters experience the highest tide or lowest tide.

Figure 11. Tidal Chart (blue) and period USV data capture (red).

The USV performance test in the waters of the island of Bintan, precisely on the Coast of the Sand-Based Island, was carried out on Wednesday, September 5, 2018, at 17.31 WIB to 17.50 WIB. Figure 12 shows a daily tidal chart for September 5, 2018. When the USV performance test was carried out, the graph showed that the waters were in the lowest low tide conditions at 17.00 WIB to 18.00 WIB. Based on the graphic form, the tidal type in these waters is mixed, which tends to be double where the waters experience two times the high tide and the low tide. The time of the USV performance test was by the expected conditions so that the tides did not significantly affect the performance test of the USV in data collection.

4. Conclusion
Based on the measurement results, the average value of the roll condition is 2.18° and for the pitch condition is 1.13°, the USV is quite stable. USV has performed well in collecting underwater vegetation data, even though during data collection the USV vehicle is disturbed by several factors that affect the movement of the USV, among them are wind speed and tidal condition.
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