Study on design and construction of unmanned surface vehicle (USV) as a marine survey vehicle

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Abstract. Marine surveys may provide hydrooceanographic, hydrobiological, and spatial information. Surveys often face the problem of limited professional resources and inadequate equipment. Continuous technological development requires further development in this field. This is also the reason for future research on the development of unmanned surface vehicles (USV) to support marine survey activities, especially underwater topography. The studies were conducted starting with design and construction, USV vehicle performance tests, control and motion system performance tests, and sensor performance tests. The USV design uses a catamaran ship model, where the USV has two hulls and two propulsion. Construction tests were performed using the inclining test and rolling test methods. Control and motion system tests were performed using the free running test and turning ability methods. The sensor test was performed by field sounding test. The results showed that the USV functioned well. All the systems were integrated as planned. Acoustic and GPS sensors can also be used for underwater topographic surveys. The deficiencies identified were related to the durability of the propulsion system and GPS sensor system, which can be further optimized.

1 Introduction

A survey is a discipline that includes all measurement methods and information collection related to the physical environment, information processing, and dissemination of various products produced. A hydrographic survey is a survey of coastal objects, lakes, rivers, seas, and other water bodies. More specifically, the marine survey is a survey activity carried out with the object of marine waters. Marine survey activities include hydrooceanography, hydrobiology, and spatial information. Conducting a survey according to certain categories requires professional resources and adequate equipment. Surveys, especially in Indonesia, often encounter problems of limited equipment availability, and with ongoing technological development, the ability to follow technological development must also be a concern. This certainly encourages the conducting of a study regarding the technological development of marine survey activities, and this also becomes the background for conducting a study

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regarding the design of an Unmanned Surface Vehicle (USV), which aims to assist marine survey activities in the future, especially for underwater topography survey activities.

An Unmanned Surface Vehicle (USV) is an unmanned vehicle that operates on the water surface and has a specific purpose. The USV is also known as an Autonomous Surface Vehicle (ASV) or surface vehicle that operates automatically using GPS to determine the direction and destination of its movement [1]. The concept of unmanned marine vehicles (UMV), including USV, was initially developed for military purposes, mine clearance, and battle-damage assessment. However, in recent decades, this technology has been used by civilians and various science missions, one of which has been used in environmental survey activities. An environmental survey that has become one of the USV developments is bathymetric survey activities [2][3].

The use of robots in bathymetric measurement must actually involve various considerations, including the quality of data, the number of data that can be processed, and system endurance when working close to 100% [4]. There are two kinds of unmanned systems that can be used in this activity: unmanned underwater vehicles (UUV) and USV, and the analysis of both showed that the USV is better when used for bathymetric survey activities. The parameters used for reference are speed/endurance, payload processing, payload sensor, survey coverage, navigation accuracy, low vehicle motion, real-time coms, and launch/recovery ease [5].

In this study, the activities carried out not only created the design of the USV vehicle but also designed the construction process. However, the USV testing was also performed. Testing was performed on the USV vehicle and USV maneuvers, and each sensor was used. This was carried out to achieve the objective of this study, which was to produce a USV design that can be utilized in marine survey activities in the future, especially water topography.

2 Method

2.1 Location, Time and Type of Study

This study was conducted in Bandung, Pangandaran, Indonesia. This study was conducted over 8 months, starting from design, construction, and testing. The study type was Research and Development (R&D). Based on [6]**.** There are four main characteristics in R&D: conducting a study or research to find findings related to the product that will be developed, developing the product according to the findings of previous studies or research, conducting field tests in real conditions where the product will be applied, and revising or improving the weaknesses found.

2.2 Boat Design and Construction

The USV vehicle was designed as a catamaran-type vehicle. The catamaran type is a multihull boat with two hulls or two pontoons, and this type of boat can trap fluid flow between the two hulls [7]. The USV vehicles are also designed with an asymmetric catamaran type, where the outer body of the boat is streamlined and the inner body of the boat is straight. The asymmetric catamaran was chosen because this type requires a lower thrust. Fluid acceleration in the convergent section involves a reduction in the quantity of motion of the water mass, thereby increasing the efficiency of the catamaran [8]. A detailed design of the boat is shown in Figure 1.

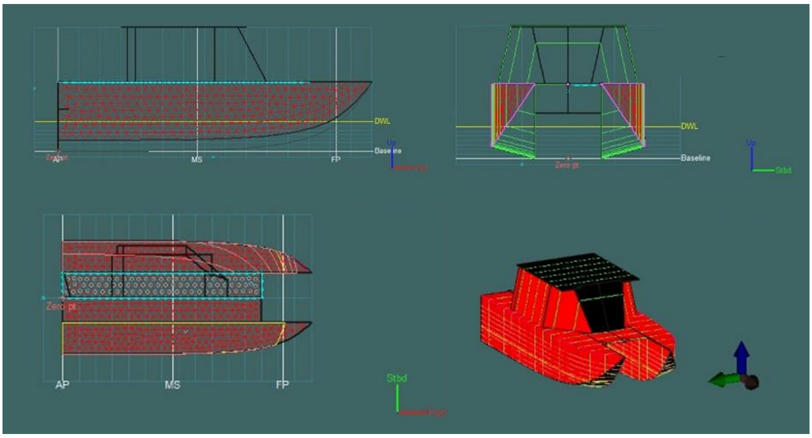


Fig 1. USV Boat Design

2.3 Control and Propulsion System

The USV control system is built wirelessly using control in the form of a Ky-023 joystick module, with a radio signal communication system using NRF24L01 on the transmitter and receiver. The transmitter was built as a remote control, whereas the receiver was built as a box placed on the deck of the USV vehicle. The signal receiver was directly connected to the USV drive system such that the USV movement could be controlled remotely.

The drive system of the USV uses two 22 mm Turbo Jet Thrusters and Brushless Motor 2845 with a speed controller in the form of a 13 V Electronic Speed Control (ESC). This machine works like a water jet pump; therefore, its movement produces a water spray.

2.4 Sensor and Electronic System

The acoustic sensor becomes a sensor is applied to the USV prototype. The acoustic sensor used had a transducer with a single beam and single frequency, working at a frequency of 115 kHz with a maximum range of 30m. This sensor can be used as an instrument to assist underwater topography mapping.

A GPS sensor is also added to the USV prototype. This sensor was used to determine the position of the USV when moving and as tracking points when the acoustic sensor sounded. The sensor used is Ublox Neo-6MV2 with a tracking and navigation sensitivity of -161 dBm, speed accuracy of 0.1 m/s, and horizontal position accuracy of 2.5m. This specification can change according to the amount of GPS satellite signals received by the sensor and the physical conditions of the sensor.

The electronic system of the USV was assembled separately. There are three main electronic circuits. First, the electronic circuit in the remote system is from the USV-control transmitter. Second, the circuit in the USV control receiver is connected to the USV drive. Third, the circuits in USV sensor systems are acoustic and GPS sensors. The third circuit consists of a data storage system using an SD Card module. The components of the electronic system are listed in Table 1. All electronic systems in the USV were powered by 9-volt and 12-volt DC power sources, with the control center as an Arduino microcontroller.

Table 1. Components in Electronic Systems

No	Components Name	Function
1	Ping Sonar Echosounder	Acoustic Sonar Sensor

No	Components Name	Function
2	GPS Neo-6MV2	USV Positioning System
3	NRF24101+	Control System Communication
4	Arduino Uno	Controls all electronic system functions
5	Remote Controller Kit	USV Motion Control

2.5 Boat Performance Test

The USV vehicle performance tests included load capacity and stability tests. A load capacity test was performed by placing a load in the middle of the boat until the lowest side of the boat was parallel to the water. The load was applied gradually at intervals of 1 kg. The parameters recorded were the weight of the load and the freeboard height. Freeboard is the vertical distance between the deck line and freeboard, leading down to the upper side of the load line measured in the middle of the boat. This is important because it is directly related to safety, production economy, and boat operation [9]. The measurements were performed 10 times. The testing method is illustrated in Figure 2.

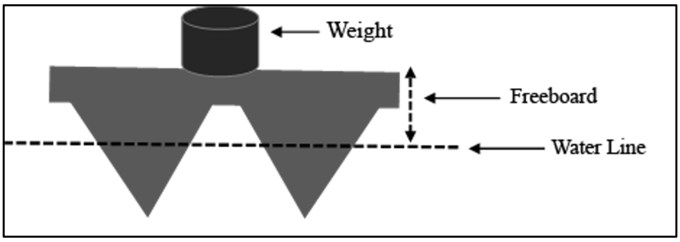
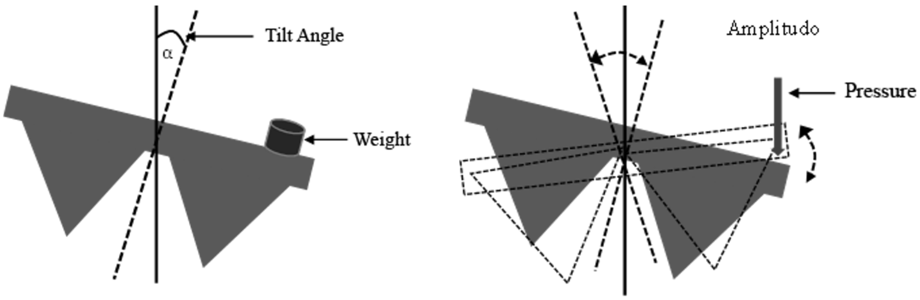


Fig 2. Load Capacity Test

A stability test was performed by inclination and rolling. Inclining was carried out by placing a load on one of the boat sides until the boat was capsized. The given load varies from 0 to 10 kg or 1 – 4 °. The parameters measured were the weight of the load and the angle of inclination formed between the metacentric line and vertical axis[10]. The inclination angle was measured by using a protractor. Measurements at each load weight were performed 10 times to obtain accurate results. Rolling was carried out by pressing the side of the boat until the boat tilted and then calculating the number of boat swings until the boat returned to an upright position. Testing was performed at a small inclination angle (10°) up to 60° with an interval of 10°. According to [11], the initial condition in stability is the ability of the boat to return to its original upright position when tilted at small angles (=60°). This initial stability stage is limited to discussions on transverse stability.



(a) (b)

Fig 3. (a) Inclining Test, (b) Rolling Test

2.6 Control and Propulsion Performance Test

A USV control system test was conducted by testing the connectivity of the remote control. The remote control was tested by connecting the receiver and transmitter at a certain distance and carrying out a transfer file to generate data that was received to determine the connectivity between them. The distance used was between multiples of 50m and 500m with unobstructed conditions.

The USV motion test or maneuver test was carried out using two testing methods: open free running and turning ability tests [12][13]. Open-free running involved three testing steps. The first test was carried out in a straight line with an angle of 0°, the second test was moving towards the starboard with an initial angle of 0° to 90°, and the third test was moving towards the portside with an initial angle of 0° to 90°.

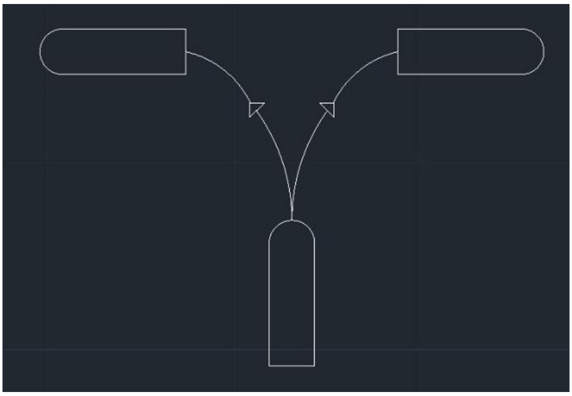


Fig 4. Open Free Running Test Illustration

The turning ability test was tested 3 rounds, starting with the control direction at -30° to the port side, and the engine was turned on at maximal speed until the boat formed a circle with a certain center diameter; when the boat was circling, the center point was marked as the center of the circle and had a circle diameter as the calculation [13][14]. An illustration of the turning ability test is shown in Figure 5.

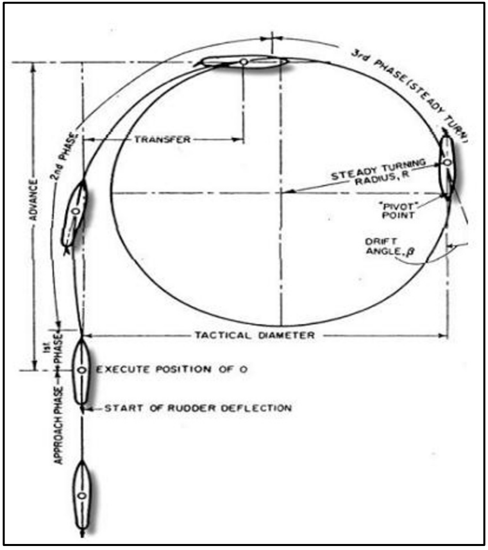


Fig 5. Turning Ability Test Illustration

2.7 Sensor Performance Test

Sensor performance tests were carried out simultaneously, where a GPS sensor and an acoustic sensor were operated to obtain the depth of the water that would then be made into the topographic map. Testing was carried out in the Cikidang Fish Landing Port, Pangandaran, and Bulaksetra River, Pangandaran. The testing was performed using a zigzag path with circular ends.

2.8 Data Analysis

Data analysis was performed based on the test results. The tests to be carried out and the analysis method to be used on the data obtained are listed in Table 2.

Table 2. Test Materials and Data Analysis

No	Test Material	Data obtained	Analysis used
1	USV Vehicle Performance Test	- USV Dimension - USV Stability	- The mean value of data obtained
2	USV Control System and USV Motion System Performance Tests	- Connectivity of transmitter and receiver - USV maneuver time	- Controller connection - Descriptive analysis
3	Sensor Performance Test	- Data on the depth - Coordinate position	- Depth analysis - Depth validation - Coordinate validation

3 Result and Discussion

3.1 USV Vehicle Performance Test

The USV vehicle was successfully manufactured as a catamaran-type boat using e-glass fibers or marine materials. The catamaran was manufactured as a type-B asymmetrical hull. The dimensions of the catamarans are listed in Table 3.

Table 3. Specification of USV Vehicle

No	Information	Size
1	Length of All (LoA)	148 cm
2	Width (B)	95 cm
3	Height	33 cm
4	Draft	12 cm
5	Maximum Load	80 kg
	Hull	
1	Interhull Distance (S)	30 cm
2	Width of Hull (Bl)	30,8 cm
	Deck	
1	Width of Deck	78,6 cm
2	Height of Deck	15 cm
3	Length of Deck (LDL)	122 cm
	Hatch	
1	Width of Hatch (L)	29 cm
2	Height of Hatch (D)	15 cm
3	Length of Hatch (P)	122 cm
	Superstructure	

No	Information	Size
1	Length of Structure	43 cm
2	Height of Structure	26 cm
3	Width of Structure	73 cm

The table shows that the catamaran vehicle had an overall length (LoA) of 148 cm, width (B) of 95 cm, and height of 33 cm. There were two hulls; each hull had a distance (S) of 30 cm, and the width of each hull (BI) was 30.8 cm. The catamaran deck is quite spacious, with a deck width of 78.6 cm and deck length of 122 cm.

The results of the load capacity test showed that the boat flooded the deck at a load weight of 80 kg with the load center in the middle of the boat. The load was gradually applied at intervals of 10 kg. The boat had an unladen draft measuring 12 cm. When the boat was given a load of 10 kg, the boat draft increased by 2.23 cm to 14.23 cm. The increase in the draft from a load of 30 kg to 40 kg was only 1.69 cm. An increase in draft height decreased with an increase in load, so the change was only 0.72 cm when the boat added a load from 70 kg to 80 kg. An increase in boat draft when given a load with an interval of 10 kg is shown in Figure 6.

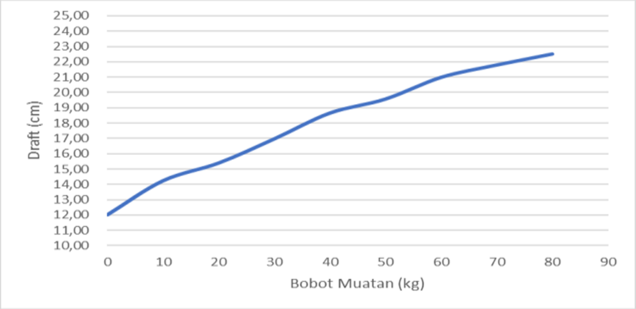


Fig 6. Load Capacity Test Result

Providing a load with the same weight interval caused the boat draft to increase with an increasingly small added value. This is because the shape of the boat hull is v-bottom. The amount of load required by a boat when the draft is increased by 1 cm is known as ton per centimeter (TPc). The magnitude of TPc in the v-bottom boat was smaller than that in the round-bottom or u-bottom boat. This shows that the loading capacity of a v-bottom boat with the same dimensions is lower than that of other or both types of boat hulls.

The results of the inclination test showed that the boat began to capsize when the load was 50 kg. When the boat was subjected to a load of 10 kg, it experienced a tilt of 14.9°. A load of 20 kg tilts the boat by 27.2 Â °. The boat was tilted by 34.3° when the load was 30 kg. A load weight of 40 kg resulted in a tilt angle of 44.8°. The final result was that when the boat was given a load of 50 kg, it began to capsize slowly. The change in tilt when adding a 10 kg interval load is shown in Figure 7.

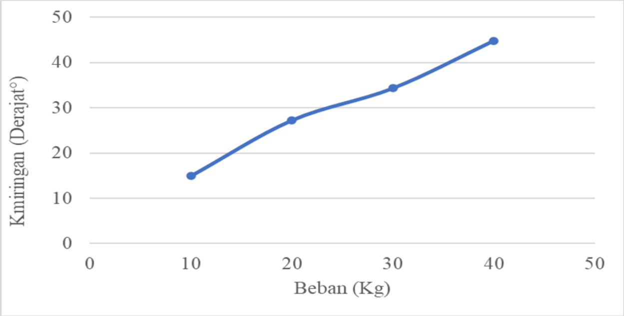


Fig 7. Inclining Test Result

The changes in the tilt were relatively high, with an average increase of 11°. This condition is caused by the use of large-volume loads in the form of sand-filled plastic bags. This type of load causes the center of gravity on the boat to move upward, making it easier for the boat to tilt. The center point of the downward force of gravity is called the gravity point or the center of gravity.

The rolling results showed that rolling testing with an initial angle of 10 °had an average of four swings in 1.7 seconds to return to stability. Moreover, in the rolling test with an initial angle of 20°, the boat had an average of five swings in 2.8 seconds to return to its initial position. This can occur because a boat with two hulls has good stability compared to a monohull boat. A catamaran boat still has good stability because, in a tilted position, to return to its initial position or stability, a catamaran boat does not take a longer time. The results of the rolling testing with initial angles of 10° and 20° are shown in Tables 4 and 5.

Table 4. Rolling Test Result with an angle of 10°

Repetition	Inclination (degree)	Rolling (times)	Time (second)
1	10	3	1,41
2	10	5	3
3	10	4	1,56
4	10	4	1,5
5	10	3	1,66
6	10	4	1,64
7	10	3	1,7
8	10	4	1,56
9	10	3	1,57
10	10	3	1,67
Average		4	1,7

Table 5. Rolling Test Result with an angle of 20°

Repetition	Inclination (degree)	Rolling (times)	Time (second)
1	20	4	2,20
2	20	8	6,00
3	20	6	3,00
4	20	5	2,64
5	20	5	2,53
6	20	4	2,28
7	20	5	2,45
8	20	4	2,35
9	20	5	2,36
10	20	5	2,40
Average		5	2,80

3.2 The Results of the USV Control System and Motion System Performance Test

In the connectivity test, to determine the performance of the USV control system, the frequency of NRF24L01 was set at two data rates: 250 kbps and 2 Mbps. A 250 kbps rate was used as the maximum range, and a 2 Mbps rate was used as the minimum range. The results of the NRF24L01 connectivity distance test at 250 kbps and 2 Mbps rates are listed in Table 6.

Table 6. Control Conectivity Test Result

Distance (m)	**Rate**	**Signal**	**Result**
50m	2 mbps	Min	Connect
	250 kbps	Max	Connect
100m	2 mbps	Min	Connect
	250 kbps	Max	Connect
150 m	2 mbps	Min	Connect
	250 kbps	Max	Connect
200m	**2 mbps**	**Min**	**Connect**
	250 kbps	Max	Connect
250m	2 mbps	Min	Disconnect
	250 kbps	Max	Connect
300m	2 mbps	Min	Disconnect
	250 kbps	Max	Connect
350m	2 mbps	Min	Disconnect
	250 kbps	Max	Connect
400m	2 mbps	Min	Disconnect
	250 kbps	Max	Connect
450m	2 mbps	Min	Disconnect
	250 kbps	Max	Connect
500m	2 mbps	Min	Disconnect
	250 kbps	**Max**	**Connect**

Based on the results obtained, it can be found that the maximum connection distance between the transmitter and receiver was 500 m with a frequency rate of 250 kbps. At a frequency rate of 2 Mbps, the connection maximum distance between the transmitter and receiver was only 200 m; therefore, the best frequency rate that could be used in the USV control system was 250 kbps. The frequency rate used affects the data exchange between the transmitter and receiver. Because the signal in this control system is one-way without two-way data exchange, the frequency rate used is not a problem at a low rate.

In the maneuver test, two types of tests were performed: free-running test and turning ability test. In the free-running test, the USV moved forward to the starboard and towards the port side. The calculated measurements were the speed and time per turn values, starting with the boat at 0° until it turned 90°. Testing was performed three times for each maneuver. The test results are shown in Table 7.

Table 7. Free Running Test Result

Repetition	Maneuver	Distance (cm)	Time (second)	Drift Angle (degree)	Speed (cm/s)
1	Straight	478	22	0°	21,7
2	Straight	408	22	0°	18.5
3	Straight	824	22	0°	37.5
Average	**Straight**	**570**	**22**		**25.9**
1	Starboard	411	22	30°	18.7
2	Starboard	511	22	30°	23.2
3	Starboard	363	22	30°	16.5
Average	**Starboard**	**428**	**22**		**19.4**
1	Portside	559	22	-30°	25.4
2	Portside	350	22	-30°	15.9
3	Portside	330	22	-30°	15
Average	**Portside**	**413**	**22**		**18.7**

The results of the free-running test showed that the USV could move straight forward at an average speed of 25.9 cm/second. This also depended on the power conditions used. The engine uses a DC electric current with a battery voltage of 12 V. During testing, the battery was in good condition and fully charged. During maneuvers towards the starboard and portside, the average speed of the USV was 19.4 cm/second and 18.7 cm/second, respectively. This almost identical speed shows that the drive system on the left and right sides of the USV was able to work properly. If there is a significant speed difference during the maneuver, one side of the USV drive system is not working properly.

In the turning ability test, the initial position of the USV at the reference point of 0° rotated up to 360° three times. The rotation diameter, circumference, time per turn, and speed were measured according to the maneuver. Data from the turning ability test results are listed in Table 8.

Table 8. Turning Ability Test Result

Path Num	Diameter (cm)	Circumference (cm)	Time per turn (second)	Speed (cm/s)
1	**148**	464,72	24,49	**18.9**
2	114	357,96	47,94	7,46
3	112,5	353,25	105,61	3,34

Based on the criteria of IMO 2022, calculations related to tactical diameter and advance were also carried out in the turning ability test. The results of the tactical diameter and advance calculations are shown in Table 9.

Table 9. Comparison of IMO Standard Criteria Values with Test Results

Num	Parameter	IMO Criteria	Test Result
1	Tactical Diameter	<5L (750 cm)	148cm
2	Advance	<4,5L (675 cm)	116,18 cm

According to the data in Table 9, the tactical diameter and advance tested at a speed of 18.9 cm/second obtained a value that could be included in the turning ability maneuver criteria. The results of tactical diameter were found below the 5 times length of the USV, with a value of 148 cm or 0.98 L, and advance was found below 4.5 times the length of the USV, with a value of 116.18 cm or 0.77 L.

3.3 The Results of the Sensor Performance Test

The sensors used in the USV test were GPS and acoustic sensors. The GPS sensor used was a Ublox Neo-6MV2. The acoustic sensor used was a Ping Sonar Echosounder from Blue Robotics. The GPS sensor and ping sonal echosounder were assembled into one instrument and placed on the USV vehicle. The instrument circuit containing the GPS sensor and the ping sonal echosounder is shown in Figure 8.

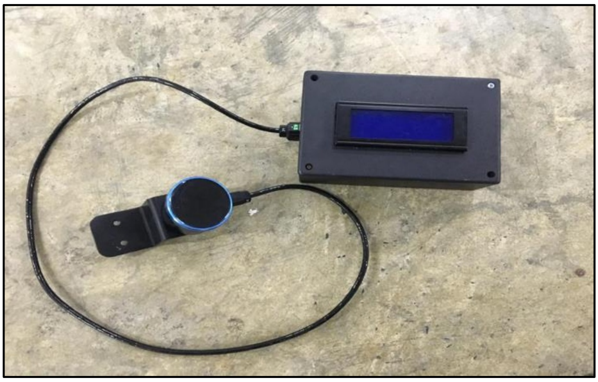


Fig. 8. Acoustic Instrument and GPS Sensor

A GPS sensor test was performed simultaneously with an acoustic sensor test. The GPS sensor Neo-6MV2 was tested by comparing it with GPS Garmin eTrex 10 and 585. The results of the test showed that compared with the GPS Garmin eTrex 10, the GPS sensor had an average difference of 15.4 meters, and compared with the GPS Garmin 585, it had an average difference of 55.9 meters.

The results of the test showed that the comparison between GPS Neo-6MV2 and Garmin eTrex 10, and Garmin 585 still had quite a large difference. This is because several factors can affect the GPS accuracy. According to [15], the accuracy of GPS is influenced by several factors, including the quality of the GPS receiver, number of satellites received, and location of satellites. The number of satellites read by GPS Neo-6MV2 ranged from 3 to 7 satellites. This is relatively small; therefore, it can affect the accuracy of the position read by the GPS.

The ping sonal echosounder used as an acoustic sensor can measure depth up to ±30 meters in water with a nearfield distance of 0.5 meters and a beam angle of 30°. The specifications of the sensors are listed in Table 10.

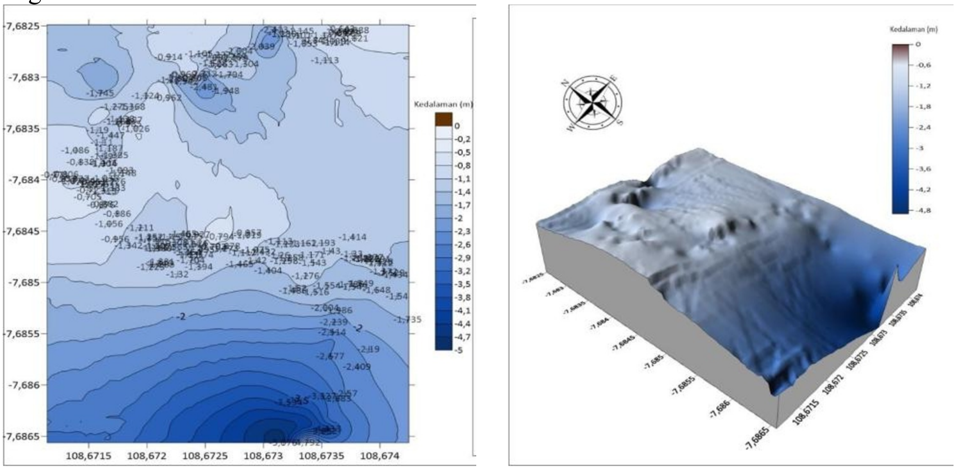
Table 10. Ping Sonar Echosounder Specification

Parameter	Specifications
Available Firmware Baud Rates	115200 bps (default), 9600 bps
Frequency	115 kHz
Beamwidth	30 degrees
Minimum Range	0.5 m
Maximum Range	30 m
Range Resolution	0.5% of range
Range Resolution at 30 m	15 cm

Parameter	Specifications
Range Resolution at 2 m	1 cm
Maximum Supply Voltage	5.5 volts
Minimum Suppy Voltage	4.5 volts
TTL Voltage Level	3.3 -5 volts

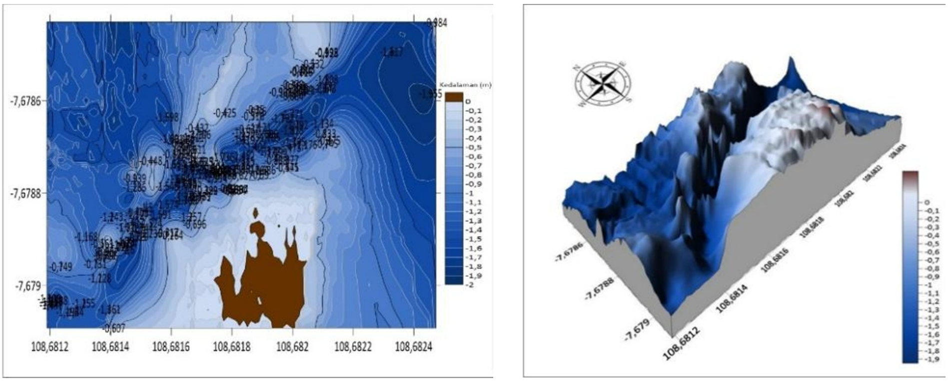
The use of ping sonar echosounders for measuring water depth has been well tested. However, development in providing coordinates and further data processing is very important to obtain good results [16], and this was performed in this study. When conducting sounding, the sensor takes depth data, and the GPS sensor takes data of latitude and longitude coordinates. During sounding, an LCD was used to monitor the data recorded by the sensor. The data were then calibrated and stored in a data logger, which entered the processing stage. Data calibration was performed using the tidal values in Pangandaran. Further processing of the data involved visualizing the data into a contour map and 3D view.

The acoustic sensor test was conducted in two locations: the Cikidang Fish Landing Port and Bulaksetra River. The visualization results of the sounding from the ping sonar echosounder are shown in Figure 9 and 10. Figure 9 is the visualization of a contour map and 3D view of the sounding location in Cikidang Fishing Port, Pangandaran, while Figure 10 is the visualization of a contour map and 3D view of the sounding location in Bulaksetra River, Pangandaran.



(a) (b)

Fig. 9. Visualization of (a) Contour Map and (b) 3D View from the Results of Sounding in Cikidang Fishing Port



(a) (b)

Fig. 10. Visualization of (a) Contour Map and (b) 3D View from the Results of Sounding in Bulaksetra River

Based on the visualization results, the depth condition in the port area recorded that the deepest point was at a depth of 5.076 m and the shallowest point was at a depth of 0.562 m. In the Bulaksetra River, the deepest point was recorded at a depth of 2.49 meters, and the shallowest point was at a depth of 0.17 meters. Visualizations in Figures 9 and 10 were obtained by processing the sounding data corrected by the tide of 0.1 MSL.

4 Conclusion

Unmanned surface vehicles (USV) have been successfully built with success in USV vehicle design, USV control systems, USV vehicle tests, and USV sensor systems. Unmanned surface vehicles (USV) that have been built still encounter problems in the drive and GPS sensor systems, where the durability of the drive system used can be further improved and the accuracy of the GPS sensor used also needs to be further improved.

References

1. H. Niu, Y. Lu, A. Savvaris, A. Tsourdos, Ocean Engineering, **169**, 13 (2018)
2. NAP, *Thrusts of the time critical strike FNC program overview*, In 2002 assessment of the office of naval research's air and surface weapons technology program, (2002), Retrieved from https://nap.nationalacademies.org/read/10594/chapter/6
3. V. Schmidt, Best Practices Guide. International Hydrographic Review, **24**, 13 (2020)
4. M.L. Seto, A. Crawford, *Autonomous shallow water bathymetric measurements for environmental assessment and safe navigation using USVs*, in OCEAN 2015, 19-22 October 2015, Washington DC, USA (2015)
5. K. D. V. Ellenrieder, H. C. Henninger, S. Licht, *Dynamic Modelling and Control of a portable USV for Bathymetric Survey*, in Global Oceans 2020, 5-31 October 2020, Singapore-US. Gulf Coast (2020)
6. Organisation for Economic Co-operation and Development, Frascati Manual 2015 : Guidelines for Collecting and Reporting Data on Research and Experimental Development (OECD Publishing, Paris, 2015)
7. K. Ulgen, M. R. Dhanak, J. Mar. Sci. Eng, **10**(9), 1169 (2022)
8. M. A. Yengejeh, M. M. Amiri, H. Mehdigholi, M. S. Seif, O. Yaakob, J. Engineering for The Maritime Environment, 230 (2), 18 (2015)

9. I. Backalov, S. Rudakovic, J. FME Transactions, **45**, 1 (2017)
10. International Maritime Organization, International code on Intact Stability (IMO Publishing, 2008)
11. D. E. Setiawan, B. Hascaryo, F. Purwangka, V. Rumanti, S. Purbayanto, B. Wibowo, Int. J. of Marine Engineering Innovation and Research, **9** (2), 8 (2024)
12. P. Xu, Q. Cao, Y. Shen, M. Chen, Y. Ding, H. Cheng, J. Mar. Sci. Eng, **10** (12), 1899 (2022)
13. A. Sulisetyono, *The Simple Open Free Running Test for the Evaluation of Turning Ship Ability*, in ISOCEEN 2018, 8-10 August 2018, Surabaya, Indonesia (2018)
14. D. Kim, T. Tezdogan, A. Incecik, Applied Ocean Research, **123**, 103176 (2022)
15. P. Misra, P. Enge, Global Positioning System : Signals, Measurement and Performance (2nd ed)(Ganga-Jamuna Press, 2011)
16. T.F. Ilyas, F. Arkhan, R. Kurniawan, T.H. Budianto, G.B. Putra, *Thingsboard-based prototype design for measuring depth and pH of kulong waters*, in The 3rd ICoGEE 2021, 29-30 September 2021, Bangka, Indonesia (2021)