Performance analysis of a multi-purpose winch integrated with the UAV Phantom 3 type for marine conservation and survey applications

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Abstract. Global climate change affects the dynamics of aquatic environmental quality, which results in pressure on marine ecosystems. Efficient data collector is needed for ecological management strategies. This research explores the development of unmanned aerial vehicle (UAV) utilization to collect in situ water data through a controlled transport system of measuring instruments. The Multi-Purpose Winch (MPW) innovation was developed to integrate the UAV Phantom 3 type with multi-parameter measuring instruments for in situ data collection. The research method used is the research and development (R&D) approach, which adopts the Design Thinking concept framework with five stages: (1) empathize, (2) define, (3) ideate, (4) prototype, and (5) test. The results show that the design and construction of the MPW allows integration with the UAV Phantom 3 type, which consists of NodeMCU, winch, electronic speed controller (ESC), global positioning system (GPS), and battery components. GPS accuracy tests on the MPW showed values between 1.57 and 9.99 m, with an average of 4.27 m. The load pulling speed test showed a range of 3.36×10^{-2} - 4.89×10^{-2} m s^{-1}, while the load dropping speed test ranged from 5.53×10^{-2} - 4.54×10^{-2} m s^{-1}. Performance testing of the MPW showed that increasing the load and altitude would decrease the speed and increase the duration of retraction and descent. This MPW design has the potential to carry survey tools weighing between 75 and 290 grams. Drone-based surveys are more cost-efficient measurement of the aquatic environment than boat-based surveys with a total cost of ownership (TCO) of IDR 35,434,000, cost saving percentage (CSP) of 88.17%, and benefit-cost ratio (BCR) of 8.46.

Key Words: CSP, design thinking, ecological monitoring, GPS, TCO.

Introduction. Accelerating global climate change affects the dynamics of changes in the quality of the aquatic environment (Rockström et al 2009; Whitehead et al 2009; Mujere & Moyce 2017; Han & Bu 2023; Thomas & Cheung 2024; Wang et al 2024). Changes in the quality of the aquatic environment result in pressure on marine ecosystems (Dyer et al 2013; Woznicki et al 2016; Zhao et al 2019). Appropriate management strategies are needed to address these pressures. To produce the right management strategy, the availability of accurate, fast, and efficient data is required (Peterson et al 2018; Oktorini et al 2024). Obtaining accurate, fast, and efficient data requires data collection tools that utilize the latest technology. Unmanned aerial vehicles (UAVs) or often referred to as drones, are one of the latest technologies that are widely used for the mapping process (Trasviña-Moreno et al 2017; Arefin 2018; Yang et al 2022; Jiang et al 2024; Li et al 2024), coral reef monitoring (Fallati et al 2020), fisheries data collection (Desfosses et al 2019), and macroplastic identification (Balsi et al 2021). Most of these uses utilize the UAV's ability to capture visual data from a certain height (remote sensing systems). UAVs are still limited to visual data generated by digital cameras mounted on UAVs (Pargieła 2023; Basyuni et al 2025). This research explores the development of UAV utilization for direct measurement in the field with a controlled transport system for measuring instruments. This development will be useful for fast and efficient in-situ field data collection. Specific module designs and constructions with measurable capabilities are required to develop a controlled measuring instrument transport system with UAVs. Therefore, this research was conducted to design a prototype product capable of being integrated with a UAV to transport measuring instruments of a certain weight and can be controlled remotely through Internet of Things technology.

Material and Method

Time and location of research. This experimental study was conducted over a period of 196 days, from May to November 2023, at Universitas Diponegoro.

Reseach method. This research method used a prototype product design approach based on research and development (R&D) methods. The R&D methods process adopts the Design Thinking concept framework, which consists of 5 (five) stages, namely (1) empathize, (2) define, (3) ideate, (4) prototype, and (5) test (Henriksen et al 2017; Pande & Bharathi 2020; Zulaikha et al 2023; Menéndez Mueras et al 2025). Design Thinking is an iterative innovation approach that identifies problems and generates creative solutions through prototyping and testing (Brown & Wyatt 2010; Stackowiak & Kelly 2020). The following is a description of the stages carried out in this research based on the Design Thinking framework:

1. Emphatize: at this stage, the problems and needs of field survey actors using conventional survey equipment were identified. This process was carried out through literature studies and interviews with key informants;
2. Define: at this stage, the data generated from the Emphatize stage is analyzed to gain a perspective on the problems obtained at the Emphatize stage;
3. Ideate: at this stage, innovative solutions are developed for the problems identified in the Define stage;
4. Prototype: at this stage, ideas are developed as innovative solutions to the point of view problems generated at the Define stage;
5. Test: at this stage, the process of designing an innovative product prototype design is carried out, which contains design drawings, components, and prototype specifications.

Haversine method. In this study, we used a haversine formula to calculate the distance difference between the two GPS points by calculating the distance between two points based on the straight line length between two points on the longitude and latitude lines (Maria et al 2020):

$$D = 2r \times \arcsin\left(\sqrt{sin^2\left(\frac{\emptyset_2 - \emptyset_1}{2}\right) + cos(\emptyset_2) \,.\, cos(\emptyset_1) \,.\, sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right) \qquad (1)$$

where: D is a distance (km), radius r = 6371(km), λ is longitude and ϕ is latitude.

Velocity measurement. In this study, we used a velocity measurement formula to measure the average speed during the winch rope pulling and lowering processes. The velocity measurement formula is as follows (Bian et al 2024):

$$v = d/t \qquad (2)$$

where: v represents velocity, d is the distance of the rope, and t is the time taken.

Operational cost efficiency analysis. In this study, we used calculations of total cost of ownership (TCO), cost saving percentage (CSP), and benefit-cost ratio (BCR). Several researchers who used these types of financial indicators include: Ellram (1995), Baker & English (2011), Horngren et al (2015), and Boardman et al (2018):

$$TCO = Ci + (Cs \times S) \qquad (3)$$
$$BCR = Ck / TCO \qquad (4)$$
$$CSP = (Ck - TCO) / Ck \qquad (5)$$

where: TCO = total cost of ownership;
Ci = investment cost of the new method (IDR);
Cs = operational cost per survey for the new method (IDR);
S = number of surveys conducted annually (days);
BCR = benefit-cost ratio;
Ck = total cost of the conventional method (IDR);
CSP = cost saving percentage.

By using CSP, cost savings can be quantitatively measured. A high CSP percentage reflects a higher cost-saving impact. TCO provides an overview of the full expenditure, and BCR compares the conventional value benefit to the innovation cost.

GPS performance testing locations. GPS performance testing was conducted in the Diponegoro University area (as shown in Figure 1). The testing location consisted of five different points to determine positioning accuracy.

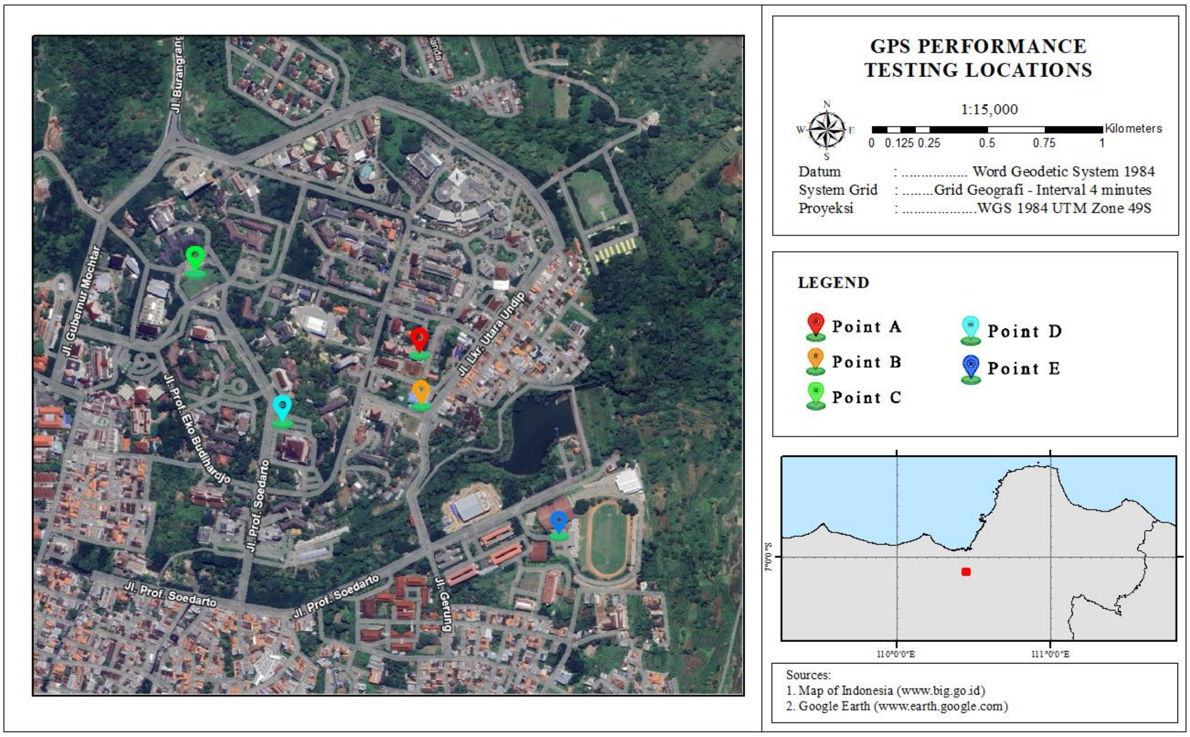

Figure 1. GPS performance testing locations.

Multi-purpose winch flowchart. The multi-purpose winch (MPW) innovation was created to integrate the UAV with Phantom 3 type with a multi-parameter measuring instrument to perform in-situ measurements. Figure 2 is a flowchart of the MPW usage mechanism.

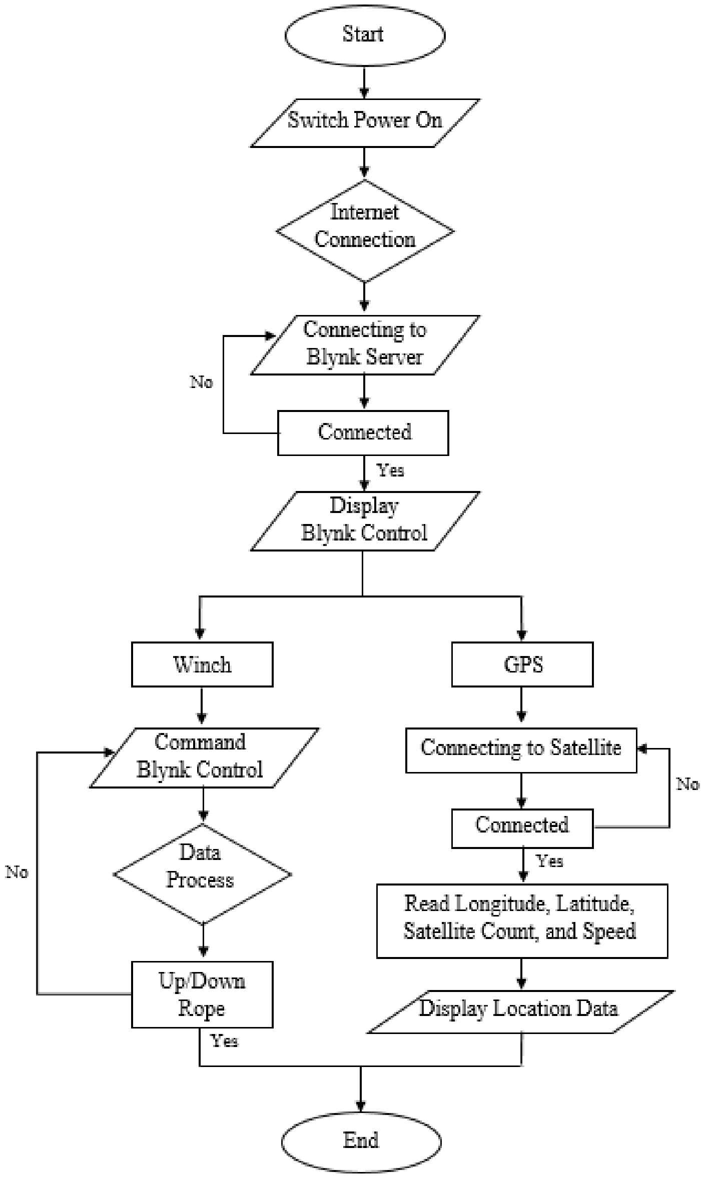

Figure 2. Flowchart of multi-purpose winch prototype.

Results

Emphatize. The availability of data is important in the process of marine area management planning. Based on the data obtained, the data analysis process can be carried out to produce an appropriate marine area management strategy plan. Research data is divided into two categories based on data collection methods: primary data and secondary data (Boaduo 2011; Emanuelson & Egenvall 2014; Senekane 2024). Primary data is a type of data obtained directly at the location of the study object (Grbavac et al 2010; Wilcox et al 2012; Emanuelson & Egenvall 2014; Mazhar et al 2021). Primary data can be obtained through in-situ measurements with specific measuring instruments, direct observation, and interviews with respondents. Secondary data is a type of data obtained indirectly. Secondary data can be obtained through the scientific literature, the study of important documents, or other sources that have collected data before (Ellram & Tate 2016; Näher et al 2023; Pernat et al 2024). This research examines the process of collecting primary data in situ using specific measuring instruments to collect water quality data for management planning purposes for marine water areas. The results of identifying problems of in situ data collection with measuring instruments in marine waters with key persons can be seen in Table 1.

Table 1

Identification of in situ data collection issues

No.	*Measurement parameters in-situ data*	*Problems*
1	Water quality	1. High cost: measuring instruments are carried to the measurement location points by ship. The higher the number of measurement location points, the longer the vessel must be used, affecting the field survey's cost. 2. There are many measuring instruments: one measuring instrument for one measurement parameter. 3. Data recording is done manually. Some water quality measuring instruments produce data as a screen display and do not have an automatic data storage system, so manual data recording is required.
2	Water bathymetry	1. High cost: the measurement process is carried out by ship, so the higher the observation area, the higher the cost. 2. Long measurement time duration: the measuring instrument for water bathymetry provides an automatic data storage feature, but it requires transferring the measurement data from the instrument to another device (laptop/PC). The data transfer process can only be done after completing the measurement process.
3	Coral reef and seagrass condition	1. High cost: data collection requires the services of divers. At least three divers are required for one dive station point, and diving equipment is expensive. 2. Data recording was done manually: the data collected by the divers was recorded manually. 3. Long measurement time duration: the data collection process for one observation station point ranges from 1 to 2 hours and depends on the visibility of the water.
4	Survey coverage	1. Limited accessibility: not all locations can be reached by boat. The more difficult it is to access the measurement location point, the more it will affect the data collection process. 2. Data recording was done manually: adding to the difficulty of the measuring team in manually retrieving water data.

***Define**.* Based on the results of identifying the problems of measuring water data in situ, its objective is to synthesize the data to discover key findings to formulate the design problem (Menéndez Mueras et al 2025). Several information needs are obtained as follows:

1. an efficient in-situ measurement method is required to minimize field survey costs;
2. a fast measurement method with a large observation area is required;
3. a measuring instrument capable of taking multiparameter data simultaneously is required;
4. automation of data transmission of measurement results in real-time is required.

***Ideate**.* Based on the identification of problems and needs, the idea of a solution that can be applied is a fast and efficient in situ measurement system. A measurement device that utilizes the latest technology is needed to make in-situ measurements quickly and efficiently. The technology that can be used is using UAVs in the measurement process. However, there are still obstacles, namely that UAVs are not explicitly designed to carry measuring instruments for field data collection in waters (Wen et al 2018; Amorim Reis-Filho & Giarrizzo 2022). To overcome these problems, it is necessary to create an innovation to connect the UAV with measuring instruments that the UAV can transport.

This type of UAV is used for various situations due to its affordability and maneuverability (Zacharie & Kyuhei 2017).

The design of the holder for MPW serves as a place to adjust the utility and the need to place some electronic components so that they can be placed on the UAV with Phantom 3 type camera bracket. Determination of the design form pays attention to the center of gravity for load distribution so that the UAV remains stable when flying. Figure 3 is an illustration of the design form of the holder for the multi-purpose winch.

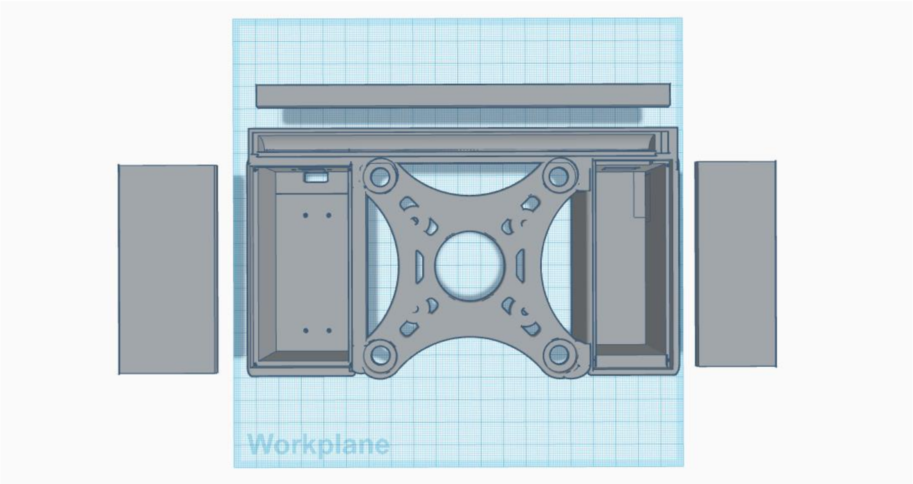

Figure 3. Multi-purpose winch design.

***Prototype*.** Based on the results of the ideas generated in the previous phase, prototypes are created to perform realization, testing, and evaluation. Prototypes are the primary tool used to experiment and visualize solutions. The prototype assembly process is carried out over several stages, namely (1) determining component specifications, (2) design and dimensions, and (3) software integration.

The following are the stages of assembling the prototype based on the predetermined assembly parameters:

Component specifications. The components used in developing the MPW prototype are detailed in Table 2 and Figure 4. Each component was selected with consideration to meet specific minimal operational requirements, ensuring compatibility with the UAV with Phantom 3 type platform and suitability for in situ transport of measuring instruments.

Table 2

Specifications of components for multi-purpose winch prototype

Name	*Description*	*Function*
Winch	Winch SCX 1/10	Pulling and releasing the rope to lift or lower the load.
ESC	Electronic speed controller (ESC) 20A	Regulating the motor speed for precise control of the winch mechanism.
Switch on-off	Swith on-off	Providing manual control to turn the system on or off.
NodeMCU	NodeMCU ESP8266	Acting as the main control unit to communicate between hardware and software.
Battery	Li-Po 7.4V 1100MaH	Supplying power to the system and ensuring operational continuity.
GPS	GPS NEO7M	Providing real-time positional data for accurate location tracking.
Filament	PETG filament	Used for creating a durable and lightweight casing for the prototype.
3D print	Ender 6	3D printing the casing and components with high precision.
Rope	PE ⌀ 0.7, 3 meter	Serving as the lifting medium for carrying the payload.

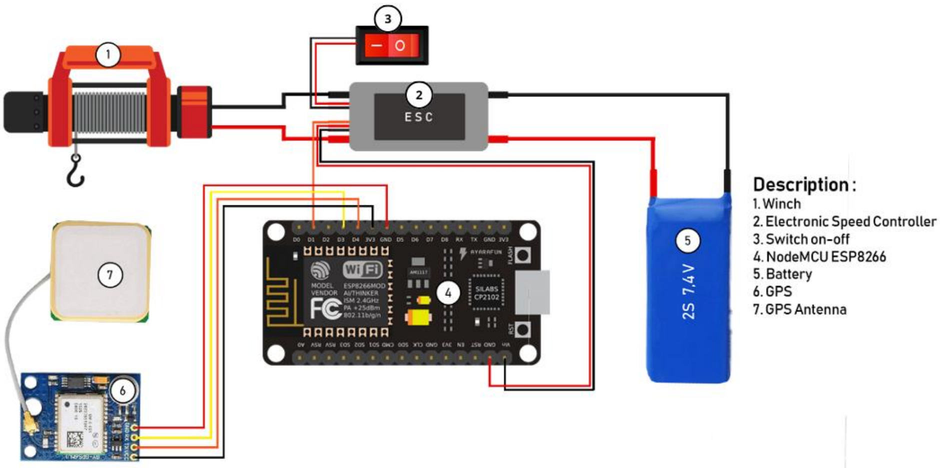

Figure 4. Electronics components of multi-purpose winch.

The winch mechanism, model SCX 1/10, is the primary means of pulling and releasing the rope to lift or lower the measuring instrument. At the same time, the 20A Electronic Speed Controller (ESC) ensures precise control of the motor on the winch. The NodeMCU ESP8266 module is the central control unit, enabling communication between the hardware and software components, while the GPS NEO7M module provides real-time position data. The power system consists of a 7.4V 1100mAh Li-Po battery, chosen for its portability yet sufficient energy capacity to support aquatic data capture.

The module casing was printed using PETG filament using a 3D printer (Ender 6) to protect the internal components while maintaining the maneuverability of the UAV. In addition, the lifting medium used polyethylene (PE) rope with a diameter of 0.7 mm and a length of 3 meters, which was chosen for its strength and flexibility to carry the measuring instruments.

Design and dimensions. The design and dimensions of the MPW prototype are illustrated in Figure 5. The prototype was developed to optimize stable weight distribution for integration with the bracket on the UAV with Phantom 3 type. The portable design, with an overall length of 165 mm, width of 85 mm, and height of 46 mm, allows the device to be safely mounted on the UAV without significantly reducing flight stability. The winch is positioned outside the case, while other components are positioned inside the case to guard against external conditions such as weather. The casing made of PETG filament has good resistance to environmental conditions, making it suitable for in-situ water data collection.

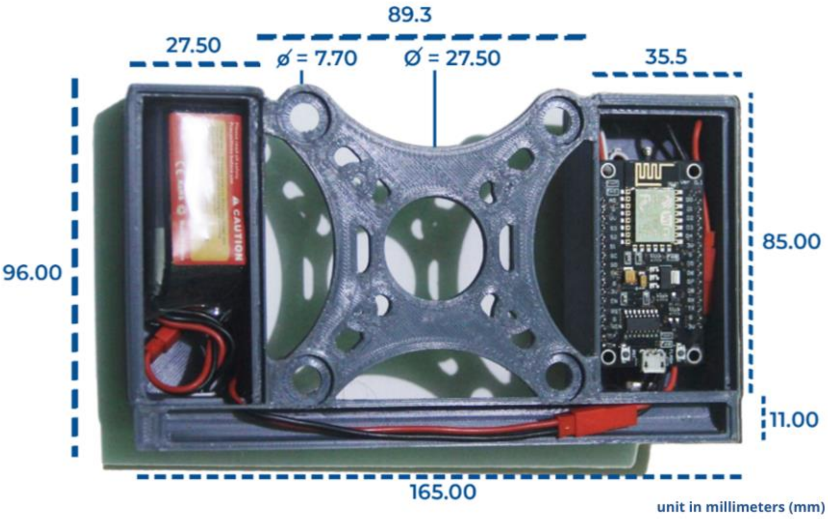

Figure 5. Design and dimensions of multi-purpose winch prototype.

The dimensions and layout of the structure were planned with several considerations to meet the operational needs of the prototype. These considerations include determining the balance point ensuring that the UAV remains stable during operation when the winch is transporting loads (such as sensors). In addition, the placement of each component was optimized to improve efficiency and minimize interference between parts. The design also adopts the UAV's default mount shape, allowing the gimbal and camera to remain in their default positions to maintain the UAV's default functions so as not to interfere with the UAV's performance.

Software integration. The prototype MPW was integrated via wireless connectivity using the Blynk 2.0 application, a versatile IoT-based software enabling remote winch control. The software is connected to the NodeMCU ESP8266 microcontroller via Wi-Fi, facilitating wireless data transmission between the MPW and the user interface. Through this application, users can perform several commands on the MPW, such as raising and lowering the rope on the winch and adjusting the winch's speed and direction. The user-friendly user interface (Figure 6) makes it easy for users to control the MPW.

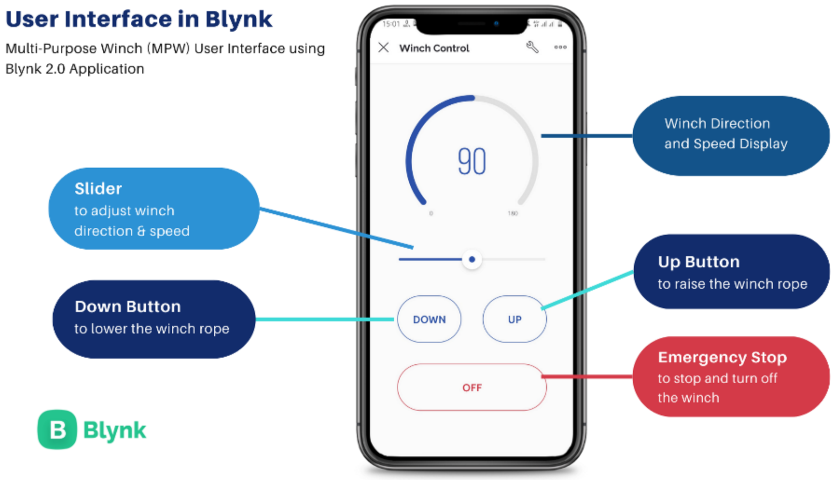

Figure 6. User interface of Blynk 2.0 application for multi-purpose winch control.

In addition to the winch control, Blynk 2.0 integrates the Neo7M GPS module to display the MPW coordinate position data during the in-situ data capture process. The user interface of the GPS (Figure 7) displays several important parameters, such as latitude, longitude, speed, and number of connected satellites, along with a dynamic map. This map-based visualization will make it easier to know the coordinate position when taking in-situ data.

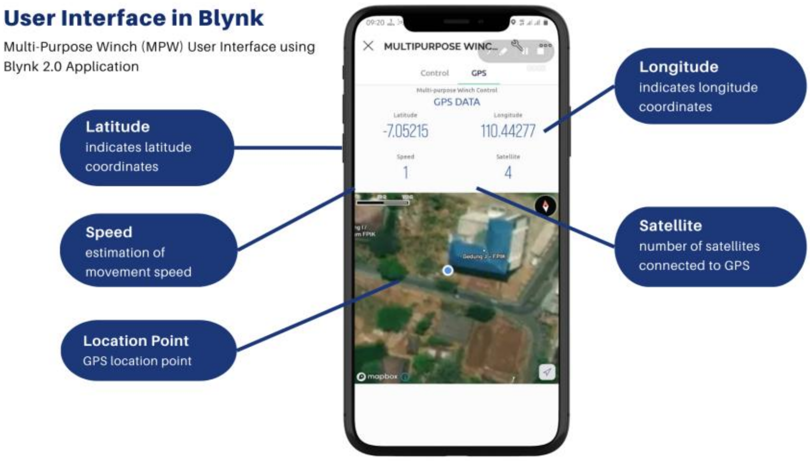

Figure 7. Real-time GPS monitoring via Blynk 2.0 for multi-purpose winch.

Compatible sensors. The prototype MPW is designed to transport various measuring instruments for in situ water data collection. Table 3 summarizes the specifications of various measuring instruments that the UAV can transport through the MPW. Several parameters, such as weight, connectivity method, and primary function, can be considered for integration into the MPW.

Table 3

Specifications and functions of sensors compatible with the multi-purpose winch prototype

Sensor name	*Weight (g)*	*Connectivity*	*Function*
PTR salinity meter	162	Data logger	To measure salinity levels.
CHUSHEN pool thermometer wireless	290	Wireless	To measure water temperature.
XF06 sonar fish finder	75	Wireless	To map the water bottom, mark places, record water temperature and depth, add bait, species and videos in trip logs.
BLE-9100 dissolved oxygen meter	84	Wireless	To measure dissolved oxygen and temperature.
RBRduet^3 T.D wave16	150	Data logger	To measure temperature and pressure, average tides, intermittent and continuous wave bursts.
CTD-Diver	95	Data logger	To monitor water level, pressure, conductivity and temperature.

Based on Table 3, the measuring instruments vary in weight from 75 grams (XF06 sonar fish finder) to 290 grams (CHUSHEN pool thermometer wireless) to ensure compatibility with the prototype's weight limit. Connectivity options, including wireless communication and data loggers, offer flexibility when capturing in-situ ocean data. Integrating these measuring instruments can increase the flexibility and efficiency of in situ aquatic data collection.

Operational cost efficiency analysis. Operational cost efficiency analysis was conducted using TCO, BCR, and CSP, based on a total of 32 survey activities per year, using both conventional (boat-based) and innovative (drone-based) methods. Operational cost efficiency analysis is summarized in Table 4. The following assumptions were applied in the analysis:

- the number of surveys conducted each year was 32;
- the total cost per conventional survey (boat-based) was IDR 9,362,500, including fuel, rental, and labor;
- the drone-based requires an initial investment of IDR 6,586,000 and operational costs per survey of IDR 901,500;
- the drone system is assumed to be used for only one year of operation (32 surveys), without depreciation allocation;
- revenue components are not calculated, as this analysis focuses on cost efficiency;
- all costs are calculated in Indonesian Rupiah (IDR).

Table 4

Operational cost efficiency analysis

Variables	*Average value*
TCO	35,434,000
BCR	8.46
CSP	88.17%

Based on the analysis results, the use of drone-based surveys for water data collection is much more cost-effective than conventional methods using boats. The CSP is 88.17%, indicating that nearly 90% of the cost burden can be reduced by adopting a drone system. The TCO of the drone-based system for one year of operation is IDR 35,434,000, compared to IDR 299,600,000 for the conventional survey (boat-based) (Hidayat et al 2015). This results in a BCR of 8.46, indicating that for every IDR 1 spent on the drone-based system, the equivalent benefit from the conventional system is nearly IDR 10. Drone-based innovation has proven to be not only cost-efficient but also suitable for sustainable use, particularly in repetitive or long-term water data monitoring programs. The high level of efficiency supports the feasibility of this method for larger-scale operations by enhancing the capabilities of drones to reduce budgetary burdens and improve operational efficiency compared to conventional boat-based methods.

Test. A performance testing process is carried out on the prototype to determine its performance. Prototype performance testing uses a limited-scale experimental research method/laboratory. Experimental research methods are used to evaluate prototype performance. This test is intended to provide information on the performance of the designed prototype. The testing process was carried out on several parameters, namely (1) the accuracy level of the GPS device, (2) the speed of pulling and lowering the load, and (3) the duration of pulling and lowering the load. The load used in the test consists of 4 (four) different weights, namely (A) 230.89 gr, (B) 350.51 gr, (C) 647.00 gr, and (D) 999.97 gr.

The following are the results of testing prototype performance based on predetermined test parameters:

GPS accuracy level. Accurate positional data is essential for knowing the location of the water when taking in-situ data. GPS accuracy was evaluated by comparing the recorded coordinates with the actual location using the Haversine Formula. Haversine is an equation that finds the arc distance between two points on longitude and latitude (Maria et al 2020; Prasetya et al 2020). This formula is commonly applied in smartphone systems for the identification of two different locations (Alam et al 2016; Winarno et al 2017). Test the accuracy level of the Neo7M GPS module integrated into the MPW prototype was conducted through data collection at five different locations (Points A-E) (see on Table 5) and compare it with the existing GPS on the smartphone. Table 5 presents the latitude and longitude coordinates recorded by both systems and the margin of error calculated in meters. The comparison between the Neo7M GPS module and the smartphone shows variations in accuracy across locations, with a maximum error margin of 9.99 meters observed at Point A and a minimum of 1.57 meters at Point E. The average error margin across the test points was 4.67 meters. This variation is likely influenced by environmental factors, such as signal obstructions or satellite availability, which can affect GPS performance. Despite the variations, the overall accuracy remains within acceptable limits for most surveying applications. Integrating the Neo7M GPS module with the winch system ensures precise location tracking, essential for in-situ data capture

Table 5

Neo7M GPS performance for positioning accuracy

Place		*GPS Neo7M*		*GPS Smartphone*		*Margin of error (m)*
		Lattitude	*Longitude*	*Lattitude*	*Longitude*	
Point A	Indoor	-7.05101	110.44289	-7.05102	110.44298	9.99
Point B	Outdoor	-7.05205	110.44293	-7.05206	110.44291	2.47
Point C	Outdoor	-7.04938	110.43840	-7.04941	110.43842	4.00
Point D	Outdoor	-7.05234	110.44014	-7.05237	110.44014	3.34
Point E	Outdoor	-7.05464	110.44570	-7.05465	110.44571	1.57
Average						4.27

Load testing on the prototype. The performance of the MPW prototype was evaluated using four load categories, as summarized in Table 6. The loads used consisted of water bottles of various sizes filled to a specific volume and measured in grams using a digital scale. The loads ranged from 230.89 grams (Load A) to 999.97 grams (Load D), representing light loads to near maximum capacity. This selection of loads aims to simulate realistic field conditions. Load A, equivalent to a 250 mL water bottle, represents a light load like a small sensor. Load B (350 mL) and Load C (600 mL) simulate medium to heavy instruments, reflecting commonly used field equipment. Finally, Load D, a 1-liter water bottle weighing approximately 999.97 grams, approximates the maximum operational capacity of the system on the winch and UAV carrying capacity. The loads used can provide information and insight into the optimal performance and reliability of the system in real applications.

Table 6

Details of load variations used in prototype testing

Code	*Weight (g)*	*Material*	*Purpose*
Load A	230.89	Small water bottle (200 mL)	Simulate light loads, such as small sensors.
Load B	350.51	Medium water bottle (330 mL)	Representing medium-sized equipment used for field testing.
Load C	647.00	Large water bottle (600 mL)	Simulate heavier instruments or loads.
Load D	999.97	Extra-large water bottle (1 L)	Testing the maximum capacity of the winch system.

Evaluation of rope pulling speed. The rope pulling speed of the MPW prototype was tested at four load categories (Load A to Load D) and three operational heights (1 m, 1.5 m, and 2 m). The results of the tests are presented in Table 7, showing the variation of the pulling speed as the weight of the load increases and the height changes. The highest withdrawal speed was recorded for Load A at 1 m, reaching 4.89×10^{-2} m s^{-1}, while the lowest speed was observed for Load D at 2 m, at 3.36×10^{-2} m s^{-1}.

Table 7

Rope pulling speed of multi-purpose winch across load variations and heights

Test load	*Height (m)*			*Unit*
	1	*1.5*	*2*	
Load A	4.89×10^{-2}	4.62×10^{-2}	4.48×10^{-2}	m s^{-1}
Load B	4.53×10^{-2}	4.35×10^{-2}	4.24×10^{-2}	m s^{-1}
Load C	4.25×10^{-2}	3.96×10^{-2}	3.79×10^{-2}	m s^{-1}
Load D	3.88×10^{-2}	3.53×10^{-2}	3.36×10^{-2}	m s^{-1}

The data shows a clear trend where the withdrawal velocity decreases as the weight of the load increases. For example, at a height of 1 m, the withdrawal speed decreased from 4.89×10^{-2} m s^{-1} for Load A to 3.88×10^{-2} m s^{-1} for Load D. Similarly, at higher heights, the withdrawal speed continued to decrease, with heavier loads showing a more significant decrease. This decrease could be due to the increased mechanical resistance and energy required to lift heavier loads over longer distances.

Interestingly, for light loads such as Load A, the decrease in speed due to the increase in height was relatively small, indicating optimal performance under the conditions. These findings demonstrate the prototype's ability to maintain an effective pulling speed across a wide range of load weights and heights, providing insight into its reliability in field operations.

Evaluation of rope pulling duration. The pulling duration of the MPW prototype was evaluated under four different load categories (Load A to Load D) and three operational heights (1 m, 1.5 m, and 2 m). As presented in Table 8, the results illustrate the time the winch takes to lift each load to the specified heights. The shortest pulling duration was recorded for Load A at 1 m, taking 20.46 seconds, while the most extended duration was observed for Load D at 2 m, with a value of 59.58 seconds.

Table 8

Rope pulling duration of multi-purpose winch across load variations and heights

Test load	*Height (m)*			*Unit*
	1	*1.5*	*2*	
Load A	20.46	32.46	44.61	seconds
Load B	22.09	34.45	47.18	seconds
Load C	23.52	37.90	52.75	seconds
Load D	25.80	42.50	59.58	seconds

The data showed a consistent trend. The retraction duration increased as the load weight and lifting height increased. For example, at a height of 2 m, the retraction duration for Load D (59.58 s) was much higher than that of Load A (44.61 s). This trend reflects the increased mechanical effort and energy required to lift heavier loads over longer distances.

Nonetheless, the winch system showed stable performance within its operational range, ensuring reliability for both light and heavy loads. This finding confirms the system's ability to handle various load conditions while maintaining consistent operational stability.

Evaluation of rope drop speed. The rope drop speed of the Multi-Purpose Winch prototype was tested under four load categories (Load A to Load D) and three operational heights (1 m, 1.5 m, and 2 m). As shown in Table 9, the results provide insights into the system's ability to lower loads efficiently while maintaining consistent performance. The highest drop speed was recorded for Load C at 1 m, reaching 5.53×10^{-2} m s^{-1}, while the lowest speed was observed for Load D at 2 m, with a value of 4.54×10^{-2} mm s^{-1}.

Table 9

Rope drop speed of multi-purpose winch across load variations and heights

Test load	*Height (m)*			*Unit*
	1	*1.5*	*2*	
Load A	5.42×10^{-2}	5.13×10^{-2}	4.95×10^{-2}	m s^{-1}
Load B	5.23×10^{-2}	4.91×10^{-2}	4.79×10^{-2}	m s^{-1}
Load C	5.53×10^{-2}	5.00×10^{-2}	4.91×10^{-2}	m s^{-1}
Load D	5.38×10^{-2}	4.85×10^{-2}	4.54×10^{-2}	m s^{-1}

The data showed a slight decrease in descent velocity as the operational height increased, with heavier loads experiencing a more significant decrease in velocity. For example, Load A showed a decrease in speed from 5.42×10^{-2} m s^{-1} at 1 meter to 4.95×10^{-2} m s^{-1} at 2 meter, while Load D experienced a decrease from 5.38×10^{-2} m s^{-1} to 4.54 × 10-2 m s-1 over the same height range.

These trends reflect the ability of the system to maintain stability and control during lowering operations despite variations in load weight and height. These results show that the winch system is suitable for transporting measuring instruments in the water environment.

Evaluation of rope drop duration. The rope lowering duration of the MPW prototype was tested using four load categories (Load A to Load D) at three operational heights (1 m, 1.5 m, and 2 m). The results, as presented in Table 10, show the time taken by the winch to lower each load to the specified height. The fastest duration was recorded for Load C at 1 m (18.10 s), while the longest was observed for Load D at 2 m (44.07 s).

Table 10

Rope Drop Duration of Multi-Purpose Winch Across Load Variations and Heights

Test load	*Height (m)*			*Unit*
	1	*1.5*	*2*	
Load A	18.42	29.24	40.38	seconds
Load B	19.13	30.55	41.77	seconds
Load C	18.10	30.01	40.76	seconds
Load D	18.61	30.94	44.07	seconds

The data showed that the descent duration increased consistently with height and load weight. For example, at a height of 2 m, Load D takes the longest time (44.07 seconds), while Load A takes 40.38 seconds for the same descent. This trend shows that the winch system can control the lowering process well, maintaining stability and safety during operation.

In addition, the relatively small variation in duration for lighter loads, such as Load A and Load C, indicates that the system has been optimized to handle the load efficiently, even at higher heights. These results demonstrate the system's ability to adapt to various load weights and operational conditions, ensuring its reliability in field applications.

Discussion. The UAV with Phantom 3 type integrated MPW prototype was realized through the principles of the design thinking method. The UAV-based MPW's ability to operate in shallow and remote areas overcomes the limitations faced by traditional methods, such as limited access and high operational costs (Adade et al 2021; Yang et al 2022). Integrating a GPS module ensures precise coordinate location tracking for monitoring marine protected areas and their effectiveness over time (Wu et al 2015; Odolinski & Teunissen 2017).

Testing the NEO7M GPS module on the MPW proved its accuracy compared to mobile phones with an average error margin of 4.67 meters. However, studies on the NEO-M8N GPS, a more advanced version, showed that accuracy levels could be improved by combining GPS with other GNSS systems such as Galileo, QZSS, and BDS (Odolinski & Teunissen 2017; Mahato et al 2023). Winch testing on the MPW performed well in various load categories and test heights. The test results showed an inverse relationship between load weight and rope pulling speed, which agrees with findings in crane systems where heavier loads cause a decrease in operational speed due to increased mechanical resistance (Lee & Kim 2021; Visser & Spinelli 2023). Tests on Load A that simulated a light load showed minimal speed degradation, while heavier loads such as Load D experienced significant speed degradation. These findings are similar to research results on tower crane systems, where the interaction between load weight and speed affects operational efficiency and stability (Tian et al 2021; Shi et al 2022). The rope pulling and lowering duration increases proportionally with load weight and operational height. This correlation indirectly reflects the additional energy required to lift or lower heavier loads over longer distances, as observed in ship winch and forest crane operations (Wang et al 2013; Sun et al 2015). The load-carrying capability of the MPW also considers the maximum load that can be carried on the UAV with Phantom 3 type. Based on research by Zacharie & Kyuhei (2017), the UAV with Phantom 3 type has stability in carrying loads up to a weight of 900 grams and starts to become unstable at a load of 1 kg. Information on the capabilities of UAVs and MPWs helps determine what measuring instruments can be carried out to collect water data in situ.

Operational cost efficiency analysis was conducted by comparing budget data from monitoring and surveys on marine resource utilization in Sawu Sea National Park. The total number of days spent on marine resource utilization monitoring activities using boats in a year is 32 days, with an estimated total direct cost of around Rp 9,362,500 per day (Hidayat et al 2015). The TCO of the drone system for one year of operation is IDR 35,434,000, compared to IDR 299,600,000 for the conventional method (Hidayat et al 2015). The comparison shows that drone-based surveys are more cost-efficient with a

CSP of 88.17%, meaning that nearly 90% of costs can be reduced by adopting a drone system. This results in a BCR of 8.46, indicating that for every IDR 1 spent on the drone-based system, the equivalent benefit from the conventional system is nearly IDR 10.

The flexibility to integrate various measuring instruments can expand the utility of the prototype for aquatic data collection, ecological monitoring, habitat mapping, and water quality assessment. The MPW prototype shows improved efficiency over conventional survey tools, such as manual water quality meters and sonar systems, which require high labor and cost (Kieu et al 2023; Giordano et al 2015; Shukla et al 2025). Integrating IoT technology streamlines the data collection, reducing the time and resources required. In addition, the flexibility to integrate multiple measurement tools can expand the scope of data that can be collected and improve the efficiency of data capture. However, challenges remain in optimizing the pulling and lowering speed of the rope to maintain stability and accuracy. Studies show that increasing speed can cause oscillations, especially in underactuated systems (Shi et al 2022; Wang et al 2013). Effective control strategies, such as adaptive coupling control or anti-swing controllers, can overcome this effect to ensure stable and precise operation (Sun et al 2015; Shi et al 2022).

Conclusions. This research resulted in designing and constructing a Multi-Purpose Winch (MPW) that allows it to be integrated with the UAV Phantom 3 type. This MPW has NodeMCU, Winch, ESC, GPS, and battery components. Drone-based surveys are more cost-efficient than boat-based surveys with a TCO of IDR 35,434,000, CSP of 88.17%, and BCR of 8.46. The test results of the GPS accuracy level on MPW are in the range of 1.57-9.99 m with an average of 4.27 m. The load-pulling speed test results showed a value of 3.36×10^{-2} m s^{-1} - 4.89×10^{-2} m s^{-1} with a load-pulling duration of 20.5-59.6 s. The test results showed a value of 5.53×10^{-2} m s^{-1} - 4.54×10^{-2} m s^{-1} with a load drop duration of 18.10-44.10 s. The MPW performance test results show that as the load and altitude increase, the speed will decrease, and the duration will increase. This MPW design can carry survey equipment with weights between 75-290 g.

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