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An Integrated Controller System For Unmanned Surface Vehicles (USV)

Nazreen Rusli*, Zulkifli Zainal Abidin, Muhammad Aiman Norazuddin, Taufik Yunahar

Abstract – Unmanned Surface Vehicles (USVs) are extensive used in several industries, such as environmental monitoring, offshore resource exploration, and maritime security. The benefits of USV for risk minimization and prolonged operational endurance cause an increase in demand. USVs are essential for administering marine security laws since they can remotely monitor traffic. Their ability to navigate well and avoid collisions improves the efficiency and safety of marine traffic. The incorporation of cutting-edge sensors and battery-powered vehicles enhances the dependability and operating capacities while minimizing environmental impact. Unlike traditional fuel-powered vessels, battery-operated USVs produce no direct water pollutants, contributing to cleaner oceans and more sustainable maritime operations. In response to these technological advancements and the unique maritime needs of Malaysia and neighboring oceanic nations, Centre for Unmanned Technologies (CUTE) at the International Islamic University Malaysia (IIUM) collaborated with Prostrain Technologies to develop a robust controller for USVs called "CxSense". The controller board of CxSense has been designed to meet the stringent compliance requirements of IPx8, ESD test, and vibrations test, demonstrating their robustness, reliability, stability, and adherence to industry standards for high-level protection. This invention has the potential to significantly improve the efficiency and

safety of maritime operations in Malaysia and the surrounding oceanic nations.

Keywords— *Unmanned Surface Vehicle, Modular System, Controller Box, Autonomous Navigation, Maritime.*

I. INTRODUCTION

Advancements in automation, Artificial Intelligence (AI), and renewable energy integration are further enhancing USV capabilities, making them valuable for industries such as oceanography, fisheries, and maritime transportation [1]. This growing interest reflects the increasing reliance on autonomous technologies for safer, more efficient, and sustainable marine operations [2]. Building upon these technological advancements, this study explores the conceptualization and execution of a modular, cost-effective, adaptable autonomous surface vehicles adapted for inland water environments. The design methodology encompasses three key phases: mechanical and electrical-electronic design, and software design.

The mechanical framework adopts a trimaran (three-hulls) configuration, chosen for its heightened stability, particularly in turbulent waters. This design

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provides a broader deck space, facilitating the deployment of various sensors and equipment without significantly affecting the vessel's center of gravity or navigational stability. To optimize cost-efficiency while maintaining functionality, the USV utilizes off-the-shelf hulls with an electric trolling motor for propulsion by Hydrokinetic Technologies. Steering is facilitated through a rudder mechanism actuated by a servo motor, reinforcing a commitment to simplicity and reliability.

Integrating with this mechanical architecture, the electrical and electronic systems serve as the backbone of the boat's operational capabilities. This phase involves the selection and integration of power management systems, communication modules, and navigation sensors, ensuring reliable and sustained autonomous operations. The seamless interaction between hardware and software is critical to achieving autonomy, requiring robust software architecture to process sensor data and execute navigation algorithms. Meanwhile, to bridge the mechanical and electrical subsystems with high-level decision-making capabilities, the vehicle integrates an open-source module called Mission Oriented Operating Suite Interval Programming (MOOS-IvP) with an onboard computer. This integration ensures a seamless transition to autonomous control and enables adaptive control strategies.

Intensive field tests confirm the effectiveness of this system, demonstrating its reliability and performance. The system's well-designed features, such as ample deck space and modular software architecture, facilitate the continuous integration of CxSense controller box with diverse sensors and mechanical components, making it highly adaptable for various operational needs.

II. LITERATURE REVIEW

The current state of Unmanned Surface Vehicle (USV) technology can be viewed from two distinct perspectives: off-the-shelf products and research-based solutions. These perspectives offer unique insights into the evolution and diversification of USV applications. Off-the-shelf products provide solutions for various tasks, offering convenience and reliability for users seeking immediate deployment. Conversely, research-based products represent the cutting edge of USV innovation, pushing the boundaries of technology to address specialized challenges and exploring new boundaries in autonomous navigation and marine exploration. Together, these perspectives shape the landscape of USV technology, catering to both practical applications and pioneering research undertakings.

A. Commercial USV Controller

The technology for small, unmanned surface vehicles (USV) used in bathymetry surveys has made significant progress, offering efficient, precise, and cost-effective solutions for mapping and exploring underwater terrains. Two standout off-shelves product examples are the Apache Series from CHCNAV [3],

and the CEE-USV™[4] from CEE Hydrosystems, each bringing unique capabilities to hydrographic surveying.

The Apache Series, including models such as Apache 3, 4, and 6, are designed for the efficient hydrographic, bathymetric, and hydrological surveys of lakes, inland rivers, and coastal areas. They focus on providing stand-alone hydrographic solutions with autonomous navigation and single or multibeam echosounders for depth measurement. Integrating GNSS real-time kinematics (RTK) system enhances positional accuracy, offering about 2-3 cm accuracy, which is crucial for detailed underwater mapping. These vessels are particularly expert at handling tasks in lakes, inland rivers, and coastal areas, providing 3D modeling capabilities for objects or terrains underwater.

On the other hand, the CEE-USV™ developed by Bruttour International in 2011 is another high-quality survey vessel that incorporates a single-beam echo sounder, GNSS positioning, live video, and onboard data management, making it a powerful tool for precise bathymetric surveys. It features a rugged and durable hull design for reliability in various conditions, and the propulsion battery condition monitoring ensures uninterrupted operation during surveys. The USV supports high-quality electrical systems and has optional long-range telemetry for effective data transmission.

In addition to bathymetric surveys, unmanned surface vessels like the SL40 and SL20 USVs from OceanAlpha [5] are utilized for various applications, including river velocity measurements with Acoustic Doppler Current Profile (ADCP) and water quality monitoring in cooperation with Unmanned Aerial Vehicles (e.g., drones). These platforms demonstrate the versatility of small USVs in conducting multifaceted environmental monitoring tasks, further enhancing their value in modern hydrographic surveying and ecological studies.

Besides the Seafloor System [6], the founder has also developed a controller specifically for USV by following the predetermined track lines when performing surveys. Similarly, Maritime Robotics also produced a controller for a USV named Mariner, equipped with an advanced auto navigation control system, enabling it to navigate through pre-programmed survey routes autonomously. This system likely includes GPS for positioning and sophisticated algorithms for path planning and obstacle avoidance, ensuring the USV can perform tasks with minimal human intervention.

The development of these technologies underscores the growing importance of USV in hydrographic surveying [7], providing safer [8], and cost-effective options to traditional manned operations. These small, unmanned vessels are revolutionizing underwater surveys, offering greater accessibility to remote or hazardous areas and delivering high-resolution data [9] for a comprehensive understanding of aquatic environments.

B. Researched-based USV Controller

Meanwhile, research-based development of USV controllers focuses on new algorithms or integrating cutting-edge technologies. These controllers might be part of a study on new navigation systems, autonomy levels, or integration with other technologies such as Artificial Intelligence and machine learning. They are highly configurable and flexible, which can be adjusted, improved, or expanded as research progresses.

Recent research has focused on enhancing the precision and effectiveness of USV operations in complex and dynamic maritime environments. Two notable studies have discussed the exploration of advanced control strategies to improve USV trajectory tracking [10] and introduce intelligent control systems through deep learning [11].

Li X et al. [10] proposes a trajectory-tracking control method for USVs that integrates fixed-time disturbance observer and integral sliding-mode control technologies. This approach addresses the challenges of navigating ocean environments with unknown disturbances by proposing an innovative control strategy that achieves high accuracy. The method is designed to handle both single USV trajectory tracking and cooperative tracking of multiple USVs. The key innovation here is the development of a novel fixed-time stable-convergence disturbance observer (FT-DO) that can accurately approximate unknown disturbances as lumped uncertainties. For trajectory tracking, the study introduces an accurate trajectory tracking controller (FTFISM-TTC) for single USVs alongside a cooperative tracking controller for multi-USV operations. The effectiveness of these controllers was validated through rigorous simulation using MATLAB, highlighting their potential to improve tracking accuracy and reliability in USV operations.

Another study by Alejandro et al. [11] investigates the potential of deep reinforcement learning to create an intelligent controller for USVs. This research highlights the importance of adaptive and intelligent control systems that can learn and optimize their performance over time, particularly in handling high-speed navigation and complex decision-making scenarios. Deep reinforcement learning signifies a shift towards more autonomous and self-improving control mechanisms for USVs, allowing for more sophisticated and responsive behaviours in a wide range of maritime tasks. Those studies collectively point towards a future where USV operations can be significantly enhanced through advanced control strategies and intelligent systems. Incorporating fixed-time disturbance observers, integral sliding-mode control, and deep reinforcement learning into USV controllers improves their operational accuracy, efficiency and adaptability to maritime environments' unpredictable conditions.

C. CxSense USV Controller

CxSense, an innovative commercial USV controller, offers enhanced adaptability, AI-driven autonomy, and modular integration to meet the growing demands of modern maritime operations.

CxSense aims to deliver reliable, efficient, and autonomous solutions by integrating real-time decision-making capabilities and improved environmental adaptability. It has undergone extensive testing and validation to comply with international standards, including IEC certifications such as EMC, ESD, and water ingress protection standards. Table 1 annotates the intended tests to validate the CxSense controller's robustness and operational efficiency.

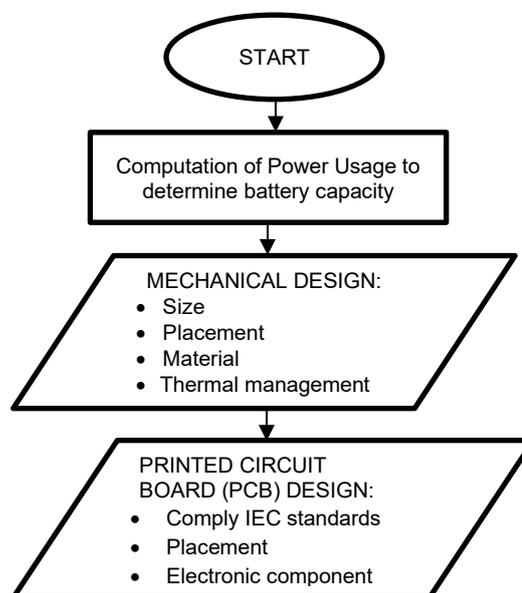
TABLE 1. Compliance tests were conducted on CxSense.

Testing Type	Description	Standard	Purpose
Electrostatic Discharge (ESD) Testing	Assesses protection against electrostatic discharges.	IEC 61000-4-2 [12]	Prevents component failure due to ESD events.
Dry Heat Test	Assesses durability against high-temperature environments	IEC 60068-2-2 [13]	To create CxSense ability in high-temperature environments.
Water Ingress Protection Testing	Validates resistance to water penetration and submersion.	IEC 60529 [14]	Confirms protection against prolonged submersion and bad weather.

In summary, commercial controllers provide reliability, while research-based controllers offer flexibility. However, CxSense uniquely integrates both features with commercial-grade durability, setting a new benchmark in the marine industry with superior adaptability and compliance. As a TRL 8-rated solution, it is an ideal choice for organizations seeking a robust and field-proven USV controller.

III. DEVELOPMENT PROCESS

The development process of CxSense controller consists of three main phases: the design, integration, and compliance phases. The process flow is presented in the flowchart shown in Figure 1.



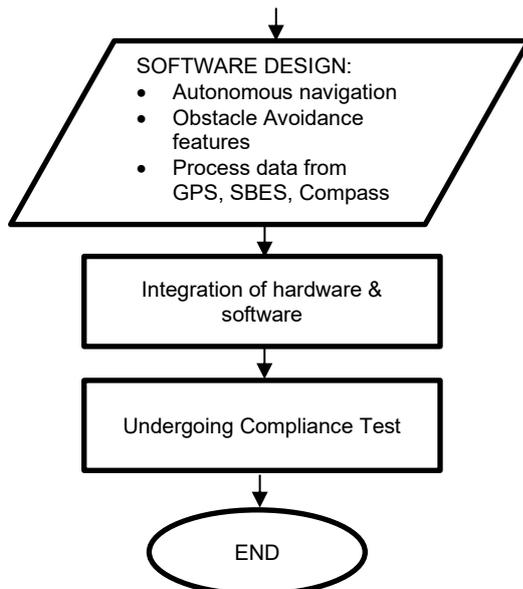


FIGURE 1. Phases in the development of CxSense Controller.

A. Design Phase

The design phase of a CxSense controller box is crucial, and it is divided into three niche parts: Mechanical, Electrical, and Electronic Design and Software.

Mechanical Design

The CxSense controller box is designed to comply with rigid spatial constraints and is added with an intelligent autopilot feature. The box dimensions are 141.5 mm in width, 133.5 mm in length, and 135 mm in height. This compact form ensures compatibility with various vessel sizes, including hobby-sized boats approximately 1.5 meters long. Remarkably, the design is optimized for vessels equipped with integrated electric propulsion systems, emphasizing the system's versatility. Despite its small build, this controller is distinctive. It houses communication devices to link all the sensors, electrical boards, a computational hub, and a microcontroller within a singular enclosure. The design also considers the cooling effect provided by the thermal heatsink, as the box is placed under direct sunlight. The exposure will build up excessive heat and negatively impact the system performance and longevity. Therefore, the study examines the effectiveness of thermal management features, such as heat dissipation mechanisms and material selection, in maintaining optimal internal temperatures. By evaluating the thermal response of the enclosure, the CxSense controller promises a smooth operation under extreme heat conditions, preventing thermal-induced failures that could compromise USV performance during missions.

In contrast, the choice of material for developing enclosure boxes is critical in establishing an effective barrier against Electromagnetic Compatibility (EMC) disturbances. Stifanese et al. [15] introduced stainless steel SIL316 and then selected it as the enclosure box

material for CxSense. This material is renowned for its ability to reflect electromagnetic waves, inhibiting their entry into the shielded enclosure. This is advantageous in the context of high-frequency electromagnetic waves.

Electrical and Electronic Design

CxSense circuit board was developed upon consideration of an electronic system for optimized power consumption for prolonged battery operation. The board is designed to meet comprehensive compliance testing standards such as EMC compliance and ESD compliance. It is imperative to conduct EMC testing [16] in marine applications to discover whether electronic systems do not adversely affect human beings or marine life. It is well understood that electromagnetic fields can emit and affect electronic devices. Therefore, integrating TVS diodes onto the circuit board represents a conscious strategy to protect against transient phenomena, mitigate EMI, and increase the likelihood of achieving EMC compliance. As a result, the TVS diode is placed at each output terminal on the PCB that connects to the controller panel. Despite this, implementing an optocoupler in the circuit protects against Electrostatic discharge (ESD). The optocoupler may act as a safeguard and can establish an effective isolation barrier from the potential detrimental effects induced by ESD sources.

Software Design

Improvement in the navigation aspect to have a safe journey is crucial. The navigation system should have the ability to self-localize and perceive the surrounding environment so that a safe path of operation can be generated. The capability to detect obstacles along the way and reroute the path to avoid the obstacles is a necessity.

The existing methodology in [17] discussed obstacle detection and avoidance and can rely on the Global Positioning System (GPS) to determine the tracking data of an object on the sea. However, it depends on the GPS coverage of the area and weather conditions. The stability of the GPS signals is highly important to track objects. The drawback of the vessels that are equipped with only GPS is that they are prone to missing object detection as several vessels have no GPS installed and have poor signal transmission. Though an automated identification system (AIS) is used to report the existence of vessels on the sea, it is not reliable as AIS is mandatory to be installed in specific sizes of vessels. Further limitations of AIS data relate to the quality of the records received, where potential sources of error exist within the data. As a result, RADAR is introduced by Nikolić [18] to be embedded on the board. However, in a practical test, RADAR cannot detect small obstacles at close ranges.

Meanwhile, vision sensors' reliability in limited light sources is doubted. The accuracy of the vision sensor system highly depends on distance and time. The sensors usually can see an object at a limited distance, and if it goes beyond, it is hard to view the

object. On the other hand, vision sensors can observe the environment very clearly in the daytime with the light from the sun, but at night, in an environment without light, other senses are added to increase the USV's perception of the surroundings. To conclude, no single sensor can fulfill all limitations on its own; hence, as an autonomous surface vehicle, to perceive surroundings for obstacle avoidance, it is ideal for fusing input from several sensors to overcome the shortcomings. The merging input from two sensors is considered in the CxSense controller. A combination of vision sensors and 3D LiDAR sensors to address challenges related to achieving high resolution, precision, and weather resistance is aimed to enhance the system's capability to perceive its surroundings, even in adverse weather conditions.

B. Integration Phase

CxSense comprises two integrated components: hardware and software. The hardware component encompasses the payloads used in surveying tasks, basic navigation, and communications infrastructure, enabling interaction between the ground station and the vehicle. Meanwhile, the software components include algorithms, data processing, and user interface. The integration of these two components allows for seamless communication, supporting the system's efficient performance.

Hardware Integration

CxSense controller has been carefully selected as a modular system to serve as the central hub for integrating all sensors necessary for basic navigation and hydrographic surveying tasks. By prioritizing power efficiency, our modular system is well-suited to integrating a wide range of sensors, catering to various requirements, and ensuring adaptability to different sizes of vessels and operational scenarios.

Furthermore, our system is designed to adhere to the communication and formatting standards of the National Marine Electronics Association, called NMEA0183 [19]. This deliberate choice facilitates smooth and easy operation across diverse applications and vessel sizes, ensuring compatibility with existing marine electronics and enhancing interoperability in marine environments. By adopting standardized communication protocols, our modular system promotes ease of integration and operation, empowering users with a versatile solution for their navigation and hydrographic surveying needs.

Within the modular system framework, they are interconnected in a unified communication setup that facilitates smooth data exchange and coordination. The modular design approach ensures that sensor modules can be easily added, removed, or replaced as needed without disrupting the overall system functionality.

Software Integration

The control software is proposed to integrate an open-source platform named MOOSivP to

autonomously navigate the vehicle. The LiDAR and RGBD cameras are used in avoiding hazards as well as complying with the Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) by the International Maritime Organization [20] to obtain a safe and effective path to accomplish the desired navigation route.

Upon detecting an obstacle, the system promptly recalibrates its path to circumvent the impediment, ensuring uninterrupted progress toward the next programmed waypoint. This real-time adjustment is critical for maintaining the route's integrity and completing the navigational task efficiently

C. Compliance Tests

The CxSense controller box represents a comprehensive and robust solution for modern Unmanned Surface Vehicle (USV) operations, bridging the gap between advanced navigation, autonomous decision-making, and seamless integration of hardware and software components. Its development has undergone rigorous testing and refinement, ensuring compliance with international standards, such as IEC certifications for surge protection, temperature durability, and water ingress protection. The following testing environments and scenarios were implemented.

Electrostatic Discharge Test (ESD) as per IEC 61000-4-2

The Electrostatic Discharge (ESD) test, as defined by IEC 61000-4-2, evaluates a device's resilience to electrostatic discharges that may occur during handling or operation. The test simulates ESD events by applying high-voltage discharges (contact or air) to the device at specified points, replicating real-world scenarios like human touch or proximity to charged objects. The test ensures that the device continues to function correctly or recovers gracefully after exposure to these discharges, ensuring compliance with electromagnetic compatibility (EMC) requirements.

The CX Sense was placed on an insulated table, and the box was grounded. The gun was set to produce 8,000 V of voltage during the test. The test was conducted when 1) the gun was in contact with the box and 2) when the gun was placed near the box without any contact. The setup for ESD test is conducted as described in Figure 2.

Dry Heat Test

The Dry Heat Test is a crucial validation process designed to evaluate the thermal resilience of the CxSense controller when subjected to extreme temperature conditions. Since CxSense operates in direct sunlight on USVs, thermal management is a critical factor in ensuring continuous operation and preventing overheating-related failures. The initial test assesses heat dissipation efficiency with and without a heatsink under maximum computational load using AI processing. A test bench AI program is deployed to simulate real-world AI processing loads with and without heatsink on the preliminary box. It pushes the

GPU to full utilization at 100%, resulting in maximum power consumption and ensuring worse-case heat buildup conditions. This prior test is to justify the effectiveness of the heatsink in terms of power.

Then, the fully functional CxSense underwent a dry heat test in the chamber at an ambient temperature of 55°C for 16 hours, as shown in Figure 3.



FIGURE 2. Setup for Electrostatic Discharge Test (ESD) Test.



FIGURE 3. Setup for Electrostatic Discharge (ESD) Test

Ingress water protection testing as per IEC 60529 (IPX8)

IPX8 testing assesses a product's ability to withstand continuous immersion in water under specified conditions. It is part of the Ingress Protection (IP) rating system and indicates that the device is waterproof beyond 1 meter of submersion, with the exact depth and duration determined by the manufacturer. The test typically involves immersing the product in water at a specified depth and verifying its functionality and integrity afterward.

IV. RESULTS AND ANALYSIS

In the ESD test, the CxSense functionality experienced a temporary loss of function for a short period, but it managed to reboot, and the system eventually functioned as normal. This condition refers to class B, where class B is stipulated as follows: -

“Equipment that may experience a temporary degradation or loss of function or performance during the test but recovers automatically after the disturbance ceases. The equipment must remain safe and capable of resuming its normal operation without operator intervention.”

On the other hand, thermal response assessment aims to ensure that the CxSense controller remains operational under extreme heat conditions, preventing thermal-induced failures that could compromise USV performance during missions. Overheating can affect electronic components, impact system stability, and degrade performance, making thermal management a critical factor in the design and operation of CxSense. The PCBs in the CxSense are intended to function securely at temperatures up to 85°C, beyond which the processing unit may automatically power down to prevent overheating. Thus, a functionality test to track temperature rises in the power output terminals when subjected to a controlled dummy load independently. The test is to identify potential hotspots and analyze thermal dissipation patterns, the readings were recorded in Table 2.

TABLE 2. Load Tests.

Connectors	Temperature (deg C)		
	0 minute	2 minutes	4 minutes
J1	27.0	28.0	30.0
J2	28.3	29.9	31.5
J3	29.8	33.4	36.1
J4	29.8	29.9	31.1
J5	28.5	29.2	31.4
J6	27.0	31.4	31.5
J7	27.7	29.9	31.3
J8	27.2	29.8	30.2
J9	28.6	30.8	32.7
J10	28.0	31.0	32.4
J11	29.0	30.4	32.3

The initial temperature of 0 minutes ranged between 27.0°C to 29.8°C, indicating a stable starting condition. After 2 minutes, there was a noticeable increase of up to 4.0°C at certain terminals (J3, J6, J10). By 4 minutes, temperatures continued to rise, with J3 experiencing the highest peak at 36.1°C, indicating higher heat generation in that region. The temperature rise pattern indicates that some power output terminals handle higher electrical loads, leading to localized heat concentration. Laboratory evaluations carried out over an eight-hour duration revealed that the control box's internal temperatures stayed within a range of 26 to 33°C under various load conditions. As a result, the CxSense enclosure needs to attach to its body with passive heat spreaders or heatsink that can improve overall thermal stability.

The configuration of the thermal heatsink is tailored to satisfy the thermal resistance calculated as in Eq. (1):

$$\begin{aligned}
 R_{sa} &= (T_j - T_a) / P_d - (R_{j-a} + R_{j-b} + R_{j-d}) \\
 &= (T_{max} - T_{amb}) / power - TTR \\
 &= 1.791530945 - 0.2383834597 \\
 &= 1.553147485 \text{ } ^\circ\text{C/W}
 \end{aligned}
 \tag{1}$$

*TTR is total thermal resistance

Thus, the selected thermal heat sink design achieves a thermal resistance of 1.5°C/W. Concurrently, the components within the controller, particularly the interface connectors and PCB connectors, have been thoroughly evaluated to function effectively in a vibration-prone environment. This rigorous evaluation helps guarantee the controller's durability and consistent performance, meeting international standards.

To evaluate the thermal performance of the process to a maximum AI computational load, testbench software was executed to simulate real-world processing conditions. The objective was to analyze the temperature rise over time and determine whether the system remains operational within safe thermal limits.

The maximum operating temperature for the system is 85°C, beyond which the computer automatically shuts down as a protective measure against overheating.

temperatures may accelerate hardware degradation, affecting long-term reliability.

The thermal test results highlight the importance of effective cooling solutions when running high-performance AI workloads. Without a heatsink, excessive heat accumulation can push the GPU past safe operational limits, leading to automatic shutdown and potential hardware damage. With a heatsink, temperature levels are maintained within safe margins, ensuring reliable and stable system performance.

In the last test of water ingress protection, the CxSense controller box was submerged to a depth of 3.5 and remained in that depth for 45 minutes. The first test was conducted when there was no equipment i.e. no electrical boards and circuits. This is to prevent unwanted damage if the test fails. The test showed a positive result and based on this result the electronic circuits were assembled and in fully operating condition. During the actual test of submersion, the CxSense controller box with all the electrical and electronics components in the box, the results showed no leakage, and the computer circuit functions accordingly after the test.

V. CONCLUSION

Ultimately, CxSense is more than just a controller—it is a highly adaptive, intelligent, and future-ready system that enhances USV capabilities for hydrographic surveying, environmental monitoring, and autonomous maritime operations. Through severe testing, CxSense proves its superiority as a robust, interference-free, and energy-efficient USV controller. Its advanced protection mechanisms and intelligent power management ensure uninterrupted operation, even in diverse and challenging maritime environments, setting a new benchmark for highly reliable and scalable solutions for the next generation of maritime autonomy.

The mechanical blueprint, adopting a trimaran setup, emphasizes stability and adaptability, facilitating easy sensor and equipment integration. By utilizing readily available components, functionality is ensured while keeping costs in check.

From the perspective of electrical design, the focus is on reliability and adherence to standards. Measures such as incorporating TVS diodes for EMC mitigation and opting for stainless steel enclosures underscore the commitment to robust performance in various scenarios.

In-house testing justifies the system's reliability, trying to meet global standards and promising elasticity even in environments prone to sea vibration. The successful integration of open-source software and adaptable hardware sets a benchmark for future developments in autonomous marine technology. This initiative lays the groundwork for revolutionary progress in the marine field with potential applications

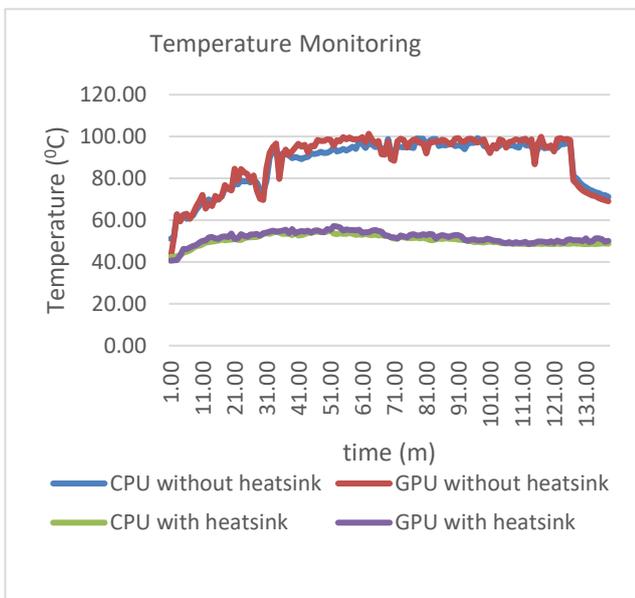


FIGURE 4. Actual tests on the USV.

From the graph in Figure 4, it shows that CxSense without heatsink may cause the GPU to exceed the safe operating limit (~100°C), which could trigger thermal shutdown and cause performance degradation. Prolonged exposure to such high

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AUTHOR CONTRIBUTIONS

Nazreen Rusli: Conceptualization, Data Curation, Methodology;

Zulkifli Zainal Abidin: Validation, Writing – Original Draft Preparation;

Muhammad Aiman Norazuddin: Project Administration, Writing – Review & Editing;

Taufik Yunahar: Project Administration, Supervision, Writing – Review & Editing.

CONFLICT OF INTERESTS

No conflict of interest was disclosed.

ETHICS STATEMENTS

Ethical approval was not applicable to this research since it did not involve human participants, animals, or sensitive data.

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