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Short Paper*

Midrange Unmanned Autonomous Watercraft for Search and Rescue

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Abstract

Purpose – The maritime sector is a crucial industry in shaping the Philippine economy, yet it is plagued by a high rate of accidents and fatalities. To address these challenges, this study explores the integration of unmanned technologies into maritime Search and Rescue (SAR) operations.

Method – This research explores using a low-cost USV for SAR in the Philippines. Analyzing various unmanned options (ROVs, AUVs), the study focused on an affordable USV design. Built with readily available materials and open-source software, the USV prioritizes stability, real-time data collection (sensors, camera), and remote control for operator intervention. Rigorous testing evaluated its performance and functionality.

Results – Testing yielded promising results: the USV autonomously navigated waypoints and transmitted clear video and sensor data. However, these tests revealed limitations in GPS accuracy and telemetry range likely due to the controlled setting. Further evaluation in real-world environments is necessary.

Conclusion – The proposed USV design shows promising potential as a mid-range SAR platform. The successful completion of autonomous waypoint navigation and the functionality of various sensors demonstrate the USV's capabilities. However, further testing in more complex environments is crucial to assess its real-world effectiveness, particularly regarding GPS accuracy and communication reliability.

Recommendations – Based on the findings, the study recommends several areas for improvement. Optimizing the telemetry range through higher power configurations or alternative communication protocols is essential. Additionally, integrating object identification technology would significantly enhance search efficiency. Implementing additional measures like Real-Time Kinematic (RTK) correction systems could improve GPS accuracy. Finally, further testing of Ardupilot's fail-safe mechanisms for GPS loss is recommended.

Research Implications – This research shows promise for low-cost USVs in the Philippine SAR. The design can aid PCG in developing affordable SAR technology to save lives.

Keywords – autonomous navigation, unmanned, ardupilot, waypoints, search and rescue

INTRODUCTION

Every year, countless lives are lost due to accidents at sea in the Philippines, a nation heavily reliant on its maritime industry. Harsh weather and environmental conditions caused by typhoons, floods, and other natural calamities, often hamper traditional search and rescue (SAR) efforts, putting the lives of rescuers at risk and making it difficult to locate survivors. To address these limitations, Unmanned Surface Vehicles (USVs) offer a promising solution. In 2021, the Maritime Industry Authority (MARINA) recorded approximately 214 maritime accidents within Philippine waters (Marina, 2021). The Philippine Coast Guard (PCG) is crucial in responding to maritime emergencies and conducting Search and Rescue (SAR) operations. Even though their SAR operation methods are effective in most cases, the harsh Philippine climate can limit their capability and put the lives of the rescue operators at risk. The most challenging aspect of maritime search and rescue is locating survivors and objects of interest in the water. This is especially difficult after typhoons when strong winds and high waves can make it difficult for search and rescue teams to operate. Moreover, survivors may be injured or unconscious, making it difficult or impossible to signal for help. In return, rescuers are deployed to the site to search for survivors.

One of the primary goals of SAR operations is to avoid causing more casualties, this can be addressed by integrating unmanned technologies into maritime SAR operations. Integrating this technology into SAR operations can mitigate the risk to human lives by minimizing the necessity of deploying rescuers to uncharted/unknown sites. These unmanned technologies can survey the area beforehand, assessing conditions and searching for survivors, ensuring that rescuers are well-informed before being deployed into potentially hazardous maritime environments.

As described by Murphy (2014) in his book Disaster Robotics, three different technologies can be used for marine SAR operations, they are categorized as Autonomous Underwater Vehicles (AUV), Remotely Operated Vehicles (ROV), and Unmanned Surface Vehicles (USV). Table 1 shows the consolidated data from the book and compares the practicality of applying these technologies for maritime SAR operations. The following are specific unmanned vehicles used for each category: YSI Oceanmapper AUV, SeaBotix SARbot ROV, and AEOS Sea-RAI USV. As shown in Table 1, it is evident that USVs stand out as the best choice for maritime SAR operations than other presented technologies. USVs offer the advantage of untethered operation and the ability to carry larger payloads, but they face challenges such as transportation difficulties, the need to adhere to marine collision regulations, and the potential disruption of GPS and wireless signals in urban littoral environments (Murphy, 2014). Despite these limitations, USVs have proven to be valuable assets in disaster response, as evidenced by their successful deployments in various incidents, including the aftermath of Hurricane Ike. USVs offer a versatile platform that can operate autonomously and gather crucial data from accident sites, allowing rescue teams to make informed decisions and minimize risk. While existing USVs have limitations in areas like cost-effective design and real-time data processing, this research aims to develop a low-cost, functional USV equipped with robust navigation and object detection capabilities to enhance maritime SAR operations in the Philippines.

Table 1. Comparison of Three Marine Unmanned Technologies for Search and Rescue

Criteria	Marine Unmanned Technologies for SAR		
	ROV	USV	AUV
Obstacle Detection	Obstacles are difficult to detect and avoid.	Relatively easy to detect and avoid.	Limited capability may require additional sensors.
Communication	Can maintain continuous communication with the ground station.	Can maintain continuous communication with the ground station.	Difficult to maintain communication with a ground station, may require surfacing or special communication methods.
Data Processing	Integrated with visible light and sonar imaging that provides real-time data.	Designed for emersed sensor applications, this system integrates a camera with GPS and real-time wireless data transmission capabilities.	Maps underwater regions with sonar and collects data samples with sensors.
Payload Capacity	Small payload capacity	Medium payload capacity	Small to medium payload capacity
Area Coverage	Limited to the length of the device's tether	Large area coverage	Large area coverage

Although a lot of researchers have already attempted to study USV technology implementation in maritime incidents it still has certain limitations (Xiao et al., 2017; Johnston & Poole, 2017; Gaugue et al., 2019). Among the limitations covered by these studies are the uncertainty surrounding optimal cost-effective boat design, the challenges of real-time data processing and transmission, and the seamless integration and synergy between hardware and software components within the USV system. Although the concept of USVs is not new, its application in SAR operations is evolving. This research sees potential for originality in how these USVs can be specifically designed and deployed for search and rescue operations in the Philippines, considering the unpredictable maritime behavior.

Objectives of this Project

- Develop the ability for the watercraft to navigate autonomously using GPS technology and Ardupilot, ensuring it can reach predefined waypoints accurately.
- Design a user-friendly remote-control system that allows operators to intervene or adjust the watercraft's course if necessary, during the missions.
- Establish reliable communication systems to transmit real-time data, including camera feed, wind speed, wind direction, and GPS coordinates, to operators.
- Design a cost-effective watercraft that still serves its purpose to operate effectively in a range of environmental conditions, including rough waters.

The remainder of this paper is structured as follows: in Section II, related research papers and literature sources are reviewed. These works serve as the foundation for the research, offering valuable insights and guiding principles for enhancing existing projects in the field. Through this review, inspiration is gained to shape the direction of the investigation. In Section III, a detailed overview of the system is provided, here the insights from the previous section are synthesized to explain and specify the methods in the implementation of the system. In Section IV, the technical specifications of the system are described. Section V examines what the system achieved and provides insights into the USV's effectiveness in its broader context. Finally, in section VI, a conclusion is provided.

LITERATURE REVIEW

Prioritizing Maneuverability and Real-World Testing

Effective Search and Rescue (SAR) hinges on the ability to safely navigate and maneuver around survivors. Research by Lunde and Tellefsen (2019) underscores this critical aspect. Our project directly addresses this need by employing a catamaran hull design. This design choice is well-supported for its superior stability and agility in various water conditions, allowing for safer and more precise maneuvering when approaching survivors.

Bridging the Gap Between Simulation and Reality

Beyond maneuverability, Jain et al. (2021) emphasize the importance of optimizing a USV's design through careful consideration of boat size, hardware configuration, and software architecture. While their study utilizes simulation tools like Gazebo and Kalman filtering to model real-world dynamics, a crucial gap remains – the translation of these simulations into practical application. Our project bridges this gap by constructing a physical USV based on the insights gleaned from Jain et al.'s (2021) research. This physical USV will undergo real-world testing, allowing us to validate the effectiveness of the proposed design in a SAR scenario. The data collected from this testing will be instrumental in informing future advancements in SAR USV technology.

Leveraging Existing USV Functionalities While Introducing a Unique Advantage

USVs have become a well-established technology within the realm of SAR operations. However, as evidenced by our review of existing USVs such as the Blue Robotics BlueBoat, the Sea-RAI USV, and the Marine Guardian USV (see Table 2), these platforms possess both advantages and limitations. The BlueBoat (Blue Robotics, 2023), for instance, offers portability but lacks integrated sensors. Conversely, the Sea-RAI USV boasts a comprehensive sensor suite but comes at a significantly higher cost (Lindemuth et al., 2011). The Marine Guardian USV (Marine Thinking, 2023) sits between these two extremes, offering a wider range of sensors than the BlueBoat but at a price point closer to the Sea-RAI.

Table 2. Comparison of Existing USVs

	Existing USVs for SAR Operations		
Criteria	**Blue Robotics BlueBoat**	**Sea Robot- Assisted Inspection (Sea - RAI) USV**	**Marine Guardian USV**
Creator	Blue Robotics	AEOS Technologies	Marine Tensor TM
Weight	15.9 kg.	170 kg.	80 kg.
Dimensions	1.2 m x 0.093 m x 0.46 m	1.829 m x 1.321 m x 1.372 m	2.05 m x 1.70 m x 1.35 m
Portability	Modular design for ease of transportation	Modular design for ease of transportation	Logistically Complex
Cost/ Price	$6,200	$25,000	Not Indicated
Sensors	No sensors	Compass, GPS Module, Four Waterproof Video Cameras, Sonar, and Acoustic Sensor	Sonar, Depth Sensor, Water Quality Sensor, 360 Panoramic Surface Camera, Thermal Imaging, and Optical Imaging
Does it have autopilot?	Yes	No	Yes
Top Speed	11.11 km/h	14.26 km/h	11.11 km/h
Area Coverage	Not explicitly stated but the article notes the USV can inspect a "large area"	Not explicitly stated but the article notes the USV can inspect a "large area"	up to 8 km (via controller) up to 10 km (via control station)

Our USV design incorporates functionalities proven valuable in existing models, such as an FPV camera, GPS module, and remote control for navigation. However, we introduce a unique and critical feature: the ability to collect and transmit real-time wind speed and direction data. This data plays a vital role in SAR operations by enabling search pattern optimization based on wind conditions. Additionally, real-time wind data can improve situational awareness for operators, allowing them to anticipate and navigate around potential environmental hazards that could hinder the USV's mission or endanger survivors.

Building Upon Past Work and Introducing Autonomous Operation

The research conducted by (Mansor et al., 2021) provided a valuable foundation for our software design. Their work on an autonomous surface vessel for deep-water SAR operations informed our approach, particularly regarding GPS navigation, depth data recording, and communication protocols. We have further enhanced this foundation by incorporating features such as live onboard video transmission and a user-friendly remote-control system. Inspired by Mansor et al.'s (2021) concept, our software design allows the USV to operate autonomously, offering greater flexibility in mission execution. This autonomous capability can be particularly advantageous in situations where manual control might be hindered by distance or environmental conditions.

METHODOLOGY

This section details the design and development of a cost-effective Unmanned Surface Vehicle (USV) for search and rescue operations. The USV prioritizes functionality while maintaining affordability, making it suitable for resource-constrained environments.

System Design

The USV employs a catamaran hull configuration for inherent stability, with rounded bows to minimize drag (see Figure 1). Construction materials prioritize affordability, utilizing readily available PVC pipes and treated wood (e.g., Papanikolaou, 2014).

Hardware Design

A key aspect of the USV is its hardware design, which balances performance and cost-effectiveness for real-time data acquisition in search and rescue scenarios.

- **Physical Structure:** The USV utilizes a dual-hull (catamaran) design constructed from PVC pipes for affordability and ease of fabrication. Rounded conical bows on each hull minimize drag (refer to Figure 1). Two brushless DC motors with 3-bladed propellers mounted on removable 3D-printed frames propel the USV. A water-resistant container houses electronic components on the deck, with masts for instrumentation like a wind vane, anemometer, FPV camera, and telemetry radio (refer to Figure 1).
- **Component Selection:** The USV prioritizes cost-effective components while ensuring functionality.

- BeagleBone Blue (Flight Controller): Offers a balance of affordability, processing power, and open-source Linux compatibility compared to Raspberry Pi and PX4 (Beagleboard, 2021).
- Brushless DC Motors (A2212/13T 1000KV): Provide efficiency for longer operation times and require minimal maintenance.
- Brushless Reversible ESCs (9imod 60A ESC): Compatible with BLDC motors and have a suitable amperage rating to prevent overheating.
- ESP 32 DevKit 30 Pin: Provides wireless communication or IoT and data logging capabilities (Carducci et al., 2019).
- Flysky RC System: Reliable and proven choice for remote control functionality.
- FPV Camera (Foxeer CAT3): Compact and cost-effective for real-time FPV video transmission.
- FPV Transmitter and Receiver (Zenchansi & Eachine): Offer a robust 5.8Ghz FPV system for clear video transmission and reception.
- 3D-printed parts: Allow for design flexibility, durability, and weight optimization.
- PVC Pipes: Cost-effective, readily available, and easily shaped for a watertight catamaran hull.
- Wood Platform: Cost-effective and suitable for non-critical parts.

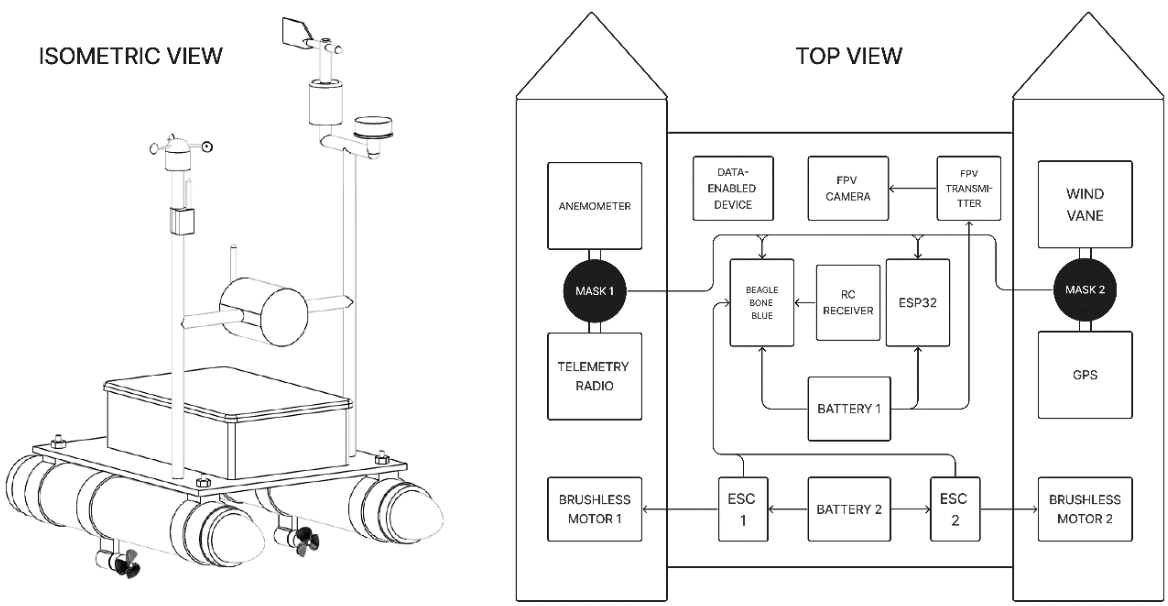

Figure 1. Isometric and Top-Down View Depicting Integration of USV Components and Materials

Software Design

The software architecture employs a modular design for efficient development and maintenance.

- **The Watercraft Navigation Module** utilizes the BBB and Mission Planner software for waypoint designation and real-time GPS tracking.
- **Data Visualization Module** is a simple application developed to display real-time wind speed data retrieved from the anemometer connected to the ESP32 module.

Operational Modes

The control system offers two operational modes: autonomous navigation and manual override. Autonomous navigation leverages the BeagleBone Blue (BBB) as the flight controller due to its affordability, processing power, and open-source Linux operating system. The system allows operators to designate waypoints and provides real-time GPS data on the ground station interface for comprehensive situational awareness.

For manual control capabilities, a Flysky RC system is incorporated. A Foxeer CAT3 camera and a Zenchansi FPV system provide a real-time video feed, enhancing situational awareness during both autonomous and manual operations.

Testing Procedures

A comprehensive testing regime evaluated the USV's performance and functionality. This included:

- **Top Speed:** Measured by setting the throttle to maximum in a controlled environment, averaging data from six trials.
- **Communication Range:** Measured by driving the ground station away from the USV and monitoring signal loss from the FPV camera, RC controller, and telemetry. Data was compared to hardware specifications.
- **Anemometer Accuracy:** Evaluated by comparing readings to a handheld anemometer under constant wind conditions.
- **Autonomous Navigation:** Tested by monitoring the USV's progress through pre-defined waypoints in Mission Planner.

Safety Measures

Rigorous safety protocols were implemented during testing, including:

- Thorough inspections of the USV before each test run.
- Clear operating procedures were established for safe operation.
- Real-time monitoring of the USV during testing.

- Presence of a safety boat during open-water testing.
- Readily available emergency procedures and safety equipment.

RESULTS

To evaluate the effectiveness of the proposed USV design for search and rescue operations, a series of tests were conducted. This section details the results of these tests, focusing on performance metrics and autonomous navigation capabilities.

Performance Testing

Effective Communication Range (km)

- **FPV Camera:** Achieved a clear video transmission distance of 1.58 km, coming close to the 2.0 km target set for optimal conditions. (Table 3)
- **Telemetry:** Measured at an average of 2.84 km, falling short of the 3.0 km target for optimal conditions. Further investigation is needed for optimization. (Table 3)
- **RC Controller:** Achieved an average range of 0.853 km. (Table 3)

Table 3. Integration Testing Results of the Autonomous Unmanned Surface Vehicle

Key Parameters	*Test 1	*Test 2	*Test 3	Average Result	Expected Result
Top Speed	1.23 m/s	1.19 m/s	1.21 m/s	1.21 m/s	Not Available
Effective Communication Range					
• FPV Camera	1.54 km	1.61 km	1.59 km	1.58 km	2.0 km
• Telemetry	2.8 km	2.84 km	2.87 km	2.84 km	3 km
• RC Controller	0.849 km	0.832 km	0.878 km	0.853 km	1.0 km
Anemometer Accuracy Deviation	+0.1 mph	-0.3mph	-0.4mph	-0.26mph	*As displayed on the handheld anemometer*

*The listed tests above are averages of 2 individual tests.

Other Sensor Performance

- **Anemometer Accuracy:** Deviation of -0.26 mph is statistically insignificant for search and rescue operations due to its use for wind force categorization based on the Beaufort Wind Scale. (Table 3)
- **Wind Vane:** Provides crucial wind direction information (eight cardinal points and intermediate points) for understanding wind patterns and effective navigation during rescue missions.

Material Selection Costing

Table 4 shows the tabulated prices and quantities of all components and materials utilized in the development of Unmanned Surface Vehicles (USVs).

Table 4. USV Component and Material Total Cost

Component/Material	Individual Price($)	Quantity (pcs)	Total
BeagleBone Blue	47.99	1	47.99
ESP 32	6.19	1	6.19
FlySky Controller (RX/TX)	61.94	1	61.94
Brushless DC Motors	2.79	2	5.58
ESC	16.63	2	33.26
GPS Module	17.13	1	17.13
Telemetry Radio	63.16	1	63.16
Anemometer	15.80	1	15.8
Wind Vane	17.38	1	17.38
FPV Kit	56.68	1	56.68
3D Printed Parts	13.46	-	13.46
Batteries (Lith-Ion)	2.58	27	69.66
PVC Pipes	14.61	-	14.61
Wood Platform (42 x 48 cm)	0.97	-	0.97
Miscellaneous Items	17.72	-	17.2
		TOTAL	$441.01

Autonomous Navigation Testing

The USV successfully navigated pre-programmed waypoints within the controlled environment. However, discrepancies observed in the Mission Planner display during testing highlight limitations beyond just GPS accuracy in open water environments (Figure 8). While limited satellite reception (likely only 3 satellites connected) can affect precision (National Oceanic and Atmospheric Administration, 2019), the testing environment itself presented additional challenges.

Figure 8. Photo of USV following the waypoints.

The researchers identified that signal strength for telemetry, crucial for real-time data transmission, was particularly affected by obstacles and line-of-sight limitations between the USV's transmitter and the ground station's receiver. This suggests that placing the receiver at a higher elevation could significantly improve signal reception. These findings emphasize the need for testing USVs in progressively complex environments that consider not only GPS accuracy but also real-world signal limitations due to terrain and obstacles. This will be crucial for assessing the USV's overall performance in real-world scenarios, particularly its real-time GPS functionality and obstacle avoidance capabilities.

CONCLUSIONS AND RECOMMENDATIONS

The integration testing results offer promising insights into the USV's potential as a mid-range search and rescue platform. The FPV camera performed well, achieving clear video transmission over extended distances (1.58 km), demonstrating its effectiveness for visual data acquisition. However, this distance did not exceed the initial target range of 2.0 km under optimal conditions. Similarly, the telemetry range (2.84 km) fell short of the 3.0 km target, highlighting the need for further optimization to ensure reliable communication in real-world scenarios.

The anemometer's accuracy deviation (-0.26 mph) is statistically insignificant for search and rescue applications, as rescuers primarily use anemometer data for wind force categorization. Additionally, the wind vane provides crucial wind direction information, aiding in navigation during rescue missions.

Controlled environment testing exposed limitations in GPS accuracy due to signal interference and maneuverability constraints. While the current 433 MHz, 100 mW telemetry configuration achieved the expected 3 km range under ideal conditions, this performance may not translate to real-world environments. Further optimization is necessary to achieve a wider range and reliable communication.

These findings underscore the need for testing in progressively complex environments. This includes evaluating real-time GPS functionality, obstacle avoidance capabilities, and communication reliability under various conditions. Future efforts can focus on:

- Optimizing telemetry range: Exploring higher power configurations or alternative communication protocols.
- Object identification technology integration: Enhancing search capabilities by automatically detecting and identifying objects of interest.
- Implementing additional GPS accuracy measures: Techniques like Real-Time Kinematic (RTK) correction systems can improve GPS precision (Thin et al., 2016).

Furthermore, the inclusion of Ardupilot, an autopilot system with built-in fail-safe mechanisms for GPS loss, adds another layer of safety. However, further testing is necessary to fully assess Ardupilot's effectiveness and potentially implement additional measures for enhanced GPS accuracy.

By addressing these limitations and exploring future advancements, the USV can fully realize its potential as a valuable tool for search and rescue operations.

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DECLARATIONS

Conflict of Interest

The researcher declares no conflict of interest in this study.

Informed Consent

This research does not have any data or procedures and methodologies that infringe upon the rights and privacy of any person.

Ethics Approval

All software used in this study is either open-source or written by the researchers.

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Author's Biography

Ephrem Joseph A. Catane is a fourth-year Computer Engineering student at CIT-U who utilizes his passions in hardware/electronics tinkering, 3D printing, CAD modeling, and photography to advance his academic work. From a young age, historical inventors and countless DIY/Maker/Engineering YouTube creators have inspired him. He has shown exceptional skill in Fusion 360, Cura Slicer, and Lightroom, as well as hands-on skills, especially during his time in his university's Makerspace. Mr. Catane is known amongst his peers as enthusiastic in his work, a valuable team member, and an exceptionally creative problem-solver.

Leary Gabutin is a results-oriented fourth-year Computer Engineering student with a strong hardware focus. While possessing software development knowledge, their passion lies in bringing projects to life. This is evident through their experience with various Arduino projects and a working understanding of Ardupilot, particularly its role in autonomous vehicle control. This hands-on approach makes him a valuable asset for research projects that combine theoretical concepts with practical engineering solutions.

Krishna Carla Tamosa, a computer engineering student at Cebu Institute of Technology-University. She has cultivated a proficiency in research writing, adept at consolidating data and articulating the significance of findings in various studies. Her passion for user interface (UI) design has driven her to immerse herself in numerous projects, encompassing website and mobile application development, where she strives to create intuitive and visually appealing interfaces. Concurrently pursuing her academic endeavors, she gained invaluable experience as a freelance project manager for a digital marketing company, effectively balancing her responsibilities alongside her undergraduate studies. Through these experiences, Krishna continues to refine her expertise in both technical and managerial domains, eager to contribute meaningfully to the ever-evolving field of technology.

Dr. Chris Jordan Aliac holds a bachelor's degree in computer engineering, a master's degree in computer science, and a PhD in Information Technology. As the manager of the university's Fabrications Laboratory Makerspace, he fosters an environment for innovation and collaboration. Concurrently, he serves as a cyber security consultant, ensuring the integrity of the university's digital infrastructure. His journey exemplifies a commitment to both theoretical understanding and practical application in the field of technology. Dr. Aliac embodies expertise and leadership, guiding the university community toward technological advancement and security.

Roel B. Lauron is the current chairperson of BS Computer Engineering at CIT University. A Professional Computer Engineer (PCpE), graduated BS in Computer Engineering at CIT University (Cumlaude) and a Master of Engineering at the Asian Institute of Technology (AIT) in Bangkok, Thailand. A Regional Quality Assurance Team member of CHED RO7 for Computer Engineering. A former VP-Education of ICpEP National and the current VP External of ICPEP 7 and Treasurer of PSITE7.