Volume 11, Issue 4, April – 2026 International Journal of Innovative Science and Research Technology
ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26apr1916

AI-Powered Remote-Controlled Rescue Board with Camera, Siren, and Lighting System for Maritime Emergency Response

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Publication Date: 2026/05/15

Abstract: This study presents the design, development, and evaluation of a remote-controlled rescue board integrated with an AI-powered camera, siren, and high-visibility lighting system for rapid maritime response in the Philippine context. The design addresses critical limitations of conventional coastal rescue tools, including delayed victim detection, limited rescuer safety, and poor operational visibility. A YOLO-based object detection model deployed on an NVIDIA Jetson Orin Nano platform enables real-time identification of individuals in distress or drowning victim. Dual brushless-motor propellers driven by electronic speed controllers provide stable navigation across varying water conditions, while LoRa-based wireless communication ensures reliable remote control at distances up to 430 meters. Functional evaluations demonstrated an average AI detection accuracy of approximately 91%, consistent buoyancy and structural stability supporting loads up to 90 kg, battery endurance of 95–120 minutes, and a 20-second response time over 100-meter deployment distances. Comparative analysis showed marked improvements over traditional rescue equipment in response speed, rescuer safety, and victim identification accuracy. User acceptance testing yielded an overall mean score of 4.49, reflecting strong stakeholder confidence in the system's safety, reliability, and operational practicality. The findings confirm that AI-enhanced, remotely operated rescue platforms represent a technically feasible and practically advantageous alternative for maritime and flood emergency response.

Keywords: *AI-Powered Rescue Board; YOLO-Based Detection; Maritime Rescue; LoRa Communication; Emergency Response.*

How to Cite: Rainier Ace H. Cabatuando; John Rick B. Maaño; John Randel C. Sorosoro; Tommy A. Ditucalan (2026) AI-Powered Remote-Controlled Rescue Board with Camera, Siren, and Lighting System for Maritime Emergency Response. *International Journal of Innovative Science and Research Technology*, 11(4), 4634-4640. https://doi.org/10.38124/ijisrt/26apr1916

I. INTRODUCTION

Aquatic emergencies, particularly drowning incidents in open and flood waters, remain a critical global public health concern. Globally, drowning causes approximately 236,000 deaths annually and ranks among the top ten leading causes of death for individuals aged 1 to 24 years, highlighting the urgent need for improved water rescue and response systems [1].

Drowning-related fatalities are disproportionately concentrated in the Pacific and Southeast Asian regions, accounting for nearly 60% of global cases. The Philippines is particularly vulnerable due to its extensive coastline, dependence on maritime transport and fishing, frequent typhoons, and recurring flooding, which increase exposure to water-related hazards, especially in coastal and low-lying communities [1], [2].

Traditional lifeguard and maritime rescue methods face serious limitations under adverse conditions. Poor visibility, strong currents, rough seas, and long distances from shore often delay victim detection and safe rescue. These challenges are intensified by limited access to modern rescue technologies, inadequate communication systems, and insufficient training in many developing coastal areas, resulting in prolonged response times and increased mortality risk [3], [4].

Despite the Philippines' reliance on maritime transport, SAR operations remain constrained by shortages of operational rescue vessels, trained personnel, and technological support. Severe weather events frequently damage coastal infrastructure, while large-scale disasters overwhelm available SAR capacity, forcing responders to rely on improvised equipment and untrained volunteers [5], [6].

Recent advances in water rescue technology emphasize integrating cameras, lighting systems, and audible alarms into rescue platforms to improve victim detection and support faster coordination among responders [7], [8]. Advances in AI-based object detection—particularly YOLO-based models—demonstrate strong potential for real-time victim identification in dynamic marine environments [9].

Accordingly, the present study aims to develop a multifunctional rescue board equipped with an AI-powered camera, siren, and lighting system to support lifeguards and emergency responders. By integrating these features into a portable rescue platform, the system seeks to enhance detection accuracy, reduce response time, and improve safety in hazardous aquatic environments, contributing to technology-driven drowning prevention efforts.

The specific objectives of this study are to (1) determine the percentage of accuracy of AI detection system of the remote-controlled rescue board in maritime emergency operations; (2) evaluate the buoyancy and structural durability of the rescue board while supporting a drowning victim; (3) identify the remote-control range and endurance of battery for its entire-operation; (4) establish a comparative analysis of traditional emergency rescue devices; (5) determine the level of acceptance of the end-user; and (6) determine the strength and limitations of the rescue board.

The scope of this research covers the design and construction of an AI-powered remote-control rescue board for rescuing drowning victim during floods and maritime emergencies. The system is equipped with an AI-camera using the YOLOv11 model embedded on the NVIDIA Jetson Orin Nano, enabling automatic identification of people stranded on flood surfaces. Operational limitations include the inability to assist submerged victims, manual navigation requiring a skilled operator, potential AI performance degradation under low-light or muddy water conditions, and a battery life of 1–2 hours per charge. The board is designed for small to medium-scale maritime deployment and is not suitable for open seas with very strong currents.

II. REVIEW OF RELATED LITERATURE

➢ *Communication Technologies for Emergency Response*

Research on LoRaWAN demonstrates its effectiveness for long-distance, low-power communication during disaster scenarios. Its ability to operate with minimal infrastructure makes it particularly suitable for IoT-based emergency systems in water-related SAR operations [10]. Studies on smart rescue technologies revealed that combining embedded sensors with wireless communication technologies such as LoRa or ZigBee, together with mobile control interfaces, significantly improves response time and victim detection in flooded environments [11].

➢ *Unmanned and Remote-Controlled Surface Vehicles*

Advancements in unmanned surface vehicles (USVs) have expanded the potential of remote water rescue technologies. Mao et al. [12] introduced the application of USVs for water monitoring and victim rescue, demonstrating improved tracking accuracy, operational stability in rough waters, and fast response to control commands. The University of the Philippines Marine Science Institute deployed Wave Gliders for long-term marine monitoring in Philippine waters, illustrating how similar platforms can be adapted for search and rescue and coastal security [13], [14].

➢ *AI-Based Detection for Maritime Rescue*

Cao et al. [9] introduced an enhanced YOLO11 model for detecting small and difficult targets such as ships and individuals under extreme oceanic conditions, utilizing Space-to-Depth (SPD) modules and Content-Aware Upsampling (CARAFE) to improve accuracy while maintaining real-time processing. Using the SeaDronesSee dataset, the improved YOLO11 outperformed earlier YOLO versions in precision and recall for rescue-related tasks, highlighting the value of lightweight AI models for time-sensitive operations.

➢ *Local Studies on Water Monitoring and Rescue Systems*

Local research in the Philippines supports the feasibility of remote-operated aquatic technologies. Rañeses et al. [15] developed a low-cost remote-controlled robotic system for river monitoring in Cavite, demonstrating that locally sourced materials and Philippine-made technology can effectively address water-related environmental challenges. Gonzales and Pineda [16] confirmed the viability of integrating communication modules into aquatic rescue devices, reinforcing the inclusion of alert systems such as sirens, lights, and long-range wireless communication in the proposed rescue surfboard.

➢ *Synthesis*

The reviewed studies collectively emphasize the growing importance of integrating smart technologies into flood and water-related emergency response systems. Research on LoRa-based communication systems demonstrated that low-power, long-range technologies enhance rescue responsiveness and reliability even in areas with damaged infrastructure [10]. Studies on unmanned surface vehicles confirmed the value of GPS-enabled, waterproof, and remotely operated platforms for accurate and stable rescue operations in turbulent waters [12]. Local studies further reinforce these findings by demonstrating the practicality of deploying low-cost, locally developed rescue and monitoring systems in Philippine settings [15], [16]. Advancements in AI-based detection through YOLO11 models provide strong technical support for incorporating real-time victim detection into aquatic rescue devices [9]. Overall, the literature supports the development of a rescue board equipped with a camera, siren, and lighting system, with the integration of communication technologies, unmanned surface platforms, and AI detection being both timely and highly relevant for improving water rescue operations in flood-prone communities and maritime situation.

III. METHODOLOGY

➢ *Research Design*

A developmental research design integrating both quantitative and qualitative approaches was utilized to evaluate the effectiveness and performance of the AI-powered remote-controlled rescue board. The quantitative method employed a structured survey questionnaire using a 5-point Likert scale to assess the level of acceptance in terms of detection accuracy, buoyancy and structural stability, operational operation, safety and risk consideration, and practicality and adaptability. The qualitative method captured descriptive feedback through structured interviews with rescue responders, government disaster response team representatives, and coastal community residents. This mixed-method approach strengthened the reliability of findings.

➢ *System Architecture and Component Specifications*

The rescue board integrates several key subsystems. The flotation body is constructed from polyethylene reinforced with Styrofoam, providing buoyancy and structural integrity. The propulsion subsystem consists of dual ApisQueen U5 brushless thrusters driven by electronic speed controllers (ESCs), enabling precise directional control and stable navigation.

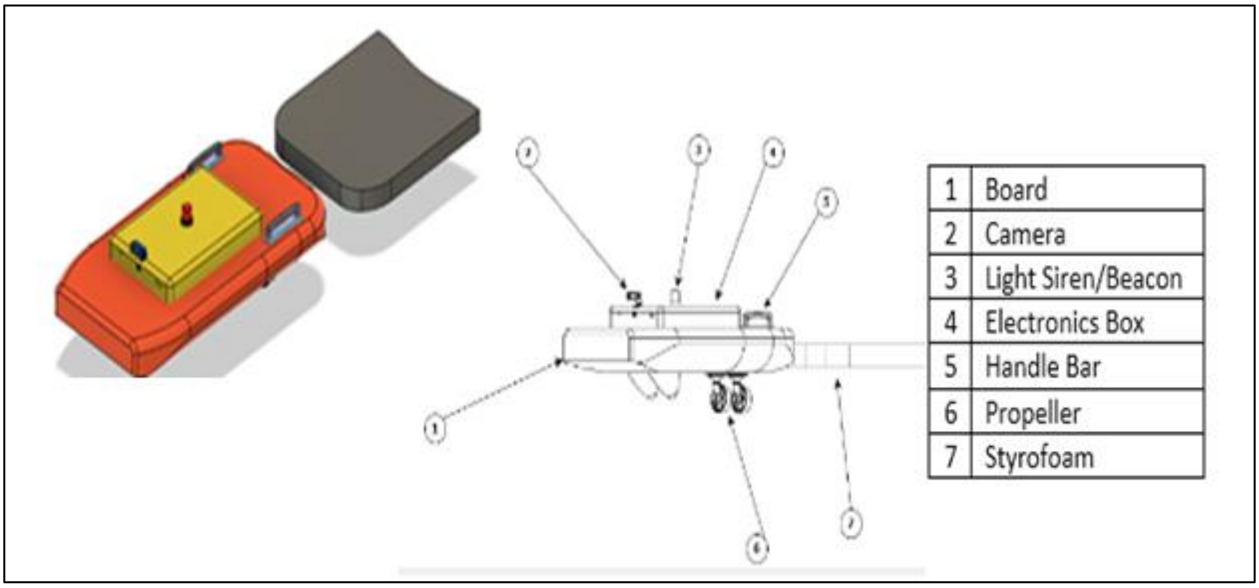

Fig 1 AI-Powered Remote-Control Rescue Board

The AI detection subsystem centers on an NVIDIA Jetson Orin Nano Super Development Kit running a YOLO-based object detection model, with live video input from a Logitech C922 camera module. Detection alerts are relayed to the operator through a LoRa SX1278 long-range wireless communication module. Signaling capability is provided by a 12V waterproof siren module and a 10W waterproof LED searchlight. Control logic is managed by an Arduino Mega microcontroller, supported by a buck converter, voltage regulator, and three 12V Li-Ion battery packs.

➢ *Sources of Data*

Primary data were collected from lifeguards, coastal rescue crew members, and Municipal Disaster Risk Reduction and Management Office (MDRRMO) personnel of coastal municipalities in Cavite. Technical information was obtained through consultations with marine equipment specialists and local engineers. Secondary data were sourced from scientific journals and standards published by the International Life Saving Federation (ILS) and the Philippine Coast Guard (PCG).

➢ *Data Gathering Procedure*

The research team coordinated with MDRRMO and coastal barangay disaster response teams. Surveys were administered to 30 individuals who were current or former emergency responders or lifeguards. On-site testing was conducted in high-risk coastal areas under simulated near-shore conditions, with performance and effectiveness evaluated through functional tests, training drills, and live monitoring activities. A benchmarking process through market analysis of existing rescue equipment identified limitations addressed by the proposed design.

➢ *Data Analysis*

All gathered data were analyzed using descriptive statistics. Quantitative metrics included AI detection accuracy, remote-control range, battery endurance, response time, and structural load tests. User acceptance data were evaluated using mean scores against a 5-point Likert scale. Comparative performance analysis between the proposed system and traditional rescue tools was conducted across multiple operational criteria.

➢ *System Design and Component Specifications*

The design of the rescue board features a smooth, rounded, streamlined shape extending from front to rear to reduce water resistance while maintaining stable buoyancy across varying water conditions. Slightly raised edges along the perimeter reinforce structural strength and reduce the risk of overturning due to waves. A rectangular compartment at the center of the upper surface houses the main electronic and control components, ensuring balanced weight distribution for stability and responsive control during both autonomous and assisted operation. Rigid handles positioned symmetrically along the outer edges allow easier manual handling during transport and deployment, while also serving as secure grip points for rescued individuals. The electronics enclosure lid serves a dual purpose: it shields sensitive components from moisture, saltwater spray, and debris, and functions as a mounting platform for essential hardware related to sensing, control, communication, and signalling.

- *System Integration*

The system architecture integrates sensing, computation, communication, and actuation subsystems into a unified platform. The Remote Controller at the core of system interaction transmits direction, speed, and emergency signaling commands wirelessly to the onboard Communication Receiver (RX), enabling real-time operation over extended distances. The Main Control Unit, comprising an Arduino Mega microcontroller and the Jetson Orin Nano AI development platform, processes commands while simultaneously executing AI-based perception through visual data from the camera subsystem. The AI Camera Unit continuously captures and transmits real-time video to the Main Control Unit, where embedded YOLO-based models perform object detection, classification, and victim tracking. The Propulsion Controller manages movement through ESCs and motor drivers, translating PWM control signals from the Main Control Unit into precise motor speed and direction adjustments. The Power System—consisting of high-capacity $LiFePO_4$ battery packs and voltage regulation circuitry—distributes energy efficiently to all subsystems, ensuring consistent supply during combined AI computation, wireless communication, and motor actuation at peak demand.

- *Assembly and Test Procedures*

Assembly begins with stabilizing fin installation, followed by brushless motor mounting on designated brackets, ESC attachment near motors, and motor wire routing through protective conduits. Electrical integration involves connecting ESC signal wires to the microcontroller, routing battery power cables to ESCs with correct polarity, and securing the control unit within the enclosure. Pre-power inspection verifies all electrical connections, propeller positioning, and cooling airflow around ESCs and motors. Testing procedures include powered ESC initialization verification, gradual throttle increase from zero to low speed checking smooth motor startup, and stability tests observing for vibration, loose components, or misaligned fins. Safety verification tests the emergency stop function for immediate motor shutdown, monitors cable and component temperatures, and maintains safe clearance around all rotating parts throughout testing.

- *Software Architecture*

The system software comprises three modules operating in conjunction. The AI Detection Module on the Jetson Orin Nano captures live video streams, applies YOLO-based inference, and sends detection results to the microcontroller via serial communication, activating downstream modules (sirens or lights) upon sufficient detection confidence. The Propulsion and Signal Control Module on the Arduino Mega translates serial input from the Jetson and PWM input from the RC receiver into ESC commands, managing motor speed, direction, and relay activation for the siren and light. The Remote Control and Safety Module performs basic safety functions by cutting output to zero upon signal loss or detection activation.

IV. RESULTS AND DISCUSSION

- *AI Detection Accuracy of a remote-operated rescue board*

Table 1 AI Detection Accuracy

Condition	**Accuracy (%)**	**Status**
Clear daylight	~94%	Optimal
Partial obstruction by waves	~89%	Acceptable
Glare/sunlight reflection	~88%	Acceptable
Average (all conditions)	~91%	Meets spec.

The AI-based detection system achieved an average accuracy of approximately 91%, confirming its suitability for maritime rescue operations. Performance was highest under regular daylight conditions. Accuracy decreased when individuals were partially obscured by waves or floating debris, and during intense sunlight reflection. These results are consistent with accuracy ranges of 80–90% reported for lightweight YOLO models on embedded platforms under real-world conditions [17], [18]. LoRa communication demonstrated stable transmission of detection alerts and control commands over 120–150 meters under line-of-sight conditions, aligning with its established use in disaster response applications [10].

- *Buoyancy and Structural Durability*

Table 2 Buoyancy and Structural Durability of the Rescue Board

Load (kg)	**Freeboard (cm)**	**Tilt Angle (°)**	**Status**
45	18	2.1	Stable
60	14	3.4	Stable
75	11	5.0	Stable
90	8	6.8	Stable (within limits)

Flotation and load-bearing tests confirmed consistent buoyancy and structural integrity across all tested weight conditions. No visible deformation, material failure, or water ingress was observed. As load increased from 45 kg to 90 kg, freeboard height decreased gradually while tilt angle slightly increased; all values remained within acceptable operational stability limits. These results validate established marine engineering principles emphasizing proper weight distribution, balanced buoyancy, and a low center of gravity for stability in unmanned watercraft [12], [13].

- *Remote-Control Range and Battery Endurance*

Table 3 Remote-Control Range and Battery Endurance

Parameter	Value	Status
Max. control range	~430 m	Acceptable
Battery endurance	95–120 min	Meets spec.
Effective deployment time	18–32 min	Sufficient
Response time (100 m)	~20 sec	Meets spec. (≤25s)

Remote-control testing showed stable and reliable operation up to approximately 430 meters, consistent with LoRa system characteristics under real-world line-of-sight conditions [19], [10]. Battery endurance ranged from 95 to 120 minutes, with higher power consumption observed during rough water operation due to increased propulsion adjustments and sustained AI processing. The effective deployment time of 18–32 minutes is sufficient for rapid-response rescue missions. A response time of approximately 20 seconds over a 100-meter deployment distance—corresponding to approximately 5 m/s travel speed—met the design specification of 25 seconds or less.

- *Comparative Analysis of AI Rescue board with Traditional Rescue Device*

Table 4 Comparison with Traditional Rescue Device

Criterion	Traditional Device	AI Rescue Board
Response time	Slow (manual)	Fast (remote)
Victim detection	Human visual scan	AI-assisted (~91%)
Rescuer safety	Direct exposure	Remote operation
Night/low visibility	Very limited	LED + AI camera
Rough water performance	Limited	Stable (ESC)
Personnel required	Multiple	Single operator

Comparative evaluation confirmed that the AI-powered rescue board outperformed traditional tools across all assessed criteria. Faster response was achieved through quick deployment and assisted navigation. Rescuer safety was significantly improved by minimizing the number of personnel required to enter dangerous water conditions, reducing the risk of secondary casualties. The system demonstrated improved accuracy in victim identification through AI-assisted detection, which is less prone to human error and delay compared to traditional visual scanning. These findings support previous studies showing that the integration of onboard intelligence and wireless communication enhances situational awareness in disaster response systems [11], [10].

- *User Acceptance*

Table 5 User Acceptance Survey Results (n = 30, 5-Point Likert Scale)

Evaluation Criterion	Mean	Verbal Interpretation
Detection Accuracy & Reliability	4.53	Strongly Agree
Buoyancy & Structural Stability	4.55	Strongly Agree
Operational Limitations	4.38	Strongly Agree
Safety & Risk Considerations	4.52	Strongly Agree
Practicality & User Adaptability	4.47	Strongly Agree
Overall Mean	**4.49**	**Strongly Agree**

The system achieved an overall mean score of 4.49, indicating a high level of user satisfaction across all evaluation criteria. Respondents expressed strong approval of functional performance, particularly buoyancy, structural stability, and detection reliability. Safety-related criteria received especially high ratings, reflecting the perceived advantage of remote operation for minimizing rescuer risk. High scores in practicality and ease of use indicate that the system can be quickly learned and integrated into existing rescue workflows with minimal training. These findings are consistent with previous studies reporting that disaster-response technology users prioritize safety, reliability, and ease of operation [11], [10].

- *Strengths and Limitations of the Prototype*

Table 6 Strengths of the Rescue Board

Aspect	Key Strengths	Avg. Score (%)
System Performance	Real-time detection of obstacles and adaptive control during operation	86%
Usability	Easy to operate, minimal user interaction, clear feedback	84%
Communication	LoRa long-range, stable up to 430 m, low power draw	85%
Safety	Remote operation, auto-stop, enclosed electronics	84%
Design	Compact, portable, space-efficient, durable casing	84%

Table 6 shows the evaluation of strength of the rescue board from the end-user which consistently well across all aspects. In terms of system performance, the respondents rated 86% that the integrated sensors and AI allow the system to detect the obstacles like the drowning victim and maintain optimal positioning while adjusting speed. In terms of usability, 84% the device is user friendly, making rescuer easy to operate the rescue board under pressure. With LoRa, system communication 85% is stable up to 430 meter. For its safety 84% believed that rescuers can control the rescue board from a safe distance rather than direct exposure to hazardous conditions of water for its rescue operation. With built-in safeguards like waterproofed electronics enclosure, it ensures reliable operation and reduce the risk of system failure during maritime rescue operation. The design is rated as 84% with its compact and portable structure.

Table 7 Limitations of the Rescue Board

Aspect	Key Weaknesses	Avg. Score (%)
System Performance	Limited capacity, fixed cycle duration, variable performance under adverse conditions	51%
Usability	Needs instructional signage, may confuse non-tech users	39%
Communication	Range below design spec; signal drops beyond 400 m	46%
Safety	Requires periodic maintenance, UV degradation, no real-time safety indicators	27%
Design	Limited space for larger payloads, aesthetics may need improvement	43%

The above tables present a balanced assessment of the prototype's capabilities and areas for improvement. The system performs well in core rescue functions—propulsion, AI detection, and buoyancy—while limitations in battery endurance, communication range, and real-time safety indicators represent priority areas for future engineering refinement. These limitations are consistent with constraints typical of first-generation embedded AI rescue platforms and do not undermine the system's overall suitability for rapid-response maritime operations in coastal Philippine environments.

V. CONCLUSION AND RECOMMENDATIONS

This study successfully developed and evaluated a remote-controlled AI-powered rescue board for rapid maritime and flood emergency response in Philippine coastal environments. The integration of a YOLO-based detection model on the Jetson Orin Nano platform, dual-thruster propulsion, LoRa wireless communication, and onboard signaling systems produced a cohesive prototype that demonstrated measurable improvements over traditional rescue tools.

Key findings confirmed an average AI detection accuracy of approximately 91%, stable buoyancy supporting loads up to 90 kg, remote control reliability to approximately 430 meters, battery endurance of 95–120 minutes, and a 20-second response time over 100-meter deployment distances. A user acceptance mean score of 4.49 reflected strong stakeholder confidence in the system's safety, reliability, and practical utility for coastal rescue applications.

Based on the findings, the following recommendations are made: (1) integrate higher-capacity or modular battery systems to extend operational duration beyond the current 95–120 minute range; (2) add GPS-based positioning for enhanced situational awareness and victim tracking; (3) incorporate thermal or infrared cameras for improved detection in low-light or turbid water conditions; (4) conduct extended field testing in rivers, coastal waters, and flood-prone zones across varying seasonal conditions to validate durability and reliability under real-world environmental stresses; and (5) initiate pilot deployment programs with MDRRMO offices and LGUs to assess operational integration requirements prior to large-scale adoption.

Future research directions include: development of semi-autonomous or fully autonomous rescue board functionality based on advanced path-planning and decision-making algorithms; establishment of multi-board coordination systems supported by centralized monitoring platforms for large-scale maritime or flood disasters; investigation of solar-assisted power supplementation for extended endurance; and exploration of swarm robotics principles for coordinated multi-unit rescue deployment. Integration with national disaster risk reduction frameworks and standardization of AI-assisted rescue tools for Local Government Unit procurement represents a significant long-term policy and technology transfer opportunity.

ACKNOWLEDGMENT

The researchers extend their sincere gratitude to their research adviser for expert guidance and constructive critique; to the academic department and laboratory personnel for access to facilities and technical support; to panel members and evaluators for insightful feedback; and to family and colleagues for sustained encouragement throughout the research period. Special acknowledgment is also given to open-source developers and online communities whose tools and documentation facilitated hardware and AI component integration.

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