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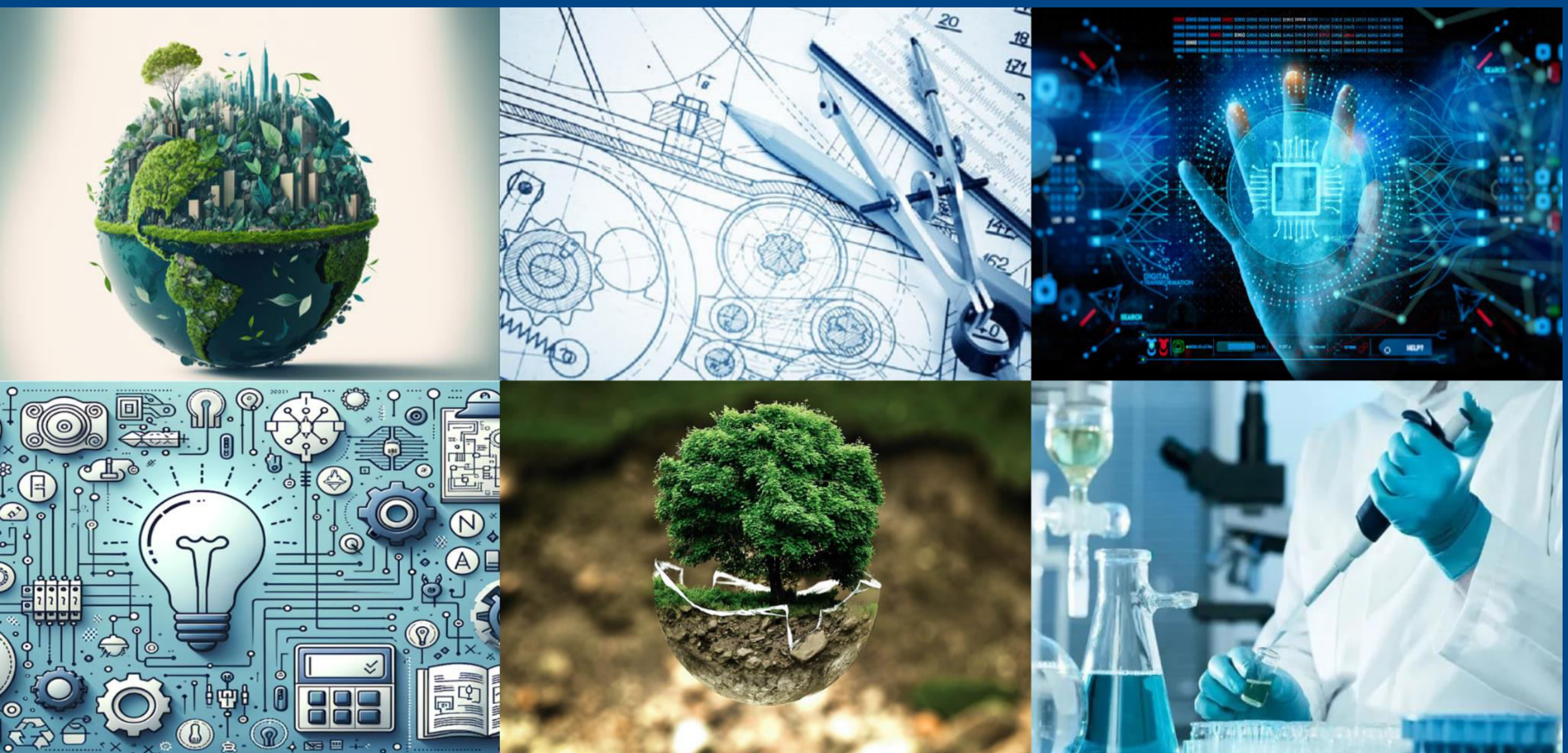

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Design and Development of an Autonomous River Cleaning Robot with a Waste Classification System

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ABSTRACT: This study developed and evaluated an Autonomous River Cleaning Robot with a waste classification system designed to detect, collect, and classify floating waste with minimal human intervention. The system integrates AI-based image recognition, sensors, and autonomous navigation to perform real-time waste detection and collection. Experimental testing in controlled conditions assessed classification accuracy, collection efficiency, and reliability. Results showed effective performance in detecting and managing waste. The findings indicate that the system is a practical and innovative solution for river cleanup, reducing manual labor and supporting environmental conservation through the integration of artificial intelligence and robotics.

KEYWORDS: Autonomous robot, river cleaning, artificial intelligence, waste classification, computer vision,

I. INTRODUCTION

River pollution caused by improper solid waste disposal continues to be a major environmental concern affecting water quality, aquatic ecosystems, and nearby communities. The accumulation of floating plastics, organic debris, and other waste materials contributes to water contamination, ecological imbalance, and increased flooding risks during heavy rainfall. Traditional river cleaning methods commonly rely on manual labor and conventional collection techniques, which may be inefficient, time-consuming, and costly for continuous environmental maintenance.

Recent advancements in artificial intelligence (AI), computer vision, and autonomous robotics have introduced new opportunities for improving environmental monitoring and waste management systems. According to Ahmad and Jama [1], AI-based technologies using machine learning and object detection algorithms can effectively detect and classify waste materials. Supporting this, Jagtap [2] emphasized that autonomous robotic systems can improve waste collection efficiency through real-time monitoring and smart navigation in waterways. These studies highlight the potential of integrating AI and robotic technologies to support efficient and automated river cleaning operations.

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In response to these challenges, this study developed an Autonomous River Cleaning Robot with a Waste Classification System that integrates autonomous navigation, computer vision, waste detection, and automated collection mechanisms. The system is designed to identify, classify, collect, and segregate floating waste materials with minimal human intervention. Ultimately, the proposed system aims to improve river waste management efficiency and contribute to environmental protection through an intelligent and sustainable river cleaning solution.

II. LITERATURE REVIEW

A critical review of related literature and studies has been conducted to establish the relationship between the present study and prior research in the field of autonomous environmental robotics and river waste management systems. In recent years, environmental researchers and engineers have increasingly adopted artificial intelligence, computer vision, and autonomous robotic technologies to address the growing problem of river pollution caused by improper waste disposal. The accumulation of floating plastics and other debris in rivers contributes to water contamination, ecological imbalance, and flooding risks, making efficient river cleanup systems increasingly important. However, despite advancements in environmental robotics, many existing systems still face limitations in autonomous navigation, real-time waste classification, and integrated waste collection mechanisms. Most studies focus only on waste detection or monitoring without fully combining navigation, classification, and collection processes into a single operational system. While significant developments have been made in smart waste management technologies, there remains a need for more intelligent, efficient, and autonomous river-cleaning solutions capable of operating in dynamic aquatic environments.

Recent studies have emphasized the importance of artificial intelligence and computer vision technologies in improving river waste management systems. Jamal et al. [1] developed an automated floating robot that focuses on plastic waste detection using a lightweight machine learning model deployed on an embedded system. Similarly, Ahmad et al. [2] demonstrated that the integration of artificial intelligence and YOLO-based object detection significantly improves the real-time detection and collection of floating waste materials in rivers. Supporting this finding, Ankit et al. [3] designed a smart river-cleaning robot capable of identifying different waste types through an AI-based vision system while simultaneously collecting debris using mechanical mechanisms. Their study further revealed that TensorFlow Lite enables efficient object recognition with lower power consumption, making the system more suitable for continuous environmental monitoring. In addition, Mendoza et al. [4] proposed a multi-agent autonomous surface vehicle system that applies deep reinforcement learning techniques for coordinated aquatic waste cleanup, improving adaptability and scalability in larger waterways.

Recent empirical investigations have also demonstrated the practical applicability of autonomous river-cleaning technologies through prototype implementation and field evaluation. Ello et al. [5] developed AquaNova, an autonomous floating robot integrating YOLO-based object detection and GPS waypoint navigation, which demonstrated reliable waste detection and stable operational performance in aquatic environments. Likewise, Obligar et al. [6] designed a solar-powered autonomous floating waste collector that combines a CNN-based vision system with autonomous propulsion for long-duration operation with minimal human intervention. Supporting these findings, Reynoso [7] developed SeaGBin, a solar-powered autonomous waste collector integrated with IoT technology for real-time monitoring of garbage accumulation, device location, and environmental conditions through a mobile application. Furthermore, Canlas [8] reported that the AI-enabled Clear Bot system deployed in Pasig City demonstrated the effectiveness of integrating autonomous waste collection with environmental data monitoring to optimize cleanup operations in local waterways.

Local studies and environmental assessments further emphasized the severity of plastic pollution in Philippine rivers and the need for adaptive autonomous cleanup technologies. According to Meijer et al. [9], several Philippine rivers, including the Pasig River, Tullahan River, and Agno River, are among the world's major contributors to marine plastic pollution. Similarly, Talavera et al. [10] documented high concentrations of macroplastic waste in the Tullahan River, highlighting the varying distribution of floating waste materials across river systems. Supporting this, De Luna et al. [11] explored the application of path planning algorithms in autonomous aquatic trash collection systems and found that optimized navigation significantly improves operational efficiency while reducing redundant movement and energy consumption. These studies collectively highlight the growing importance of integrating artificial intelligence,

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autonomous navigation, and waste classification technologies in developing intelligent river-cleaning systems capable of addressing the increasing problem of river pollution in the Philippines.

Table 1. Summary of Relevant Literature

No.	Paper Title	Author Name	Key Points	Remark
1	Automated Floating Robot for Plastic Waste Detection	Jamal et al. (2025)	Developed an automated floating robot using lightweight machine learning for plastic waste detection on embedded systems	Supports AI-based waste detection in river-cleaning operations
2	AI-Based River Waste Detection Using YOLO	Ahmad et al. (2025)	Applied YOLO-based object detection and computer vision for real-time floating waste identification	Validates use of computer vision for autonomous river cleaning
3	Smart River-Cleaning Robot with Waste Classification	Ankit et al. (2025)	Integrated AI-based vision system and mechanical collection with real-time waste classification	Supports automated waste segregation and collection features
4	Multi-Agent Autonomous Surface Vehicle System	Mendoza et al. (2024)	Applied deep reinforcement learning for cooperative waste cleanup using multiple autonomous vehicles	Supports scalable and adaptive autonomous river-cleaning systems
5	AquaNova Autonomous Floating Robot	Ello et al. (2025)	Integrated YOLO-based object detection and GPS waypoint navigation for autonomous waste collection	Supports autonomous navigation and AI-based waste classification
6	Solar-Powered Autonomous Floating Waste Collector	Obligar et al. (2025)	Combined CNN-based vision system with solar-powered propulsion for extended autonomous operation	Supports sustainable autonomous river-cleaning design
7	SeaGBin Autonomous Waste Collector	Reynoso (2025)	Used IoT technology for monitoring waste accumulation, location, and environmental conditions	Supports integration of IoT monitoring in waste management systems
8	Clear Bot AI-Enabled Cleanup Vessel	Canlas (2025)	Implemented AI-enabled robotic vessel for automated floating waste collection in Pasig waterways	Supports practical deployment of AI river-cleaning technologies
9	Riverine Plastic Pollution Assessment	Talavera et al. (2024)	Documented high concentrations and varying distribution of macroplastic waste in rivers	Highlights urgency of autonomous river-cleaning solutions
10	Macroplastic Survey in Tullahan River	Catindoy et al. (2024)	Mobile reminder systems improve medication organization and adherence	Supports need for adaptive waste classification strategies
11	Autonomous Trash Collection Using Path Planning Algorithms	De Luna et al. (2023)	Applied optimized navigation algorithms for efficient aquatic trash collection	Supports efficient autonomous navigation and reduced energy consumption

In summary, the present review is grounded on prior studies that examine the use of artificial intelligence, computer vision, and autonomous robotic systems for river waste management and environmental monitoring. Earlier research

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has primarily focused on isolated functions such as waste detection using machine learning models, object recognition through YOLO and CNN-based systems, autonomous navigation using GPS or path planning algorithms, and mechanical waste collection mechanisms, often implemented separately. Several studies also explored enhancements such as reinforcement learning for multi-agent coordination, solar-powered operation for extended deployment, and IoT-based monitoring for real-time environmental data tracking. While these developments demonstrate significant progress in improving detection accuracy, operational efficiency, and system sustainability, many existing systems still lack full integration of perception, navigation, and waste collection into a unified autonomous platform. The current study builds on these works by emphasizing an integrated approach that combines AI-based waste classification, autonomous navigation, and automated collection mechanisms within a single river-cleaning system. In doing so, it extends prior research by addressing the need for a more cohesive, intelligent, and efficient solution capable of operating effectively in dynamic aquatic environments, particularly in addressing river pollution challenges in the Philippines.

III. METHODOLOGY

Research Design

This study utilized a Design and Development Research approach to create an autonomous river-cleaning robot integrated with an AI-based waste classification system. The research focused on designing, building, and refining a functional prototype capable of detecting, collecting, and classifying floating waste while navigating water environments independently. The system combined hardware components, such as sensors, motors, and a collection mechanism, with software elements including image recognition and control algorithms. It was tested under controlled conditions to evaluate performance, adaptability, and reliability, with improvements made based on results. Ultimately, the study validated the system's effectiveness as an innovative solution for autonomous river waste management.

Instruments

This study used a structured questionnaire based on a 5-point Likert scale as its primary research instrument to evaluate the system's usability, functionality, reliability, and acceptability. Respondents rated their level of agreement to measure overall user perception of the autonomous river-cleaning robot. In addition, a system testing video and actual performance tests were utilized to assess key metrics such as waste classification accuracy, collection efficiency, and navigation capability. The combination of subjective feedback and objective performance data provided a comprehensive evaluation of the system from both user and technical perspectives.

Data Collection and Participants

The study involved 50 respondents selected through convenience sampling, consisting of 40 Computer Science students (80%) and 10 professionals and local residents (20%). The students provided technical insights on the system's design and functionality, while the professionals contributed practical perspectives on usability and real-world application. All participants evaluated the system by watching a video demonstration and completing a structured questionnaire, allowing for a comprehensive assessment of the robot's effectiveness, usability, and overall acceptability.

Data Gathering Procedure

The data gathering procedure involved collecting real-world images of floating waste from the river to create a representative dataset, which was then organized, annotated, and used to train and evaluate the AI model for accurate waste detection and classification. The system was also tested in an actual river environment to assess its performance in terms of detection accuracy, collection efficiency, and navigation capability. Additionally, respondents evaluated the system by watching a recorded demonstration and answering a structured questionnaire. All collected data from both system performance and user feedback were compiled and prepared for analysis to ensure a comprehensive evaluation of the system.

Datasets Description

The dataset in this study consisted of 1,401 real-world images of floating waste collected from a river, categorized into plastic (51%) and organic (49%) materials to ensure balance. The images were annotated using Roboflow and divided into training (70%), validation (20%), and testing (10%) sets to support model development and evaluation. Using Google Colab and the YOLOv8 algorithm, the dataset enabled the system to learn key visual features for accurate

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waste classification. The use of real environmental data improved the model's robustness, resulting in reliable performance in identifying and classifying floating waste under varying conditions.

Data Preprocessing

Data preprocessing was conducted to ensure the dataset was clean, consistent, and suitable for training the deep learning model. This involved resizing images to a uniform resolution, applying normalization, and removing unclear, blurred, or duplicate images to maintain data quality. Annotations were also carefully reviewed to ensure accurate classification of plastic and organic waste. The processed dataset was then split into training, validation, and testing sets to support effective model development and unbiased evaluation, ultimately improving the system's accuracy and reliability in real-world waste classification.

YOLOv8

The waste classification system utilizes the YOLOv8 model to accurately detect and classify floating debris into plastic and organic categories in real time. Trained using a preprocessed dataset divided into training, validation, and testing sets, the model learned key visual features through multiple training epochs while monitoring performance metrics such as precision, recall, and mAP. After optimization, the model was deployed on a Raspberry Pi, where it processes live camera input to identify waste and trigger appropriate actions like collection and sorting, enabling efficient and autonomous operation in river environments.

Training Process

The training process enabled the YOLOv8 model to accurately classify floating waste into plastic and organic categories by learning key visual features from the prepared dataset. Conducted in Google Colab, the model used pre-trained weights and was trained over multiple epochs with datasets split into training, validation, and testing sets for proper evaluation. Performance metrics such as loss, precision, recall, and mAP were monitored to assess effectiveness, and the best-performing model was selected after validation and testing. The optimized model was then integrated into the robot to process real-time camera input, ensuring accurate and reliable waste detection in real-world river environments.

Data Analysis

The collected data were analyzed using statistical methods to evaluate both system performance and user perception of the autonomous river-cleaning robot. A confusion matrix and metrics such as accuracy, precision, recall, F1-score, and specificity were used to assess the effectiveness of waste classification. Meanwhile, responses from the 5-point Likert scale questionnaire were analyzed using mean scores to evaluate usability, functionality, reliability, and acceptability. This combined approach provided a comprehensive assessment of the system's technical performance and overall user evaluation.

IV. RESULTS & DISCUSSION

System Performance Results

The confusion matrix shows that the YOLOv8 model achieved perfect classification for organic waste, correctly identifying all samples with no misclassifications. The minimal off-diagonal values indicate very low false positives and false negatives, reflecting high accuracy. However, this result may also suggest that the dataset was limited or highly uniform, which could affect the model's generalizability to more complex real-world conditions.

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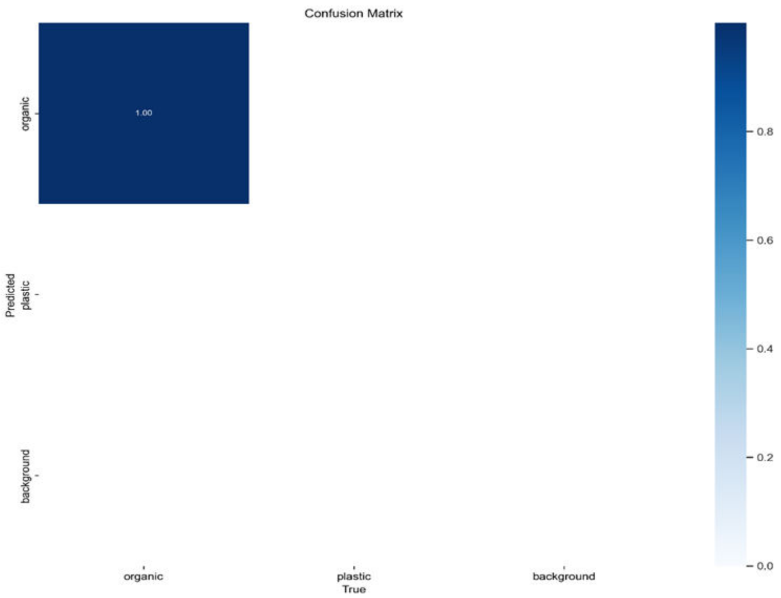

Figure 1: Confusion Matrix of the Waste Classification Model

Therefore, the results confirm that the second objective of the study was successfully achieved, with the YOLO algorithm providing a reliable and efficient method for waste classification and collection guidance.

Performance Evaluation

The evaluation of the autonomous river cleaning robot shows that the prototype achieved an excellent level of performance across functionality, usability, reliability, and overall acceptability based on responses from students, professionals, and community members. High mean scores (ranging from 4.47 to 4.51) indicate that the system effectively performs its intended tasks, operates efficiently with minimal errors, and is suitable for real-world environmental applications. The results highlight the system's strong capability in waste detection, collection, classification, and autonomous operation.

Table 2 Summary of River Cleaning Robot System Evaluation Results

Table	Category	Mean	Interpretation
1	Functionality	4.48	Excellent
2	Usability	4.47	Excellent
3	Reliability	4.47	Excellent
4	Acceptability	4.51	Excellent
	Overall Mean	4.48	Excellent

The findings confirm that the autonomous river cleaning robot is a highly effective, reliable, and user-friendly system with strong potential for real-world deployment. Its excellent ratings across all evaluation criteria demonstrate that it meets industry standards and can significantly contribute to improving river waste management, environmental protection, and community sustainability.

Response Time and System Efficiency

The results show that the YOLO algorithm performed efficiently in detecting and classifying waste under controlled conditions with a response time in just 1-2 seconds, supported by proper training, quality data, and favorable environmental factors. Although minor detection issues occurred due to reflections, movement, and occlusion, overall performance remained reliable. The system successfully integrated detection with navigation and collection, confirming that the algorithm is suitable for real-time application and that the study's objective was achieved.

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Discussion

The results indicate that the Autonomous River Cleaning Robot achieved excellent performance, with a high overall mean of 4.48 across functionality, usability, reliability, and acceptability. The system effectively detects, classifies, and collects floating waste, demonstrating successful integration of AI and robotic components. It is user-friendly, operates autonomously, and maintains stable and reliable performance. Although minor detection issues were observed due to environmental factors, these did not significantly affect overall performance. Overall, the findings confirm that the system is an effective, practical, and promising solution for real-world river waste management.

V. CONCLUSION

The study successfully developed and evaluated an Autonomous River Cleaning Robot with an integrated waste classification system designed to address river pollution caused by floating plastic and organic waste. By combining YOLOv8-based image recognition, autonomous navigation, and a mechanical waste collection mechanism using Raspberry Pi and Arduino, the system enabled real-time detection, classification, and collection of debris in river environments. The robot demonstrated the ability to operate independently while performing waste segregation efficiently.

Evaluation results showed that the system achieved excellent performance in terms of functionality, usability, reliability, and overall acceptability, with high accuracy in waste detection and positive feedback from respondents. The findings indicate that the system can effectively improve river waste management while reducing the need for manual labor. Overall, the study highlights the potential of integrating artificial intelligence and robotics to create efficient, practical, and sustainable solutions for environmental protection.

Recommendations

Considering the findings and limitations encountered during the study, the following recommendations are suggested:

1. Future studies may expand the dataset and improve the AI model to classify additional waste types such as metals, glass, and hazardous materials.
2. The navigation system may be enhanced by integrating advanced technologies such as GPS, LiDAR, or computer vision-based path planning for better accuracy and adaptability.
3. Renewable energy sources, such as solar panels or hybrid power systems, may be incorporated to extend operational time and improve sustainability.
4. The mechanical and structural design of the robot may be improved to handle submerged, heavy, or waterlogged waste materials more effectively.
5. Further testing in real-world river environments is recommended to evaluate the system's durability, adaptability, and long-term performance under varying conditions.

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