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Research Article

Automated River Cleaning Robot for Plastic Waste Segragation Using AI

Mahfooz Ahmad[1], Tasleem Jamal[2]
[1,2]*Department of Computer Science & Engineering, Khwaja Moinuddin Chishti Language University*
[1]*mahfoozahmad.iu@gmail.com*

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ABSTRACT

River plastic pollution threatens aquatic habitats, animals, and human health. This paper describes an automated floating robot concept that detects and collects plastic debris from water surfaces using computer vision and machine learning. Unlike standard cleaning systems that gather all forms of debris, the proposed robot use a TensorFlow Lite object recognition model running on a Raspberry Pi to target just plastic materials. A Pi Camera records footage in real time onboard for identification. When detection is more than 80% certain, a servo-powered loader moves the object to an interior storage area. For verification, it takes a snapshot of the recognized item and logs time and GPS data using the NEO-6M module. Robots are designed to be energy efficient and may be powered by solar energy. Robots conduct exact recognition under a variety of situations.

Keywords: Autonomous robot, plastic waste collection, object detection, environmental monitoring, river cleaning, smart waste management.

INTRODUCTION

Water is important for all living species, but because much of it is trapped in glaciers and polar regions, only a little amount is available. The quality of useable water is quickly deteriorating, which has a severe impact on ecosystems [1]. Marine habitats are threatened by garbage such as plastic bags and bottles that are carried into the oceans via storm drains and sewage systems [2]. Manual debris removal is not only time consuming and repetitious, but it is also detrimental to one's health. Industry 4.0 introduces automation, with the ability to automate a variety of processes. This research suggests a concept for an autonomous RCR capable of detecting and collecting garbage from the water surface. This concept is a low-cost, practical implementation with a conveyor-belt system for effectively gathering and removing surface-floating garbage. The Ganga river provide more than 40% of water demand of India but it is listed as the second most polluted river of world (2017) [2]. 'Namami Gange Programme' initiated by the government allocated budget of approximately ₹20,000 crores for cleaning [3]. A similar program was developed for the Godavari River. Other government-led programs have also been launched to combat water contamination in various water bodies. According to WHO, waterborne infections account for 22% of all communicable diseases [4]. Excessive algal growth reduces oxygen levels in water, which can lead to the death of fish and other aquatic creatures. To address these issues, this project proposes the creation of an autonomous watercraft outfitted with a robotic arm capable of detecting, collecting, and removing garbage from water bodies. Plastic has been more popular because of its flexibility and low cost. By 2016, the marine ecosystem included an estimated 150 million metric tons (MMT) of plastic. Up to 10% of all plastic garbage created eventually ends up in the ocean, and by 2050, plastic will surpass fish biomass in the sea (World Economic Forum, 2016). Plastic are the threat as a serious environmental consequences—it is hazardous to marine wildlife, degrading ecosystems, spreads the invasive species, and settles in sediments, endangering aquatic life [3]. International and regional government alliances have started to address the plastic marine pollution challenge [4]. Marine body plastic pollution is a serious danger to aquatic life, with long-term consequences for whole ecosystems [1]. In recent years, there has been a focus on cleaning up floating trash in rivers [2-5]. A considerable amount of rubbish enters the ocean via interior streams [6, 7]. Thus, limiting the flow of plastic from rivers is critical for minimizing plastic deposition in

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seas [8,9]. Manual efforts to clean vast bodies of water have proven ineffective. Automated RCR provide a promising approach for autonomously identifying and collecting floating garbage [8]. Such robots cover a wide surface area of water. An effective coverage path is necessary to direct movements. Traditional coverage path planning (CPP) strategies [10, 11] are applied from a long time. However, unlike ordinary floor-cleaning applications, water surface cleaning requires maneuvering across uneven limits and interior barriers. Kinematic limitations are also considerable in hidering the path efficiency and performance.

RELATED WORK

Mukhtar et al. [3] designed the River Trash Collector for removing floating garbage and fuel from the surface of river. The concept of ballast tank is used for garbage collection, with a dual-layer structure—the outer layer serves the ballast tank to assure stability, and the interior compartment allocated for garbage accumulation. The system has two major limitations: its fixed, non-mobile architecture and the significant time necessary to 3D-print its components. Chen Su et al. [4] presented an autonomous waste cleanup boat for lake surfaces. The system featured both manual and automatic operation, using ultrasonic sensors to identify the vessel's location. However, the system was designed to handle only five distinct cases, resulting in inefficient and unpredictable motion routes. Another limitation was that the boat could only run once at a time, largely to save energy. In an article [5] the designing of "Ro-boat," an automated river-cleaning device with computer vision capabilities. It consists of a robotic arm to capture the floating garbage. To detect the waste, it uses the HSV color space and SURF characteristics prior to applying Kalman Filter. However, it has shortcoming of high energy consumption, which limits the operational time for garbage collection. Research work performed by Albitar et al. [6] suggested a new underwater cleaning robot with a crawling mechanism. This design uses the adhesion and bearing response forces to ensure the steady movement across submerged surfaces. It was primarily used to remove biofouling particles that accumulated on underwater infrastructure. In their paper "Autonomous Trash Collecting Robot," G. Sivasankar et al. [7] created a self-operating robot that uses S-shaped path-planning algorithms for cleaning. It independently gathers and dumps garbage using a suction-based vacuum mechanism. The system's functioning was tested using MATLAB simulations, followed by the creation of a real prototype. Saifali et al. [8] designed an RCR to remove floating trash from water surfaces. It used a chain-drive mechanism to collect garbage as a prototype design. AGATOR (Automatic Garbage Collector) [9] collects trash from stationary bodies of water. The robot could handle up to 5 kg of rubbish. During operation, its speed was reported at 0.26 m/s when collecting rubbish. AGATOR proved consistent operation, particularly in non-flowing water situations.

Table 1: Inferences from Literature

Approach	Key Features	Advantages	Limitations	Best Model
Wireless Control+ Image Processing	Wireless control, Image processing for waste detection	Effective for remote locations, Reduces labor cost	Limited to small-scale applications	Design and Development of an Intelligent Wireless Pond/Lake Cleaning Robot
IoT-based Monitoring	Real-time monitoring , Integration with IoT	Autonomous cleaning, waste management	Lacks AI- based detection	Design and Development of River Cleaning Robot Using IoT Technology
AI + Edge Computing	Waste recognition, Edge computing in real-time control	Suitable for urban waste, Energy-efficient	Focused on urban, not water bodies	AI Edge Computing for Robotic AGV for Cleaning Garbage
AI for Waste Classification	Effective waste segregation	Automated process , Highly efficient for specific tasks	Lacks navigation mechanism	Water Cleaning Bot with Waste Segregation Using Image Processing

METHODS

River cleaning robots leverage artificial intelligence to detect, collect, and segregate plastic waste in the environment. The following sections describe various algorithms underpinning these capabilities. It consists of object detection and recognition algorithms to detect plastic objects by analysing visual data from cameras or sensors. It pre-processes the input images through layers such as convolutional, pooling, and fully connected layers. Feature extraction is performed in the convolutional layers by identifying the patterns like edges, shapes, and textures of plastics. Final layers performs the classification of objects into predefined categories (e.g., plastic, organic, metal) by using TensorFlow, PyTorch framework. It gives the advantages of high accuracy and adaptability towards the diverse datasets.

Table 2: Algorithm

1. **Initialization Phase** 1.1. Load TensorFlow Lite model for plastic detection. 1.2. Load label file to map class indices to object names (e.g., "plastic bottle"). 1.3. Initialize the camera for continuous video capture. 1.4. Initialize the servo motor (for opening and closing the loading flap). 1.5. Initialize the GPS module to read real-time location. 1.6. Create or ensure the folder /home/pi/evidence/ exists to store captured evidence images. 1.7. Begin video stream using a separate thread to improve frame rate performance. 2. **Main Loop** 2.1. Capture a frame from the camera. 2.2. Preprocess the frame (resize and format) to feed it into the TFLite model. 2.3. Run the TFLite model inference on the frame. 2.4. Get the highest-confidence result: Extract the predicted label (e.g., "plastic bottle"). Extract the confidence score (e.g., 92%).	3. **Plastic Detection Decision** 3.1. IF detected object is plastic (based on label match) AND confidence is greater than 80%, THEN: 3.1.1. Print detection details (label + confidence). 3.1.2. Activate the servo to open the flap, wait, then close the flap to allow plastic into the bin. 3.1.3. Read GPS location using the GPS module. 3.1.4. Save the current frame as an image file in the /evidence/ folder with timestamp and optionally GPS info in the filename. 3.1.5. Log the detection timestamp, GPS location, and image path into a .csv file for records. 3.2. ELSE: Continue scanning the river for plastic without taking action. **4. Exit Condition** 4.1. If the user presses 'Q' on the keyboard or triggers shutdown: - Stop the video stream. - Release the camera and GPIO pins. - Close all OpenCV windows. - Exit the program cleanly.

Software Design Description

The learning of model is performed using the YOLO (You Only Look Once) dataset for real-time detection of plastic objects. It works by following the process of dividing the image data into grids for prediction of the bounding boxes and confidence scores for the identified objects. It processes images in a single pass, making it compatible with live operations. It is faster than traditional object detection methods. Mask R-CNN is applied for object detection with instance segmentation. It detects objects and creates pixel-level masks, enabling precise recognition of irregularly shaped plastics [10]. It has advantages of high precision, useful for separating overlapping objects. The system design uses TensorFlow Lite-based object detection, which processes real-time images from a Pi Camera to detect plastic waste. Object detection models in TensorFlow Lite (like SSD MobileNet, YOLO, or EfficientDet) are CNN-based architectures, as CNNs are the standard for image processing tasks including object classification and detection [11-14]. The algorithm for the Autonomous Floating RCR to detects and collects only plastic captures GPS location, and saves image evidence upon successful collection is given in table 2.

Hardware Design Description

The hardware design part is divided in four parts (1) Plastic-only detection, (2) Plastic collection via loading mechanism, (3) GPS logging, (4) Evidence image saving. Here is a complete list of required components for your Autonomous River-Cleaning Floating Robot with the features given in

RESULTS

For facilitating the long-range communication and data transmission, the robot is equipped with a wi-fi modules for cloud-based monitoring.the li-ion batteries are provided for sufficient power transfer to motors, sensors, and controling unit. The power management module regulates energy distribution to maintain stable voltage levels. Solar panels may be integrated as the alternative power source for extending operational time. The frame and chassis is constructed from lightweight and durable materials such as aluminium/polycarbonate for providing structural stability while ensuring the buoyant and manoeuvrable design. Additional features include the buzzers, for alert of system status updates, such as a full waste container, and led indicators that display essential operational statuses of power and object detection. The waste collection container securely stores the collected plastic waste until it is disposed properly. By integrating the advanced components, the ai-based river-cleaning robot design is capable to offer a scalable, autonomous, and environmentally sustainable solution to tackle plastic pollution in water bodies.

Table 3: Component List

1.	**Core Control System**
Component	Description
Raspberry Pi 4/5	Main processor board to run camera, AI, GPS
microSD Card (32+ GB)	For OS, TensorFlow Lite, and image storage
Power Bank (5V/3A)	To power the Pi and motors in the river
2.	**Vision & Detection**
Pi Camera V2 or USB Camera	Captures video feed for plastic detection
TensorFlow Lite Model	Pre-trained MobileNet or custom model for detecting plastic objects
3.	**Plastic Collection Mechanism**
Servo Motor (SG90 / MG996R)	To open/close flap or gate for loading plastic
3D Printed Flap / Gate	Mechanism to allow plastic to enter collector bin
Plastic Collector Bin	Bucket/bin mounted inside the boat for storing plastic
4.	**GPS Tracking**
NEO-6M GPS Module	Serial GPS module to get current location
Jumper Wires	For GPS TX/RX connection to Raspberry Pi
5.	**Floating & Movement System**
Floating Platform	Boat hull / buoyant base (thermocol, plastic)
Brushless/Brushed DC Motors (2)	For propulsion, if autonomous navigation is desired
Motor Driver (L298N or ESC)	If using motors for steering or propulsion
6.	**Power System**
5V 3A Power Bank	For Raspberry Pi
Separate 12V Battery	For motor propulsion system
7.	**Storage & Evidence Logging**
/home/pi/evidence/	Folder on Pi to save images of detected plastic
CSV Log File	For storing timestamp, GPS, image path
8.	**Miscleneous**
IR / Ultrasonic Sensors	Obstacle detection
Solar Panel	Self-charging power system for long runtime
Wi-Fi or GSM Module	Send image evidence remotely
Telegram / Blynk	For alert & monitoring

The hardware architecture of the AI-based river-cleaning robot is designed to ensure efficient operation, precise waste detection, and seamless communication. The Raspberry Pi 4 Model B is at the system's core, which acts as the primary processing unit, executing AI algorithms responsible for object detection, navigation, and waste segregation. It is equipped with a quad-core ARM Cortex-A72 processor with GPU support of computer vision tasks with Wi-Fi/ Bluetooth connectivity, it processes the data efficiently from sensors and actuators. It facilitates communication to other systems, as shown in Figure 3. The crucial component is high-resolution (8–12 MP) camera that captures real-time images fo identification of plastic waste. It works with AI models, ensuring the precise detection and classification of object. This visual input is fundamental for the robot's navigation and collection mechanisms [15].

For efficient and accurate movement, the system relies on variety of sensors. Ultrasonic sensors (HC-SR04) gives the measurements of distances for finding obstacles and prevent collisions, while infrared (IR) sensors helps in identifying edges and potential hazards. Environmental sensors (DHT11) supports the monitoring of temperature and humidity levels to optimise the operational performance. A GPS module (NEO-6M) performs the tracking of

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the location and log the movement path and analyse the areas covered during waste collection [16]. The locomotion system relies on DC and servo motors, which an L298N motor driver controls to regulate speed and direction. This ensures smooth movement across the water surface [17].

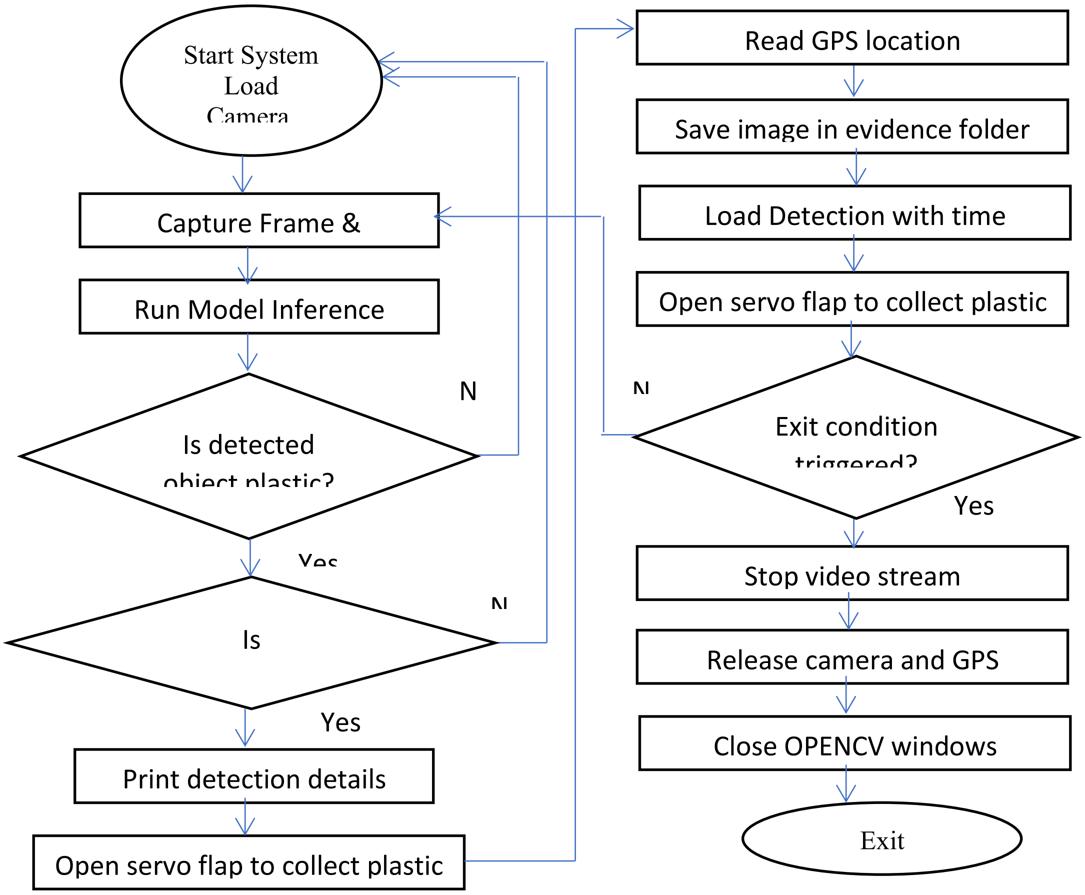

Figure 1: Process Flowchart

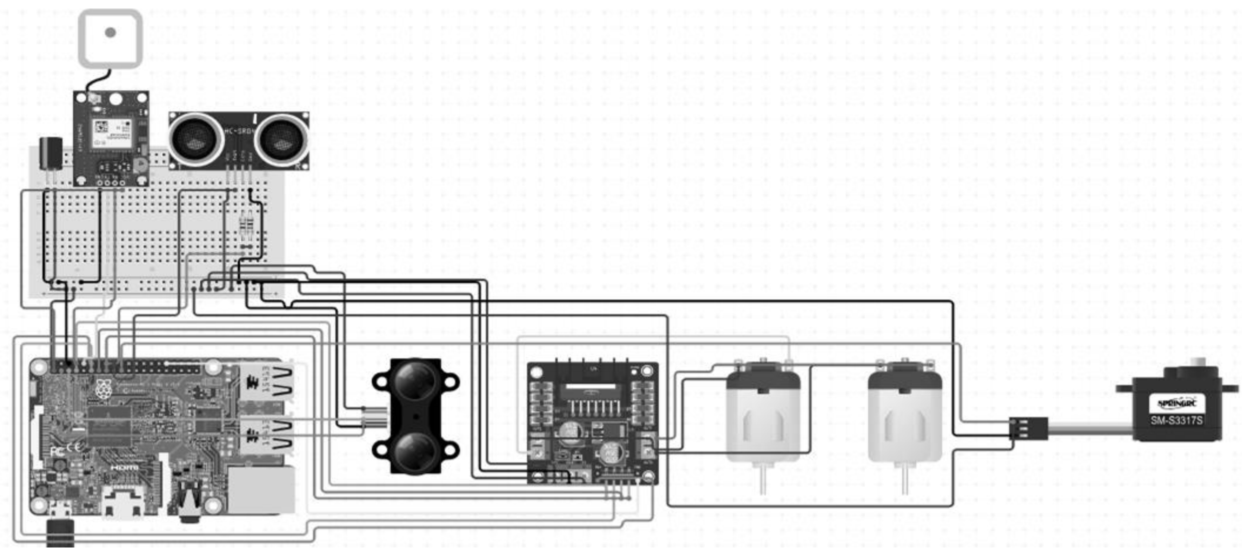

Figure 2 Connection Diagram

A comparison in between the traditional river cleaning schemes and AI-driven approaches highlights remarkable progress in the technology, efficiency, scalability, and sustainability. Conventional methods are dependent on

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human, basic tools, and nets, which are time-consuming and restricted for small-scale level. These approaches are error-prone, frequently fails to detect the small or submerged debris and face challenges in remote or inaccessible areas. Moreover, manual intervention in traditional methods often disrupts the ecosystems, and lacks the scopes of data collection hence hinders the ability to monitor and enhance cleaning efforts. Although these methods have lower costs, their reliance on continuous labor makes them less economical.

Figure 3 Prototype of AI-based river cleaning robot

The AI-based river cleaning systems utilize the principles of robotics, machine learning, and IoT to deliver desired efficiency and scalability. It functions as an autonomous system with minimum human interface that reduces the required time and workforce. Smart computer vision systems accurately detect garbage in real-time scenarios, apturing floating and submerged debris. Their capabilities of autonomous navigation systems are helpful to operate in the challenging environments, making them better compatible for large rivers and complex circumstances. The AI based methods are eco-friendly and provide cleaning solutions that minimize ecological disruption. By incorporating renewable energy sources like solar power, they promote sustainability, while IoT integration facilitates real-time data collection and analysis, supporting informed decision-making and operational enhancements. Despite higher initial cost, the long-term reduction in operational expenses makes AI-based systems cost-efficient for large-scale river cleaning initiatives. AI-based river cleaning schemes surpass traditional methods in nearly every dimension and provide better scalable and sustainable options to tackle plastic waste in the water bodies. Future efforts may involve enhancement in terms of improving accuracy, energy efficiency, and adaptability.

CONCLUSION

Using smart computer Vision with embedded electronics is a cost efficient approach to help the rivers cleaning task autonomously. Tests on the system in various circumstances have revealed it is dependable and has a good potential. It becomes even more appealing as its operation is merged with deep learning models. It becomes even more affordable, reduces energy use and is simpler for bigger rivers when used at a larger scale. Unlike older manual procedures, the technology makes waste management more efficient, fast and cost-effective. Next, the robot will be built and tested in the real world for validation. Also, efforts will be made to set up a common control unit that enables multiple river cleaning robots to work together at one time.

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