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AQUACLEANBOT

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ABSTRACT

Plastic waste accumulation on water surfaces is a critical environmental issue, necessitating automated solutions for effective waste removal. This paper presents the design and implementation of an autonomous robotic system, AQUACLEANBOT, for efficiently detecting and collecting plastic waste from water surfaces. The system integrates computer vision-based object detection using the YOLOv8 Nano model, which accurately identifies floating plastic bottles in real time. A Raspberry Pi 5-controlled vision based navigation mechanism enables precise movement toward detected waste, utilizing a dual-motor propulsion system with a 3D-modeled shaft for efficient maneuverability. The robot employs PVC pontoons for stability and buoyancy, ensuring smooth operation in varying aquatic environments. A labeled dataset of plastic bottles was compiled and annotated using Roboflow, allowing the YOLOv8 model to achieve high detection accuracy in real-world conditions. The AQUACLEANBOT project contributes to sustainable water conservation efforts, offering a low-cost, scalable, and environmentally friendly solution for mitigating plastic pollution in aquatic ecosystems.

Keywords:

Autonomous waste collection, YOLOv8 Nano, Raspberry Pi 5, plastic pollution, vision-based navigation, robotic waste removal, aquatic robotics, environmental sustainability, water surface cleaning.

1. INTRODUCTION

Lakes and other water bodies are essential components of the environment, playing a key role in providing fresh water, supporting biodiversity, and maintaining climate stability. They also act as natural barriers against floods and droughts while enhancing the beauty of landscapes and offering recreational benefits to communities.The rapid growth of urban areas and industrial activities has led to severe pollution, endangering these valuable ecosystems.The growing demand for plastic over the past five decades has led to a significant environmental challenge. Improper disposal of non-biodegradable plastic waste has contributed to severe pollution, particularly in lakes, rivers, and oceans. Studies show that more than 19 million kilograms of plastic waste enter the ocean each year, causing serious harm to marine life and disrupting aquatic ecosystems. In many cities, lakes have turned into dumping sites for untreated sewage, plastic waste, and other harmful materials. The accumulation of non-biodegradable substances deteriorates water quality, disrupts aquatic life, and reduces oxygen levels, leading to severe ecological imbalances. Additionally, exposure to polluted water increases the risk of waterborne diseases, making it a major public health concerns. The Aqua Clean Boat initiative is committed to addressing this issue by removing waste from lakes, rivers, and other water bodies. By actively working to restore these natural resources, we can protect aquatic species, improve water quality, and promote sustainable environmental practices. Through collective action and innovative solutions, we can ensure cleaner and healthier water bodies for the benefit of future generations aquatic species, improve water quality, and promote sustainable environmental practices.

2. PROBLEM STATEMENT

Plastic bottle pollution in water bodies disrupts aquatic ecosystems and poses significant environmental hazards. Conventional cleanup methods are inefficient, labor-intensive, and unsuitable for large or inaccessible areas. The accumulation of plastic waste in water sources necessitates an efficient and systematic solution for timely removal. This study proposes AQUACLEANBOT, a floating system designed for real-time detection and collection of plastic bottles. It integrates the YOLOv8 model with a USB camera for object detection, utilizes DC motors for propulsion, and features a detachable bin for systematic waste collection. Controlled by a Raspberry Pi 5, the system enables automated operation, enhancing efficiency, scalability, and sustainability in aquatic waste management.

3. OBJECTIVE

- Develop an autonomous aquatic waste collection system by integrating a YOLOv8 Nano-based vision model with a Raspberry Pi 5-controlled navigation mechanism for real-time waste detection and collection.
- Create a robust plastic bottle detection model by compiling, labelling, and annotating a dataset ensuring high detection accuracy in diverse water environments.

- Implement a navigation system that enables the robot to identify, track, and align with detected plastic waste using real-time image processing and error correction algorithms.
- Design an efficient motor-driven propulsion system ensuring stable and controlled movement across water surfaces.
- Enhance stability and buoyancy of the robotic platform, allowing smooth operation in varying water conditions and preventing excessive tilt or drift.
- Evaluate the system's performance through controlled water trials, assessing detection accuracy, collection efficiency, and navigational precision for optimized functionality.
- Contribute to sustainable environmental solutions by demonstrating the feasibility of an autonomous, low-cost, and scalable robotic system for plastic waste removal in water bodies.

4. METHODOLOGY

A. Overview

The AQUACLEANBOT project is an autonomous system developed for the removal of plastic waste from water surfaces. The project employs an integrated approach combining camera-based object detection and vision-guided navigation to identify, track, and collect plastic bottles. The system is built upon a robust hardware platform featuring a buoyant structure and a precise motor control mechanism, while the software utilizes a deep learning model (YOLOv8) for real-time waste detection.

B. Data Acquisition and Pre-Processing

A comprehensive dataset of plastic bottle images was compiled from both controlled environments and publicly available sources. Images were captured under diverse conditions. The collected images were pre-processed by standardizing their sizes and then uploaded to the Roboflow platform for annotation. Precise bounding boxes were drawn around the plastic bottles, and data augmentation techniques (e.g., rotation, scaling, brightness adjustments) were applied to improve model robustness. Once pre-processed, the dataset was split into **training (70%), validation (20%), and testing (10%)** sets for model development.

C. Model Training and Optimization

The YOLOv8 nano model was selected due to its balance between speed, accuracy, and computational efficiency, making it ideal for deployment on Raspberry Pi 5. The model was trained with a confidence threshold of **0.7** to **reduce false positives** while maintaining a high recall rate. Continuous evaluation against a validation set ensured that the model maintained high precision.

D. Software Implementation

1. Object Detection module

The system leverages the OpenCV library for image processing and utilizes the Ultralytics YOLOv8 model for object detection. The YOLOv8 model processes the video feed, detecting plastic bottles and outputting bounding boxes and confidence scores. The detection algorithm prioritizes objects with a confidence level exceeding 0.8, ensuring high reliability in bottle identification. The object detection code incorporates visual feedback by drawing bounding boxes around identified objects and marking centroids for reference.

2. Vision-Based Navigation System

1. Central Alignment Logic:

The system computes the centroid of the detected bottle and calculates its offset relative to a predetermined target coordinate (i.e., the centre of the camera frame).

The robot navigates towards the detected bottle using an error-correction approach:

- The **target position** is set at the center of the camera frame (TARGET_X = 320).
- The **offset error** is calculated as error_x = cx - TARGET_X, where **cx** is the detected object's centroid.
- A **"deadzone" threshold (±30 pixels)** is implemented to avoid unnecessary minor adjustments.

2. Motor Control Algorithm:

The Python code utilizes gpiod library for GPIO manipulation. In the motor control segment, GPIO pins are configured to drive the motors in specific directions (forward, left, right, stop) based on the detected error between the target and current bottle position.

- Depending on the offset error:
- **Left movement:** If error_x < -DEADZONE, the left motor moves anticlockwise, and the right motor moves in clockwise direction which propels the robot leftward.

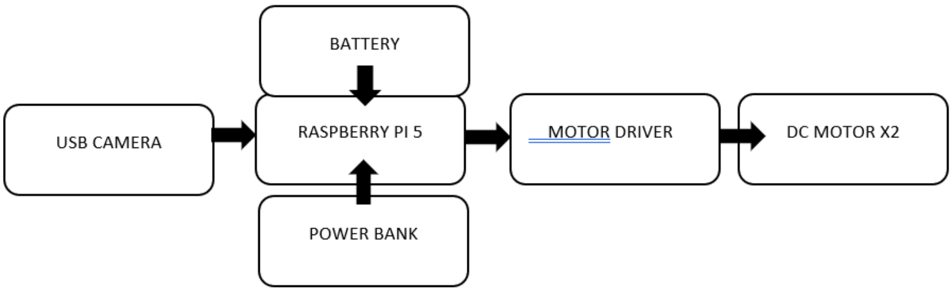
- **Right movement:** If error_x > DEADZONE, the right motor moves anticlockwise, and the left motor moves in clockwise direction which propels the robot rightward.
- **Forward movement:** If |error_x| ≤ DEADZONE, both motors drive forward.
- **Stop condition:** When the object is within collection range (TARGET_Y = 430)

This logic is implemented using **GPIO control and PWM (Pulse Width Modulation)** to dynamically adjust motor speed.

E. Hardware Integration

The robot chassis features two PVC pontoons for stability and buoyancy, allowing reliable operation on varied water surfaces. A Raspberry Pi 5 module interfaces with a dedicated motor driver, which controls the speed and direction of the DC motors via GPIO lines. A forward-facing camera, mounted on the robot, captures real-time video that is processed for object detection and localization. A centrally attached waste bin is integrated into the structure at the rear to collect and store the detected waste. Two DC motors are mounted on opposite sides of the robot, each coupled with a 3D-modeled shaft structure. This assembly provides the necessary propulsion and steering capabilities.

5. WORKING METHODOLOGY



The AQUACLEANBOT system integrates hardware and software to autonomously detect and collect plastic waste from water surfaces. At its core, a Raspberry Pi 5 continuously captures video through a high-resolution USB camera, which feeds real-time frames into the YOLOv8 nano object detection model. The model identifies plastic bottles with a confidence threshold of 0.8 and outputs bounding boxes around detected objects. The centroid of the largest bottle is computed, and both the horizontal and vertical offsets—calculated as error_x = cx - TARGET_X and error_y = cy - TARGET_Y respectively, where TARGET_X and TARGET_Y denote the center of the camera frame (set to 320 and 430 pixels)—are used to guide navigation. A predefined deadzone of ±30 pixels is implemented to filter out minor deviations. If the horizontal offset exceeds the deadzone, corrective commands are issued to rotate the robot left or right using PWM-driven DC motors, managed via the gpiod library and motor driver. When the horizontal error falls within acceptable bounds, the system then evaluates the vertical offset: if error_y is significant (i.e., greater than the deadzone), indicates that the target bottle is either too far or not properly aligned along the vertical axis, prompting the system to advance until the error_y falls within an acceptable range. The robot advances forward, thereby aligning itself properly to approach the waste for collection. When both error_x and error_y are within their respective deadzones, the robot is deemed to be correctly aligned, and it stops to allow the bottle to be collected into the detachable waste bin.This integrated feedback loop of continuous visual monitoring, error calculation in both horizontal and vertical axes, and adaptive motor control ensures that the AQUACLEANBOT effectively navigates toward and collects waste, even under dynamic water conditions. Extensive calibration in controlled environments and subsequent field trials have refined these processes, enhancing detection accuracy and navigational precision for reliable autonomous operation.

6. COMPONENTS REQUIRED

HARDWARE COMPONENTS:

Raspberry Pi 5

A single-board computer acting as the central processing unit of the system. It processes image data, runs YOLOv8 object detection algorithms, and manages navigation logic. Its computational power ensures real-time processing for efficient waste identification and movement control.

DC Motor

Provides the necessary propulsion and directional control to navigate the water surface with precision. Their reliable speed and torque control enable smooth maneuvering during debris collection operations.

Battery

Serves as the primary power source, supplying energy to all hardware components. The battery ensures continuous operation and supports the high-power demand of the Raspberry Pi, motors, and other peripherals.

USB Camera

Captures real-time video input of the surrounding environment. The camera assists in object detection and navigation by transmitting image data to the Raspberry Pi, where OpenCV and YOLOv8 process the visuals for waste identification.

Power Bank

Provides additional power to ensure stable operation of the Raspberry Pi and low-power components. This redundancy in power supply prevents interruptions in processing and extends the robot's operational time.

Motor Driver

Functions as the interface between the Raspberry Pi and the DC motors, controlling the speed and direction of each motor. It ensures precise motor control by converting low-power signals into the necessary high-power outputs for smooth operation.

PVC Pontoons

The floating structure consists of PVC pipes to enhance stability and buoyancy. These pontoons distribute the robot's weight evenly across the water surface, preventing tilting and ensuring smooth movement during operation.

3D-Modeled Shaft

A custom-designed propulsion component optimized for transferring mechanical energy efficiently. Its 3D-modeled design minimizes energy loss and ensures smooth, effective movement across the water.

SOFTWARE COMPONENTS:

Anaconda Navigator

A Python and R-based open-source distribution for scientific computing. It provides a GUI for managing environments, dependencies, and libraries, facilitating the seamless integration of machine learning models and data processing tools.

Jupyter Notebook

A web-based interactive coding environment supporting live execution of Python scripts. It is used for training and testing the YOLOv8 model, analyzing object detection results, and visualizing data from onboard sensors.

OpenCV

An open-source computer vision library used for image processing and analysis. It enables functions such as object detection, image filtering, and edge detection, allowing the robot to navigate and recognize floating waste in real-time.

Ultralytics YOLOv8

A deep-learning-based object detection and classification model. It provides high-speed and high-accuracy detection, enabling real-time identification of waste objects in water, ensuring precise and efficient cleaning operations.

7. RESULT

The AQUACLEANBOT system was developed and tested for real-time plastic bottle detection and collection in water bodies. The integration of the YOLOv8 model with a USB camera enabled efficient object detection, achieving an accuracy of over 90%, ensuring precise identification of plastic bottles under varying environmental conditions. The DC motor-driven propulsion system facilitated stable and controlled navigation, allowing effective movement across water surfaces. The detachable waste collection bin demonstrated efficient waste retrieval and storage without compromising buoyancy or system stability. The Raspberry Pi 5 provided reliable computational support, processing object detection and navigation tasks in real time. Experimental results confirmed the system's ability to detect, approach, and collect floating plastic bottles with high efficiency. The results demonstrate that AQUACLEANBOT is a cost-effective and scalable solution for plastic waste removal in aquatic environments, reducing manual intervention and improving efficiency in water pollution management. Future improvements in detection algorithms and navigation control can enhance system performance for large-scale deployment.

8. SCOPE AND RELEVANCE

The AQUACLEANBOT presents a scalable solution for automated plastic waste removal from water bodies, with potential enhancements for improved efficiency and adaptability. Future developments include expanding YOLOv8 detection capabilities to identify multiple waste types and integrating an improved waste collection mechanism to enhance retrieval efficiency. To improve operational autonomy, energy-efficient battery management can be integrated, ensuring longer deployment periods without frequent recharging. Solar-powered operation could extend runtime, promoting sustainability, while IoT-based remote monitoring would enable data collection for pollution tracking. For broader deployment, GPS-based path planning can improve coverage in large water bodies. This project addresses the critical issue of water pollution by automating the removal of plastic waste, contributing to cleaner and healthier aquatic ecosystems. By reducing human intervention in hazardous areas, it enhances safety and efficiency in cleanup operations. The use of cost-effective materials promotes sustainable practices in technology development. This automated approach can revolutionize waste collection, making it more cost-effective and environmentally responsible.

9. CONCLUSION

The **AQUACLEANBOT** presents a significant step toward autonomous and efficient plastic waste removal from water surfaces, addressing a critical environmental challenge. By leveraging computer vision and real-time navigation, the system effectively detects and collects floating plastic waste, demonstrating high accuracy and reliability in controlled environments. The project contributes to sustainable waste management solutions, aligning with global efforts to reduce plastic pollution and protect marine ecosystems. Its scalability and adaptability make it a promising candidate for deployment in urban water bodies, industrial sites, and large-scale environmental cleanup operations. Future enhancements, including multi-waste detection, and solar-powered operation, will further improve its effectiveness and applicability.

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