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Automated Debris Interceptor

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Abstract: An automated plastic collector is a robot that gathers waste, such as plastics along with organic materials, found on pavements. The brain of the proposed system is the Arduino Uno R4 Microcontroller, which handles the operation of the ESP-32 camera model, robotic arm, 2200mAh battery and IR-sensor. with this system, the motor along with the sensor is initialized followed by the ESP-32 camera capturing the image and it is stored in the dataset which has been trained by the ML model. If the material identified is not plastic then the arm will grab it and place it into the non-plastic container (which will be referred to as organic waste). If the material can be identified as plastic then the robot place it into the plastic container. In the case of an obstacle detection by the ultrasonic sensor, the automated plastic collector will avoid the obstacle and continue on its path. This process involves utilizing software tools EDGE-IMPULSE to train the model, AURDINO-IDE to merge the sensors with actuators and also enabling tests of the trained model in GOOGLE COLLAB using the YOLO-V8 model.

Keywords: ***IoT, Automated debris interceptor, ESP32-CAM,*** **Arduino R4 minima,** ***Edge Impulse, Plastic Detection, Ultra sonic sensor,***

I. INTRODUCTION

Plastic pollution has become a global crisis, threatening ecosystems and human health. The ubiquity of plastic, combined with its resistance to natural degradation, has led to a massive accumulation of waste in landfills, oceans, and natural habitats. The traditional methods of waste collection are often inefficient, labor-intensive, and fail to address the widespread dispersal of plastic debris, especially in hard-to-reach areas[1]. This project, the automated plastic collector, seeks to provide a technological solution to this pressing environmental challenge.

The Automated Plastic Collector is designed to autonomously detect, collect, and store plastic waste utilizing a three-part process consisting of sensing, actuation, and control. More specifically, the system serves as a proof-of-concept for a scalable and intelligent solution for waste management[2]. The robot applies a variety of sensors to achieve reliable object detection. The ESP-32 camera model provides a high-level visual input that enables the use of computer vision algorithms to categorize one or more plastic items from other environmental elements, such as rocks or foliage[3]. This visual information is important for recognizing and targeting plastic items when the robot approaches. At the same time, an IR sensor acts as a proximity sensor, providing real-time distance information to avoid collisions and to confirm that something is within the robotic arm's grabbing range[4]. Once a plastic object is identified, the robotic arm is activated. The robotic arm, which is powered by servo motors, is capable of executing a predetermined series of movements where it extends and then retracts to grasp the plastic object[5]. The important aspect of the arm is that it was designed knowing that plastic debris comes in different sizes and shapes. After the robot collector grasps the plastic while extended, the arm retracts and deposits the item into an onboard container for storage before later disposal[6]. The core of the system is run by a control system that can pull all of the information connected to the various sensors and motors. The entire system is controlled by the ArduinoR4 Microcontroller[7]. This board's enhanced processing capabilities allow it to handle complex sensor data, execute computer vision algorithms, and precisely control the multiple servo motors of the robotic arm. The 2200mAh battery provides the necessary power to run the microcontroller, sensors, and motors, ensuring extended operational time[8].

The need to tackle the global plastic pollution crisis, which is a disastrous threat to our environment and public health, is what drives the development of an automated plastic collector robot. Each year, more than 20 million metric tons of plastic litter are generated, while manual collection and sorting practices are ineffective in handling the sheer volume and complexity of the plastic waste stream[9]. This failure of manual sorting methods has plastic caught in drainage systems causing health and environmental hazards, wildlife ingesting or getting tangled up in plastic, and plastic breaking into micro-plastic litter, which is now found in our food and drinking water. An automated robot that incorporates components of artificial intelligence and computer vision offers a step-change solution to manual sorting processes, by delivering high speed, accuracy, and consistency in sorting, improving both the quality and economic value of recycled materials. Automation in this process improves the experience of human workers working in hazardous conditions and also mitigates long-term labor shortages in waste management due to wage disparity. In summary, this technology is an important innovation towards clean and smart cities, as well as moving towards an effective circular economy[10].

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II. METHODOLOGY

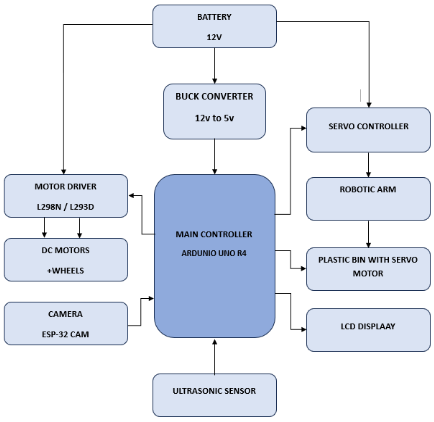

Figure 1: Block diagram

The system that you have presented is an overall Automated Debris interceptor which operates independently with its transfer of its obvious action in the block diagram and the action logic in the flowchart. The complete system obtains overall power from a single Battery (11.1V). This Battery is the base power supply for all sub-systems including high power actuators and low power control electronics[11].

The output of the battery is divided and fed directly to the Motor Driver. The Motor Driver is important since it will amplify the control signals to provide the necessary current and voltage to the DC Motor Wheels which ultimately is responsible for the robot's navigation speed, direction, and stopping as directed from the central processing unit[12]. At the same time, the battery output voltage, still at a raw voltage, will be transferred to a Buck Converter (12V to 5V) which again drives the need to step down the voltage to a stable output power of 5V. No percent of available battery voltage is 100%. to assuring the secure and dependable use of sensitive electronic components[13], such as the Arduino R4 Minima microcontroller and the Ultrasonic Sensor.

The Arduino R4 Minima serves as the brain of the system, performing the multi-step control logic displayed in the flowchart: interpreting sensor input from the input sensing modalities, controlling the robot's movement through the motor driver, and controlling the collection and sorting sequence of the system[14]. To be aware of the environment, the system utilizes primarily two input sensing modalities, including, (1) the ESP-32 CAM including the video feed necessary for debris detection, helpful to understand where the system needs to go to get the debris, and (2) the Ultrasonic Sensor, the continuous distance measurement calculated to relay information back to the Arduino for obstacle avoidance and navigation through the operational environment. Once the object(s) is detected, the Arduino activates the mechanical subsystem and sends control signal(s) to the Gear Motor which produces the necessary torque to actuate and prepare the Robotic Arm. Then the arm preforms the physical pick and place to pick up the debris. After any debris has been picked up the system will sort the debris using an implicit model (i.e. see "if plastic?" in flow chart) to material type[15]. In the block diagram the illustrated output flow is shown. the arm action ends once the debris is deposited into the Plastic Bin, indicating its role as a primary sort, although the flowchart indicates a separate bin for non-plastic materials. This integrated unit - which combines power electronics, intelligent control, visual and proximity sensing, and robotic action - creates a sophisticated closed-loop system for continuous and autonomous debris collection and initial material sorting[16].

III. IMPLEMENTATION

The implementation is explained using flowchart which outlines the ongoing operational cycle of an autonomous robotic system built for object detection, picking, and material sorting. The sequence starts with the Start terminal, quickly moving into the Initialization phase. This step is critical because it powers up and calibrates the main hardware components the camera for visual input, the robotic arm for manipulation[17], and the motors for movement. This prepares the robot for its tasks.

After successful initialization, the robot enters its main locomotion state, directing the motors to move forward. This action engages the active search phase, leading to an important decision point if an object is detected. If the camera finds no object in its field of view, the process loops back to the Move forward command, keeping the search continuous[18]. However, if the detection system confirms an object has been found, the robot stops moving forward to start the manipulation sequence.

This sequence begins with the Arm pick and place operation, where the robotic arm activates to securely grasp the detected item, lift it, and prepare it for sorting. Once the object is secure, the system must perform its sorting logic, presented as a second decision point: if it is plastic? This shows that the robot has some kind of material identification sensor, possibly attached to the camera or the arm gripper[19]. If the material sensor indicates No, confirming the item is not plastic, the robot places the object into the non-plastic bin. If the result is Yes, confirming the item is plastic, it directs the object to the plastic bin.

After sorting, regardless of which bin is used, the robot moves to the Resume movement state. This signals its return to search duties. Right after resuming, the system reaches a third and final decision point for navigational safety: to check for obstacles. If this check finds an obstacle, indicated by a Yes output, the robot must perform an avoidance routine by instructing the motors to change direction. After changing direction, it connects back to the initial Move forward search command, avoiding the detected obstacle and continuing operation. If the obstacle check returns No, meaning the path is clear, the robot simply commands itself to continue forward. This successful continuation loops directly back to the initial Move forward command, ensuring the system operates continuously, always searching, detecting, sorting, and navigating its environment[20]. This entire structure represents a self-sustaining and repetitive cycle vital for autonomous operation in automated material recovery facilities.

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IV RESULTS

Automated Debris Interceptor is a robot that helps in cleaning the waste materials along the roadsides. The main parts of the proposed system are Aurdino Uno R4 Microcontroller, ESP-32cam model, and the robotic arm. In this system, all the sensors along with the motor are initialized, then the image is captured using ESP-32cam, and the captured image is stored in the dataset trained by the machine learning model. If the detected item is plastic, the arm picks it up and places it in the plastic container. If the detected item is a non-plastic, the arm will pick it and place it in a non-plastic container. In case an obstacle is detected by the ultrasonic sensor, the robot avoids it and moves forward[21]. The software tools that are used here are edge-impulse to train the model, arduino r4 minima to connect sensors with actuators, and google-colab is used to test the trained model.

Figure 2: Integration of hardware

1. Plastic detection

It all starts with the robot turning on all its essential parts, such as the camera, arm, and drive motors. The main function is a loop of the robot's actions and its response to the environment, which is the move forward command at the very beginning. While the robot is on its way, its sensors are looking all the time for the object detection condition. If the sensors don't detect an object, the movement is still going on, thus the robot is exploring its surroundings[22]. As soon as a target is identified, the robot stops moving forward and the arm is sent out to perform the initial arm pick and place This is followed by the final classification step, which is embodied by the critical if plastic question, material identification for separation purposes.

Figure 3 : Plastic detection

2.Bot Adjustment::

Bot adjustment includes the reactive and corrective motions the robot does to keep the process going and ensure safety. Once the job of depositing a piece of waste has been accomplished, the system tells the robot to resume its movement and continue working. Right after this resumption, the robot's navigation logic also makes an obstacle check. When the way is clear, the bot is given the instruction to move forward along the current path. But if the sensor shows that the way is blocked, the adjustment mechanism will be turned on. The robot will have to carry out a change the direction command to get around the block and then come back to the main loop[23].

Figure 4: Bot Adjustment

3. Robotic arm locomotion

Arm locomotion focuses on the exact mechanical operations through which the robot is required to manage the waste item that has been detected. The whole event is like a firework that is set off at the very moment an object is detected, thus, the complicated Arm pick and place operation starts. The action is the arm being stretched out, the object getting a controlled grip and the arm being brought back to a place where it is able to perform material analysis. Upon classification, the arm is henceforth reactivated to carry the object to the depot. The arm's last movement is the event that guarantees the item is safely put into the corresponding container namely the plastic bin or the non-plastic bin[24].

Figure 5: Robotic arm locomotion

4. Segregation of waste:

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Figure 6: Segregation of waste

Segregation is the stage of the decision-making process that focuses on how the waste that has been classified is going to be properly sorted into different streams. The segregation is a direct consequence of the material analysis and it is therefore represented by the "if plastic" decision block. In the case where the sensors of the object confirm that the item is plastic, the system issues the command to the robot to put the item into the plastic bin. In contrast, if the object is made of any other material, it is considered to be a non-plastic one. Consequently, the instruction given in this case is to store the waste in the non-plastic bin, thus the waste types being successfully separated[25].

5. Ultrasonic obstacle detection:

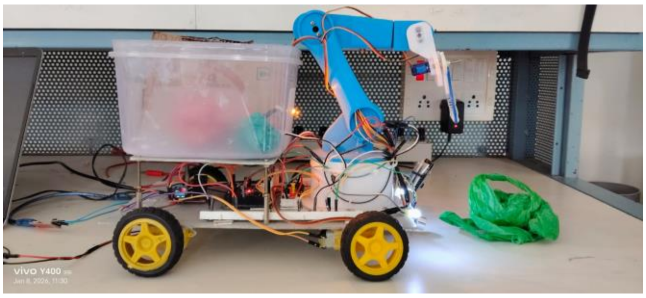

Figure 7: Ultrasonic obstacle detection

Obstacle detection is a crucial function that enables a robot to keep itself safe and to have a smooth movement of large-scale within its environment. The block checking for obstacle usually stands for the input of a distance sensor such as an ultrasonic sensor. This checking is done in advance, i.e. it is not performed if the robot has already decided to go on with a major movement of resumption. In case there is no obstacle on the way, the robot is allowed to go ahead with the movement. If the sensor finds that forward movement is obstructed, then such motion is stopped immediately[26]. The robot makes sure the change the direction command is the next one to be executed in order to maneuver around the obstacle and continue its safe journey.

CONCLUSION

The system represented by the block diagram and flowchart below constitutes a complete and workable Automated Debris Interceptor for autonomous operation in environmental cleanup and preliminary waste sorting. The architecture is centered on the Arduino R4 Minima, acting as the central control unit that executes the entire operational logic, including sensory data interpretation, navigation control, and robotic arm actuation. Powering the whole unit is the Battery at 11.1V, its output astutely managed by a Buck Converter of 12V to 5V, providing the required low-voltage, regulated 5V power supply to the critical logic components and sensors, while the higher voltage feeds into the Motor Driver to drive the DC Motor Wheels efficiently[27].

The robot's intelligence comes from the integrated sensors: the ESP-32 CAM provides essential visual data in the object detection phase, thus enabling the system to identify debris, while the Ultrasonic Sensor is imperative for non-contact distance measurement, therefore allowing for robust obstacle avoidance during the movement. These sensors enable the robot to navigate safely and effectively through the operating area. Once an object is detected, Arduino sends a signal to start the collect sequence, including a signal to the Gear Motor, which powers the Robotic Arm to execute the precise pick and place operation[28].

The system implements material segregation, an important aspect of waste management. The robot, according to the "if plastic?" decision as depicted on the flowchart, segregates the type of material. The block diagram shows that the gathered debris is deposited into the Plastic Bin, further confirming that the robot segregates the recyclable material at its source. The system, from the flowchart, has been designed as an ongoing cycle such that upon handling the object and resuming movement, it still checks for obstacles and changes direction before going back to the Move forward and search state[29]. This is a closed-loop flowchart which ensures that the robot remains highly autonomous with high persistence for the task assigned to it. Basically, this project details a technically feasible solution that integrates sensing, locomotion, and manipulation in collecting debris efficiently and sorting it automatically, hence offering a scalable model for modern environmental robotics[30].

IV. ACKNOWLEDGMENT

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence that is already publicly available.
Availability of Data and Materials	Not relevan
Authors Contributions	All authors have equal participation in this article

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