Ecobot: Autonomous Trash Collection and Segregation System

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Abstract: The rapid growth of urbanization, economic development and population has led to a significant global garbage crisis, causing severe environmental and health issues. Traditional waste management systems struggle to manage the increasing volume of waste effectively. This paper presents an innovative solution; an autonomous trash collection and segregation system designed to operate within defined areas. Utilizing robotics and machine learning, the system is built around a Raspberry Pi to navigate autonomously, collect garbage and segregate waste efficiently. This system aims to enhance the sustainability and efficiency of waste management practices, aligning with global efforts towards smart cities and technology-driven improvement in quality of life.

1 INTRODUCTION

The exponential increase in waste generation due to technological advancements and changing lifestyles has created a pressing need for efficient waste management systems. Ineffective waste disposal contributes to environmental pollution and health hazards. Existing solutions, such as trash segregators and collectors with predefined navigation, address the problem partially but often lack the ability to integrate collection and segregation seamlessly. To bridge these gaps, we propose an autonomous garbage collection and segregation system designed to operate in predefined areas such as indoor floors, pathways, and other controlled environments. This system leverages modern technology to collect and segregate trash efficiently, providing a sustainable solution to an age-old problem and supporting smart waste management initiatives.

2 LITERATURE SURVEY

The paper (Sengupta et al., 2019) proposes an autonomous system whose navigation can be controlled by the regional corporate office through a website or an application. The robot identifies the filled trash bins, lifts it, empties the bin and replaces a new bin in the spot.

The paper (Bharathi et al., 2018) explains how the authors build a trash collecting robot. The robot first detects for an object during its run using sonar. The picture of object is then captured for detection as a trash or not with DNN algorithm. The object detected as trash is picked up and dropped into bin.

The paper (Jinquiang et al., 2018) presents another method of trash collecting set-up. The object detection is done using ultrasonic sensor. The image captured by pi-cam is sent to server via TCP/IP protocol, being a client. The server uses Fast ANN algorithm to classify the object as a garbage or not, and according the robot picks it, else follows the path.

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The paper (Parashar and Tomar, 2018) has a moving bin that takes a pre- defined path and stops at every house bin. They use RFID technology for communication. If house bin is detected full through ultrasonic sensor, its opening mechanism puts out the trash into moving bin, else moving bin moves forward. The paper (R and V, 2018) uses a GPS, vehicle odometer and IMU sensor for robot location status. The path-planning, image-processing and obstacle detection are all performed by CPU. Trash classification is done by GPU. CPU controlled manipulator picks the trash and driver controls motors. The paper (D et al., 2018) has a moving bin that collects the garbage from the house bins notified by IR sensor in the house bin. Both bins communicate through RF signal, controlled by Arduino. The moving bin moves on pre- defined path; it collects the trash and dumps it to the dumping station. In the paper (Varuneshreddy and Nikhil, 2018), the robot is a trash can-collecting system that takes a designated path. The robot differentiates a can when its breadth is found less than specified breadth using IR sensor. The 2-DOF arm picks the trash and dumps it in the bed. The paper (Ulu and Radha, 2017) gives the information about a trash collector designed for beaches. It uses an IP camera for object detection with PIC.

3 PROPOSED FORMULATIONS

The existing situation of waste management is lagging behind in consideration to the amount of waste generated. Moreover, the involvement of workers in the garbage collection, transportation and other operations increase the rate of risking their health. There also exists another drawback that, the waste at places with untidy environment cannot be cleaned by creating threat to human health. The post operations in garbage management, segregation is also a tough task without proper co-ordination and response from individuals. Therefore, it is now important to include and expand the technological factors in the matter of waste management in all aspects, along with addressing the issues.

3.1 Garbage Detection

The system is structured in such a way that the camera locates the trash on its way of navigation. This task is performed with the help of ML algorithm and image processing, by classifying objects and trash on the path.

3.2 Garbage Collection

The system on identifying trash on path, it moves towards the trash and picks it up using a robotic arm.

3.3 Garbage Segregation

The same system while capturing the frame of trash, uses the algorithm and image processing technique to decide whether the trash detected is biodegradable or non-biodegradable. The arm accordingly makes its movement and drops the trash into the respective trash bin.

3.4 Autonomous Navigation

The robot is capable of making self - navigation movement with the help of GPS (Global Positioning System) and magnetometer on most of the hard land regions with single initial positioning definition and no human intervention.

4 METHODOLOGY

The Raspberry Pi (Raspberry Pi 4 Model B) microcontroller is the main task controller for the whole system. The system first starts its movement from the initial position set with help of GPS. The robot then continues its motion in the forward direction with help of GPS and magnetometer. The system ensures to avoid obstacles using ultrasonic sensors placed in front. The model continues its motion otherwise. All the movements of the robot are assisted by the Steering and DC motors. The model on its way of motion, examines for any kind of object nearby using the Pi- Camera. If an object is detected, the Pi-Camera sends the image to the Raspberry-Pi. The ML algorithm of trash identification available on the microcontroller checks for whether the object detected is a trash or not. If the object is found to be a trash. The algorithm further performs classification to recognize whether the trash is a biodegradable or non-biodegradable one. These inputs from Pi-Camera can be sorted as trash identification data and trash categorization data. The Raspberry Pi uses the data of trash identification data to decide the motion of the robot towards trash.

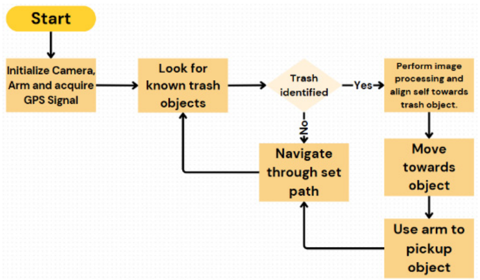

Figure 1: Flowchart of working.

The model makes turn in order to place the trash image to the center of the frame of the Camera and then moves towards trash and stops at a certain distance from the trash.

The trash categorization data determines the arm movement. The arm picks the trash and makes a left or right turn in the backward direction to drop the garbage into respective bin. The robot then comes back to its position from where the trash was detected and makes its forward movement. If the object detected is not found to be garbage, the model moves on the region for frontward motion.

The robot makes turns with the data input from GPS and magnetometer. So, to sum it up the 12v battery is the main powering unit for all the components in the system. The 12v is stepped down to 5v to power the raspberry pi and servo motors used for various applications. The GPS module and magnetometer supplied navigation of the system. They provide the input data to the raspberry pi directly based on which decisions for movement are taken.

The pi camera provides the images of the surrounding objects for trash identification. This task is done with the help of the ML model developed. Based on all these inputs the raspberry pi provides the instructions to the motor driver and the arm serves according to which DC motors and arm performs their operation of motion and object picking.

4.1 Circuit Description

The complete system is programmed using the python programming language. The Raspberry Pi (Raspberry Pi) is powered from the battery via a buck converter (XL4015) with 5V. The antenna affixed GPS module is connected to the microcontroller through Vcc-5V, Gnd-Gnd, Tx - Digital pin, Rx - Digital pin (GPS-Raspberry Pi). The module uses UART communication to feed the data into PC; that it received via RF signals. The magnetometer uses I2C protocol for communication with the Raspberry Pi 4B.

The obstacle detection component ultrasonic sensor uses the Trig and Echo pin to share data accordingly with Raspberry Pi. The Pi- Camera shares the data using CSI (Camera Serial Interface) with Raspberry Pi. The connection includes the plug in of the 15- pin ribbon cable to the CSI port of Raspberry Pi.

Ultrasonic sensor is also used for object detection. The picking mechanism of the system includes robotic arm which is directly controlled by Raspberry Pi data signals. The rotation of the servos in the arm decides the arm motion. The decision of the rotations is made concurrently by the Raspberry.

The servos are powered with 5V via buck converter (XL4015). The movement managing system includes 12V DC motors which are driven through L298N DC motor driver. The driver is powered directly. The model movement is controlled by the Ackermann steering as well. The MG995 servo motor of the steering receives the signal from Raspberry Pi. The ML algorithm provides the assistance for trash detection and segregation.

5 WORKING OF MODEL

The above image gives the flow chart for the algorithm based on which the ML model used in the system is developed. This flow chart explains the method of navigation and trash collection performed by the system. The robot is powered up for its start. This enables the arm, camera and the navigation system. The initial position of the system is noted with the help of the GPS module (via RF signal). The robot makes its movement for detection of trash.

If the trash is identified the robot aligns itself to bring the trash to its center frame and moves towards the trash. The robotic arm then picks up the trash and drops it into the respective bin. The system comes back to its position and moves along the set path continuing the trash detection task. If the trash is not detected by the robot, it would continue its motion on the set path for performing the trash detection task.

The whole system working can be divided into different parts:

(i) Control Unit

The whole system is controlled with the Raspberry Pi 4B model. The microcontroller performs all the tasks of data collection, data analyzation decision making and motion control of

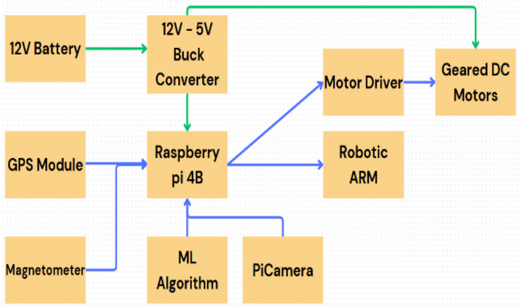

Figure 2: Block Diagram of Circuit.

the robot. It also controls the movement of the arm picking mechanism.

(ii) Powering Unit

The system is powered by a 12V 4.5Ah Sealed-Lead Acid rechargeable battery. The step down of the voltage is done from 12 – 5V for powering the Raspberry Pi and robotic arm using XL4015 5A DC-DC Step Down Adjustable buck converter. The motors driver of wheel motors is powered with 12V directly from the battery.

(iii) Navigation Module

This arrangement includes Neo 6M GPS module, HMC58831 magnetometer along with Raspberry Pi. Predetermined path set up using waypoints. The robot starts at its initial location, acquires its current location using GPS module and calculates the angle it needs to travel for the next waypoint. Then turns itself in the required direction and moves forward. The HMC5883L magnetometer module is used for the accurate directions with respect to earth's magnetic field.

(iv) Steering mechanism and motion control

The movement of the system is aided by two 12V DC motors and the Ackermann steering technique. The motors are of rating with 100 rpm which are driven by L298N DC motor driver. The turns made by the model is controlled through the steering. An MG995 servo motor is used for steering movement.

(v) Obstacle Detection

The obstacle detection is done using two ultrasonic sensors placed at the front ends of the robot on either of its sides. A signal indicating the obstacle detection commands the steering turns through Raspberry Pi.

(vi) Trash detection

This process is encountered by Pi-Camera along with ultrasonic sensor and Raspberry Pi. The camera reads images 640x480 pixels. This image is first pre-processed to bring out tinier details of the image and then given to a customer thrash detection model. The model returns category name and a bounding box around the trash object the trash is identified.

(vii) Picking mechanism

The trash picking function is performed by the robotic arm and directed by the Raspberry Pi. The arm has four joints with 5-DOF motion. It consists of three MG995 and three SG90 servo motors.

(viii) Trash segregation technique.

The hardware required for this task is Pi- Camera and Raspberry Pi Supervised by the ML algorithm. The ML model can make segregations between biodegradable and non-biodegradable garbage. Once the model returns the category name, the result if more than a threshold then it is classified into respective category.

(ix) Model Training

The model used for detecting and segregating trash was trained by retraining a pre-trained model. Retraining machine learning models is the process of updating a pre-trained model with new data or adapting it to new conditions. This process ensures that the model stays accurate, relevant, and performs well in changing environments. Around 500 images of each class were clicked in different backgrounds and lighting conditions. The images were labelled and arranged in the COCO dataset format.

The model architecture chosen for retraining was MobileNet-V2 which is a Convolutional Neural Network by Google designed to run on low-end devices. It is commonly used for tasks like image classification and object detection on mobile and other edge devices.

The hyperparameters set for the training process were input size of 256x256 pixels, a learning rate of 0.3, batch size of 8 and a total of 30 epochs. The training was done on Google collab server using a Nvidia T4 GPU runtime. The post training evaluation results were obtained as validation loss of 0.23. The model was then exported in tflite format file.

5.1 Robot Movement and Function

Robot acquires its current location and it's heading direction. Camera looks for known trash objects, if any are found then using open cv library the robot locates the object in the frame and tries to center the object in the frame by steering itself. As the robot is approaching the object its size in the frame starts to increase.

The size on reaching a preset threshold the ultrasonic sensor come into action and precisely measure the distance to the object. When this distance becomes equal to the reach of the arm, the motors stop. Now the arm reaches for the object and picks it up and puts it in the appropriate bin.

5.1.1 Trash Detection

Resize the frame and convert it to RGB. Use MediaPipe's object detection to identify trash objects. Draw bounding boxes and label detected trash items. Display or save the annotated frame with detected trash. Implemented logic to classify the detected trash into categories like biodegradable or non-biodegradable.

5.2 Comparative Analysis

The system in (R and V, 2018) performs the trash collection task only on grass whereas the proposed system can perform the trash collection on various types of hard lands.

The robot in (Bharathi et al., 2018) follows a pre-defined path and picks up the trash present only the path of movement. The developed system detects the trash away from the set path and also collects those trash objects.

The presented robots make its movement based on the path following technique or wall following technique, while this robot makes the path decision using GPS mode without the requirement of laying the path on the floor for every region or availability of bounded area. The existing projects only ensure the garbage collection neglecting its segregation. The present system collects and trash and also segregates them spontaneously. The presented robot does not require any human intervention between its start and stop operation.

6 RESULTS

Figure 3: Final Working Robot.

(i) Trash detection

The trash is detected using ML algorithm with an accuracy of 98 to 100 percent.

The task of trash detection is completely handled by the Machine learning model that is been build up. The task is supported by Pi- camera operation.

Figure 4: Trash detection and movement towards trash.

(ii) Trash classification

Trash that is completely non- biodegradable like plastic material are detected as non-biodegradable. The trash that is capable of getting decomposed like fruit peels and paper are identified as biodegradable material.

Figure 5: Biodegradable garbage identification.

(iii) Trash picking task

The arm is capable of picking up the detected garbage material with the instructions provided from the microcontroller based on the data given by Pi-Camera and ultrasonic sensor with ML training.

Figure 6: Picking of trash by the robot.

(iv) Model Training

The model is able to provide an output with the accuracy of 75.5%. The time gap between the command and the action of the system is recorded as 201ms.

Table 1: Benchmark results for model.

Average precision	Latency on Raspberry Pi 4B	Model Size
75.5%	201ms	12MB

7 CONCLUSIONS

The robot results as a system that is capable enough to address the issue of waste management efficiently from detection to segregation autonomously on numerous hard land types. The task of waste identification and classification is performed with use of camera only with the technology of ML and image processing without much hardware. This stands as one of the advantages in the system. The autonomous nature is another major plus factor for the model. The robot can be made robust for all find of lands and trash. The proposed system can be made versatile by incorporating other techniques few in number only. The use of IoT can make the robot a wirelessly accessible, locatable and manageable device. Bluetooth insertion could make it capable for manual handling and motion. This feature can be initiated with the use of radio frequency signal as well. Some structural changes of increased height can make allow for trash detection even on grassy areas. Some minor changes in tyre type, size and thickness can make the robot usable in rocky and sandy regions as well.

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