Gar-Bot: Garbage Collecting and Segregating Robot

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Abstract. This paper presents the design and development of the first prototype of an automated garbage collection robot (Gar-Bot). It operates efficiently in an indoor environment. Main functionality of the robot is to detect and classify the garbage into 3 types, and collect them in different bins. To efficiently use the space in the bin, plastics are crushed after collection. Gar-Bot uses convolutional neural networks implemented on NVIDIA’s Jetson Nano Developer Kit for garbage detection and classification. The IoT platform is used to notify the user with the status of the bin. The robot is equipped with a robotic manipulator, rotating bin for collecting garbage, Kinect V1, Processor and controller, and a base with wheels to facilitate navigation. The robot successfully detected and classified the garbage into various classes at an inference time of 5 seconds per frame, with an accuracy of 90 percent.

1. Introduction
With an increased population, and in the context of modern-day living, the requirements of supporting autonomous equipment are exponentially rising. In this regard, waste management plays an important role in the society today. Segregating the waste into different categories is a crucial step in the process. Another major issue that can be avoided is the work-related health hazards and safety issues of the refuse collectors. Municipality bodies collect the waste separately from homes and offices and send it for processing/disposal. The need of automated machines in this job has become a necessity as waste management is one of the biggest problems the modern society is facing.

Many automated robots are built to reduce physical labour in the process of collecting garbage, and several works have been reported in literature, but with their own demerits, needing improvements. For example, the inability of infra-red sensors to detect small sized waste materials [1], can be addressed utilizing vision sensors [2]. It has also been demonstrated that the Convolution Neural Network (CNN) based algorithms can be employed to identify garbage with higher accuracies [3].

The garbage detection part of Gar-Bot is implemented using a CNN model. The robotic manipulator is used to pick up the garbage, but to measure the precise location of the garbage for robotic manipulator, depth measurement is necessary. This is achieved using an RGB-Depth camera Kinect V1, using which, the robot is facilitated to get the x, y, z coordinates of the centroid of the garbage in space with respect to the base point of the robot with negligible error [4]. The open-source Robot Operating System (ROS) provides inbuilt libraries to extract 3-D images from the camera for further processing.

CNN model is trained to categorize the garbage into three categories namely Paper category (containing news paper, paper bags, tissues), Crushable plastic (containing water bottles and plastic-
coated tetra packs), and Non-crushable plastic category (containing plastic caps, single use carrier bags and polypropylene bags). The garbage collection bin is divided into three compartments to store the garbage based on its type. A 4th compartment is used to collect liquid waste when the bottles are crushed. A robotic manipulator which is equipped with a pneumatic suction cup on its moving arm facilitates garbage collection. This is further detailed in the third section of the paper. The object detection algorithm runs on NVIDIA Jetson Nano Developer Kit and the Robotic manipulator is controlled by Arduino. Mitsubishi PLC (FX5U 32M) is used for controlling motors required for rotation of bin and navigation of Gar-Bot. The parts of Gar-Bot are illustrated in the fourth section.

2. System Architecture
The system architecture of Gar-Bot is depicted in figure 1, and its functional elements are briefly explained in the following subsections.

2.1. Controller
The Mitsubishi PLC (Programmable Logic Controller) controls the movement of Gar-Bot and rotation of the bin. Ladder programming is used to program the PLC. Arduino Mega 2560 controls the servo motors in the manipulator. HMI (Human machine interface) communicates with PLC using Ethernet protocol for emergency controls and to display the status of the bins.

2.2. Processor
NVIDIA Jetson Nano Developer Kit is a small powerful computer which efficiently allows multiple neural networks to run in parallel. It has 4GB RAM, Quad-core ARM Cortex-A57 MPCore processor, and NVIDIA Maxwell 128 CUDA cores. The official operating system is called Linux4Tegra, which is a version of Ubuntu 18.04, designed to run on NVIDIA’s hardware. GPU is used for running object detection CNN [6] algorithm and CPU is utilized for collecting and communication of images.

2.3. Manipulator
The robotic arm is designed in a way to mimic the working of a human arm. The algorithm used to reach the garbage is obtained with the help of inverse kinematics.

2.4. Internet of Things (IoT)
Blynk application is used for notifying the user about the bin status. It acts as a platform to connect the user at a remote location to Gar-Bot. Some of the functionalities utilized by Gar-Bot are to control the hardware remotely, to display sensor data, to store data and visualize it. Here, data is referred to as status of bins that can be regularly updated. To establish internet connection, ESP8266 NodeMCU is used.

2.5. Sensors
Gar-Bot utilizes two types of sensors. Firstly, the UV sensors as level detectors for bins and to detect obstacles if any in the path. Secondly, Kinect, a 3-D vision sensor is used to get 3-D images and the camera is mounted on a rod to compensate for the blind spot. It uses structured light technique to map the depth and covers the range around 0.6 to 6 meters in indoor environments.
3. Object Detection
For implementation of object detection, Gar-Bot uses CNN [7], which is a class of deep neural networks, preferred for computer vision tasks. CNN is inspired by the connectivity pattern of the neurons in the human and animal visual cortex. Gar-Bot uses MaskRCNN [8] for obtaining the bounding box and it masks the detected object in the image.

Object detection [9] primarily refers to finding out the object classification and its localization. Gar-Bot uses the ResNet50[10] architecture which considers 50 layers, and the model is trained using pretrained weights from the COCO database [11]. Images for training were taken from TACO dataset [12], which has an image dataset of waste objects. TACO dataset has annotations provided in COCO format. Here, input image of the garbage to be segregated is taken from Kinect through the ROS [13] and is stored as frames in a file using OpenCV. With such image as its input, the image processing script outputs would be a mask, bounding box of the detected object and co-ordinates of the bounding box.

4. Mechanical Design
The main structural and mechanical components of Gar-Bot are detailed in this section.

4.1. Base - to hold all the components of the machine
The Base is made in the form of box using rugged plywood and is depicted in Figure 2. Its dimensions are chosen to be 500x500x130mm, adequate to hold all the electronic and mechanical components of Gar-Bot. Driven by a stepper motor, three wheels are used to move Gar-Bot towards the garbage.
4.2. Robotic Manipulator (5DOF) with a pneumatic suction cup to pick up garbage:
The robotic arm is 3D-Printed using Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). The arm links are made of ABS and the base had a mixture of ABS and PLA. A central rod supported with bearings is used to support the rotation of base. The angular motion of the arm is achieved using the Stepper motor fixed in the base, and a potentiometer to give accurate angle settings at which the base is oriented. The mechanical parts of Gar-Bot are over designed to pick up to 400g of weight at a time. The arms are controlled using two numbers of MG995 Tower Pro Servo Motors oppositely placed to achieve torque multiplication. The end effector suction cup is actuated by a 12-volt DC operated Suction Pump with an effective diameter of 30 mm.

With the given design, the robotic arm can approximately move in a range of 15 - 30 cm parallel to the ground (back and forth). The manipulator base is allowed to rotate at an angle of 30 degrees both to left and right while picking up the garbage and 360 degrees while dumping the garbage in the bin.

The Rotating dust bin is a single bin with 4 partitions made using sheet metal and fitted with a NEMA-23 motor for rotating. Figure 3 depicts the robotic manipulator developed in this work, with insets showing its components.

5. Workflow
The workflow to describe Gar-Bot’s operation is depicted in figure 4. As soon as powered, Gar-Bot starts moving in the straight direction. It stops if an object is detected under the specified maximum range of 15 cm. Image of the object is taken by Kinect and processed on the GPU of the NVIDIA Jetson Nano Developer Kit.
Figure 4. Flowchart adopted in Gar-Bot.

Start

Move Forward

Is object detected? No

Is waste detected? Yes No

Process the image & map the depth of the centroid

Is it paper? Yes No

Collect the garbage using manipulator & store in bin 1

Is it crushable plastic? Yes No

Collect the garbage using manipulator & store in bin 3

Turn on manipulator, crushing motor & store in bin 2

Update in the cloud

Is the bin full? No Yes

Stop
The object detection algorithm deployed in this work accurately detects the garbage if present and classifies the garbage into three categories as detailed in section-1. Based on the results, Gar-Bot will be taking four different actions, described next as four cases.

**Case 1 - No garbage is detected:**
The object is considered to be an obstacle. Information about obstacle detection is sent to PLC through Modbus Serial communication. PLC controls the motors for navigation and the robot takes 90 degrees turn [14] and starts moving in that direction. If the object is identified as garbage, using the bounding box generated by object detection algorithm, the centroid of the garbage is calculated as

\[
X = \frac{(x_{\text{bottom\_corner}} - x_{\text{top\_corner}})}{2} + x_{\text{top\_corner}} \\
Y = \frac{(y_{\text{top\_corner}} - y_{\text{bottom\_corner}})}{2} + y_{\text{bottom\_corner}}
\]

where, \((X, Y), (x_{\text{top\_corner}}, y_{\text{top\_corner}})\) and \((x_{\text{bottom\_corner}}, y_{\text{bottom\_corner}})\) are the coordinates of the centroid, upper left corner of the bounding box and of bottom right corner of the bounding box respectively.

Next, using the depth information collected by Kinect V1 the distance of centroid from the camera is mapped. The Developer kit sends the information about the type of garbage detected to PLC through Modbus serial communication. The \(x, y, z\) coordinates are sent to Arduino through the USB protocol. It is programmed to move the manipulator to pick the detected object. The bin is mounted on a Nema 23 motor which is attached to the centre of Gar-Bot’s base and controlled by PLC.

**Case 2 - The garbage detected is paper:**
Arduino drives the motors in the manipulator to pick up the paper and drop it in Bin1. When the manipulator comes back to its original position, PLC starts moving in the straight direction.

**Case 3 - The garbage detected is crushable plastic:**
PLC rotates the motor connected to the bin by 90 degrees right. Manipulator picks up the object and drops it in Bin 2. To crush the plastic inside Bin 2, a 12V DC motor is placed with a crusher and driven by PLC. When the crushable plastic waste is detected, PLC drives this DC motor. While entering the bin plastic gets crushed and settles at the bottom. Bin2 is designed with a metallic slope to separate liquid from the crushed plastic. The liquid is seeped below the slope which is the bottom part of Bin 2. Liquid flows to Bin 3 through a hole and gets collected there. The liquid can be emptied using the tap connected to Bin 3 when the bin gets full. Bin comes to its original position by rotating 90 degrees left.

**Case 4 - The garbage detected is non-crushable plastic:**
The PLC rotates the motor connected to the bin by 90 degrees left. Then, the manipulator places the garbage in Bin 4 and comes back to its original position. Bin attains its original position when PLC drives the motor to turn it by 90 degree right. When the rotated bin and the manipulator comes back to their original position PLC drives the navigation motors to move in the straight direction and the operation continues.

Level sensors are equipped in each bin partition and are monitored continuously. IoT platform is used to notify the user about the level of the garbage. If any of the bins get filled, the user gets an alert and Gar-Bot halts. After emptying the bins, Gar-Bot starts again.

**6. Results**
Gar-Bot successfully detected and classified the garbage into various classes with an accuracy of 90 percent, and collected them in the respective bins. The arm could pick up non-porous flat garbage. Inference time of the model is 1 frame per 5 seconds, which is found to be sufficient for the prototype designed. The figure 4 shows the picture of Gar-Bot developed in this work, process of classifying and
picking a plastic bottle, and the status of the collection bin, on Blynk application.

Figure 5. Final prototype of Gar-Bot.

7. Conclusion and future scope
The prototype reported in this work performed satisfactorily in classifying garbage. It employs integration of a range of hardware and software platforms. This model is capable of picking up 100-200gms of garbage. Future version of Gar-Bot is proposed to be designed to pick up garbage weighing up to 1Kg of weight. The next scope is to obtain more complex scene image data, so as to make its detection more robust and accurate. Also, the number of garbage items that can be detected by Gar-Bot can be increased. This project idea has very good scope with societal impact, when developed as a real autonomous model. Also, more focus can be given on Fire store distributed counters to add more real-time statistics such as zone-based daily and weekly stats per garbage types, to enhance its performance.

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