HARDWARE MODELING : GENERAL CHAMPIONSHIP 2022-23, IIT KHARAGPUR

A Small Scale Garbage Collection Robot

Contents

Abstract

In this project, we design a garbage collection robot that can navigate in an environment with obstacles and walls, accurately identify garbage and use its robotic arm to pick up the garbage and dispense it in a basket attached to the robot. The project involves developing a suitable mechanical design, creating the algorithm for the robot's operation and designing the corresponding circuitry. A prototype was built for two versions of the robot, one using ultrasonic sensors and one using image processing, and tested in various environments to demonstrate its deployability at homes, offices, hotels, parks, beaches etc. The proposed autonomous garbage collection unit provides an example of how automation can transform the field of waste management.

Introduction

Waste management is a significant challenge facing many societies, with the accumulation of waste materials leading to environmental pollution and health hazards. Traditional waste management methods are often inefficient and labour-intensive, leading to a need for innovative solutions.

Garbage collection robots are autonomous machines that have been designed to help in the management of waste by collecting and sorting waste materials. These robots can operate in both indoor and outdoor environments and can be programmed to perform specific tasks such as sorting recyclables, compacting waste, or moving waste to designated areas for pickup. They have gained popularity due to their ability to reduce physical labor, increase efficiency and accuracy in waste collection and sorting, and reduce the amount of waste that ends up in landfills.

There are many companies that are currently developing and manufacturing garbage collection robots, and the market for these machines is expected to continue to grow in the coming years. According to a report by Grand View Research, the global market for waste management robots is expected to reach $813.5 million by 2027, growing at a CAGR of 16.6% from 2020 to 2027.

This project indents to develop a programmable, self-guided, small-scale garbage collection robot that can be deployed at homes, offices and plain outdoor terrains like beaches, grounds, lawns and parks.

Problem Statement

The objective here is to design and develop a small-scale cost-effective garbage collection robot suitable for collecting waste materials in indoor and simple outdoor environments without needing human interference, ultimately improving waste management and promoting environmental cleanliness.

The bot should navigate an area with walls boundaries and other obstacles, rightly identify pieces of garbage, either using a camera(ie, image processing) or a combination of sensors and when identified pick them up using a gripper and collect them in a bin.

The proposed solution is to design and develop an autonomous garbage collecting robot that uses image processing techniques to identify and collect waste materials. The robot will be equipped with a camera and sensors to capture images of the environment and detect waste materials based on their colour, shape, and size. The robot will then use this information to navigate to the waste materials, pick them up, and collect them.

Project Definition

Two different solutions are proposed here based on the method of garbage detection. In version 1, trash detection is done using ultrasonic sensors while in version 2, a camera module is used. In version 1, using 2 ultrasonic sensor arrays, the dimensions of the object will be mapped and depending on the height and width, the bot can decide whether to go around it or pick it up. In version 2, the robot will be equipped with a camera to capture images of the environment and real-time image processing will be done to detect waste materials based on their colour, shape, and size. The robot will then use this information to navigate to the waste materials and collect them. The idea behind version 1 is to eliminate the heavy image processing algorithms and use quick and easy ultrasonic sensors. While version 1 is a cheap option, complexity saved, but it may have lesser accuracy than version 2.

The remaining part of the robot will be the same for both versions, consisting of a gripper to pick the garbage, a chassis that is within the size limits, can carry a trash bin and support the gripper, and most importantly a microcontroller, sensors and actuators to perform the specified tasks.

1. Version 1 - Using Ultrasonic sensors

Ultrasonic sensors are a popular choice for garbage collection robots because they are affordable, easy to use, and have a long-range detection. In garbage collection robots, ultrasonic sensors are used to detect the presence of objects such as trash cans, obstacles or walls and measure the distance to them. This information can be used to guide the robot's movement and avoid collisions, or to position the robot for picking up or depositing trash

Here we are using 4 ultrasonic sensors, 2 at bottom and 2 at top, such that a combination of inputs from the four can be used draw conclusions about the surroundings. For instance, when the ultrasonic sensors at the bottom are triggered it stops as the bot has detected an obstacle, and if all 4 sensors are triggered it means the obstacle has the same height as the bot at minimum and considers it as a wall and takes a turn or otherwise considers it as trash and picks it up. The maximum range of the ultrasonic sensor is 21 meters and the conical-shaped beam angle is typically 10 to 15 degrees. Ultrasonic sensor calculates distance using speed of sound as follows - Distance= (Speed of sound* Time)/2.

2. Version 2 - Using Image Processing

Image processing is a key component of garbage collector robots, as it enables the robot to detect and identify different types of waste materials in various environments.

Raspberry Pi is a popular platform for building small-scale robots, and its ability to process images makes it ideal for garbage collector robots. The image processing technology used in garbage collecting robots using Raspberry Pi involves the following steps:

1. Image acquisition: The robot captures images of its surroundings using a camera module attached to the Raspberry Pi.
2. Pre-processing: The captured images are processed using Python libraries such as OpenCV to remove noise and enhance their quality.
3. Object detection: The Raspberry Pi uses machine learning algorithms such as YOLO (You Only Look Once) to analyse the images and detect objects based on their features such as colour, texture, and size.
4. Object classification: Once the objects are detected, the robot uses a trained neural network to classify them based on their type, such as plastic, metal, or paper.
5. Navigation: The robot then navigates towards the identified objects to collect them.

Image processing plays a crucial role in a garbage collecting robot by enabling them to detect, identify, and sort waste materials. Using camera and algorithm(YOLO – You Only Look Once), the robot capture images of its surroundings, process them to remove noise and enhance quality, and then analyse the images to detect objects based on their features such as colour, shape, and size. Object classification is then performed to categorize the waste materials into different types, such as plastic, metal, or paper. This information is used by the robot to navigate towards the identified objects and collect them for proper disposal. Image processing technology in garbage collecting robots enhances their efficiency, accuracy, and reduces the need for manual sorting.

Mechanical Design

Geometric Constraints

Geometric constraints in our garbage collection robot refer to the limitations or requirements that arise due to the shape, size, and location of the objects they need to pick up. Some examples of these constraints are:

Clearance height: 1-2mm clearance is given for each component such that one does not collide with other during the motion. The rectangular components, to which the motor shafts are attached, have some clearance so that they don't touch the ground.

Gripping mechanism: the gripper dimensions should be adequate to lift the waste from the ground in all positions and orientations and reach the dustbin in a stable manner.

Weight capacity: The robot is designed to handle the weight of the garbage to be picked up.

Obstacle avoidance: The robot must be able to avoid obstacles in its path to prevent collisions.

Design in Solidworks

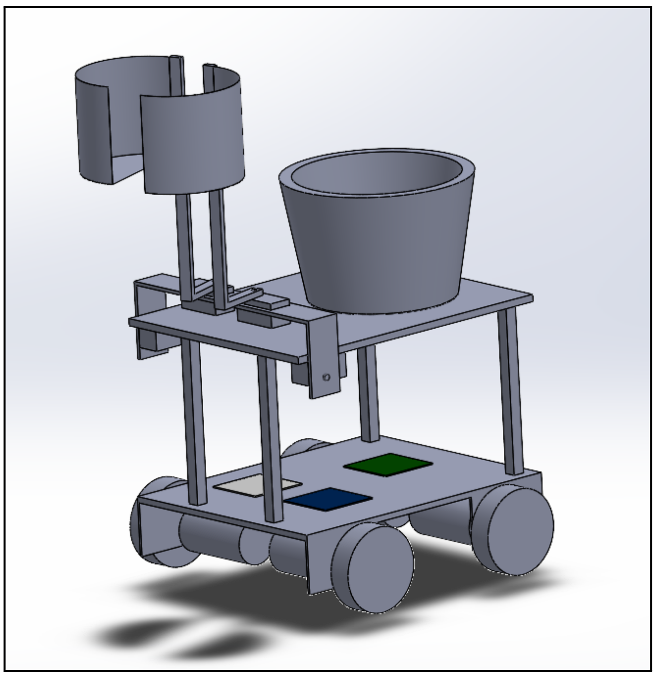
Understanding the problem statement was the first step in the design process. This required determining the robot's objectives and requirements, as well as any restrictions or limits that needed to be taken into account.

Based on the geometric restrictions, the robot's dimensions were determined. For simplicity of use and to improve the robot's aesthetics, we chose to develop a two-storey chassis for its base. The size of the base plate for each storey of the chassis was chosen to allow room for the various parts, such as the dustbin, gripper arm, sensors, Arduino, breadboard, etc. In order to prevent the servo from interfering with the wires on the base plate and to allow for connection changes as needed, the height of the second storey was chosen. After considering existing models and real-world garbage collectors, the gripping mechanism was chosen. The length of the gripper needed to be sufficient to lift the trash and deposit it in the trash can.

We started sketching the design of the robot once the geometric and material restrictions on it were established. Drawing the general design of the robot, the location of the dustbin, the method for collecting waste, and the dimensions of the gripper and dustbin were all part of this procedure.

We began building 3D models of the robot using SolidWorks software after sketching out the first design ideas. This included building detailed 3D models of the robot's many parts and components utilizing the software's various tools and functions, such as extrude boss, extrude cut, revolved boss, revolved cut, sweep cut, etc.

As we worked on the model, we evaluated the functioning of the robot by examining the way different parts moved. For reference, we used cylinders of the same size to show the motors and wheels. The Arduino, Breadboard, Differential drive was represented by thin cuboids of various colors, and the servos were indicated by cuboids.



Assembly

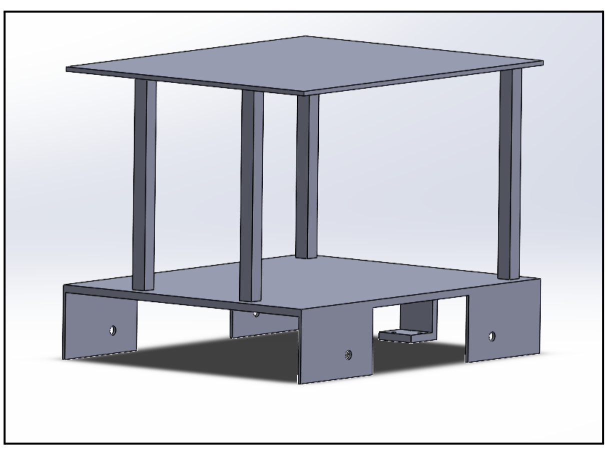
1. Chassis

A garbage picking robot's chassis is made to enable it to travel over a variety of terrain, including rocky or uneven ground. Also, it must be strong enough to handle the combined weight of the waste the robot may collect.

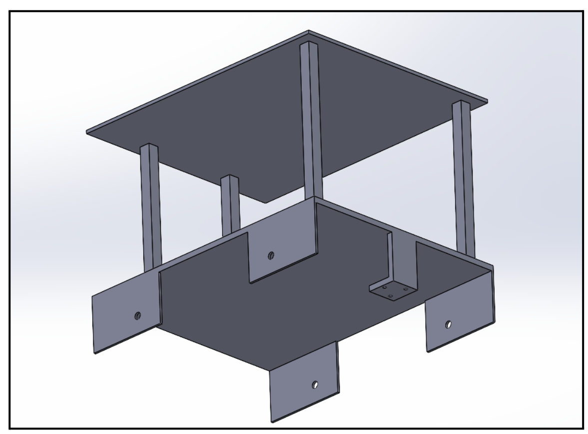
Garbage picking robot chassis consists of a base, wheels or tracks for movement, and a system to collect and store garbage. The base is wide and stable to prevent the robot from tipping over while moving. The wheels or tracks are designed to provide sufficient traction for the robot to move on various surfaces, and the system for collecting garbage is easily accessible and able to accommodate different types of waste.

The two-storey, rectangular chassis is composed of wood. The plates have the same measurements of 200*250*6 mm. Castor wheel attachment slots and four holes for connecting the motors and wheels are on the bottom plate. It has the necessary thickness to give the components and top plate adequate support. Slits were cut into the base's side panels to shorten the wire needed to link the motor to the differential drive, reduce the total weight of the base, and improve the visual appeal. The detachable top plate is supported by 4 pillars that are part of the structure. To allow appropriate room for the connections, the pillars are 110 mm long. The front pillars are closer together than the back pillars to fit the servos located on the underside of the upper plate, which are responsible for the motion of the gripper's U-shaped stand. The top plate is made thick enough to support the weight of the dustbin and gripper. To make the connections easier, the upper plate has been made detachable.

Additional features that are included in the chassis design of this garbage picking robot include Ultrasonic sensors for obstacle detection and avoidance, a camera for identifying waste. The bottom plate has connections among breadboard, Arduino and the motor drive. All of these features would help to increase the efficiency and effectiveness of the robot's garbage collection capabilities.



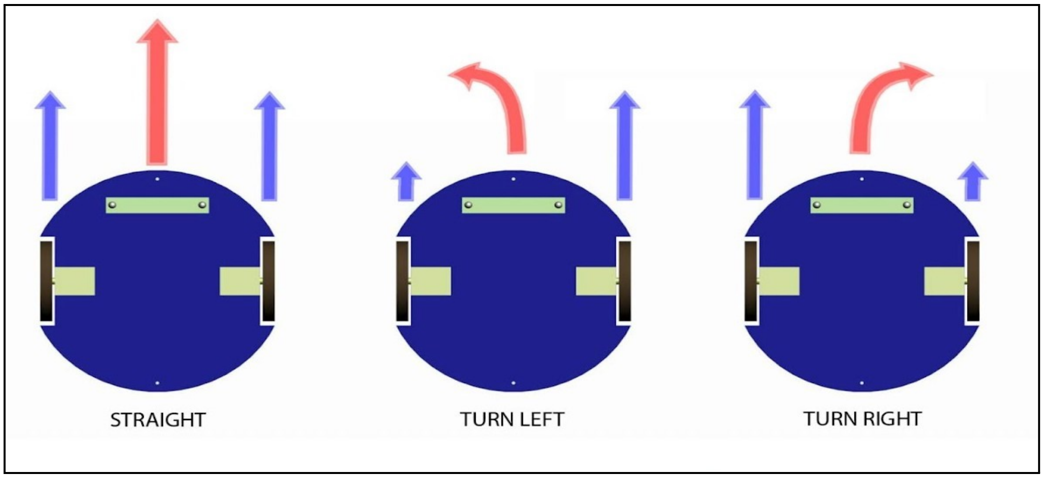
Isometric View



Bottom View

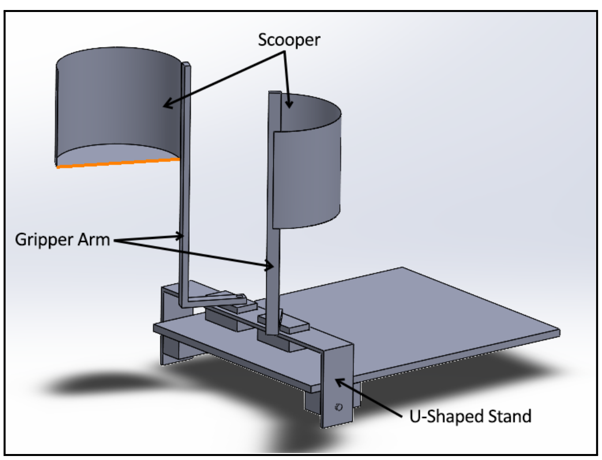
2. Drive System

The drive system we're using is a 4-wheel differential drive ie, there are 2 different sets of actuators for left and right sides of the bot and the the motion vector of the robot is sum of the independent wheel motions -

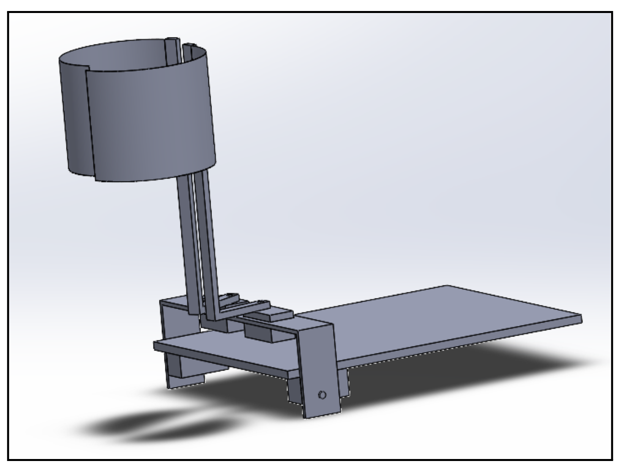


We have used four 30 RPM 12V DC motors to implement the drive and they're attached as 2 sets of 2 parallelly connected motors thereby providing independent actuation on left and right side. Functions are written move forward, backward, leftward, rightward and stop and necessary ones are called in cases of wall detection and garbage detection after setting the bot to move forward by default when powered on.

3. Gripper Design



OPEN Gripper (90°)



CLOSE Gripper (0°)

The gripper in this instance uses a scooping mechanism. The U-shaped stand is attached to the top plate which has arms of the gripper connected to it through servo motors. The gripper arm is L-shaped of 200 mm, enough to collect the waste and reach the dustbin. To lessen the load, lighter wood is utilised for the gripper compared to the wood used in the chassis. Two servo motors are attached to the U- shaped stand to allow the up and down movement of the gripper. These two servo motors can move the scooper from 0° (scooper touching ground) to ~140° (scooper reaching the dustbin). To connect the stand to the arms, two additional servo motors are mounted there. These servos are put in the slots that have been cut into the stand rather than on top of it to reduce the load on the other two servo motors. The gripper arms' opening and closing movements are made possible by the top two servo motors. They move in a 90° (open) to 0°(close) range.

On the ends of the gripper arms are scoopers that have the shape of a half-cylinder. The arms are built in the shape of a L due to the scooper's limited dimensions so they can touch the ground. The connection between the servo motors and the wood is secured using hot glue and screws. The dimensions are given considering the clearance between the servo motors, Ultrasonic sensors and plates.

4. Material Considerations

There are several material considerations that need to be taken into account when designing a garbage picking robot. Some of them are:

Durability: The robot must be made of materials that are strong and durable.

Weight: The robot should be lightweight enough to move around easily, but heavy enough to withstand wind gusts and other environmental factors.

Corrosion Resistance: Garbage can be corrosive, especially if it is wet or contains chemicals. Therefore, a plastic trash can is used.

Environmental impact: The robot is made from materials that are environmentally friendly and sustainable, minimizing its impact on the environment.

Cost: The materials used to build the robot are cost-effective, so that the robot can be manufactured and sold at an affordable price.

Resistance to wear and tear: The robot is made from materials that can resist wear and tear caused by friction, collisions, and other types of damage that may occur during operation.

Compatibility with sensors and electronics: The materials should be compatible with the sensors and electronic components that are integrated into the robot's design.

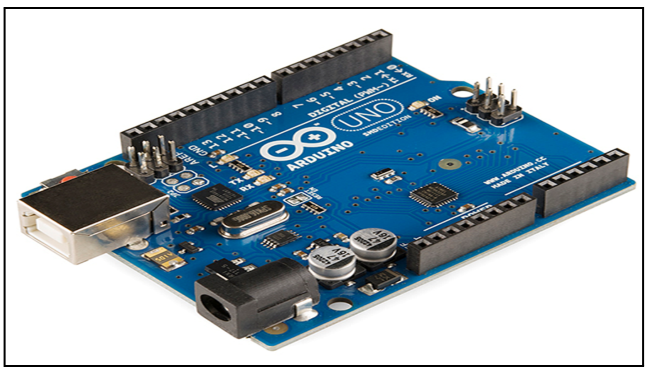
Considering the above aspects, wood is used to make the chassis and the gripper of this garbage picking robot. It is also stronger when compared to plastic or cardboard and light in weight when compared to metal.

Embedded Systems

1. Version 1

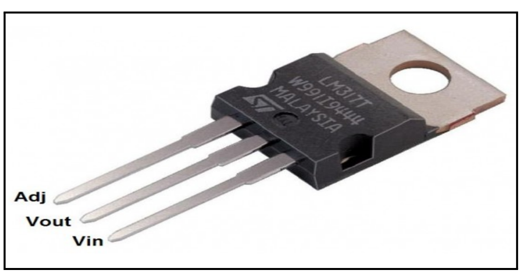
Following are the major components used in version 1 of the robot -

- Brain of the system - Arduino Uno



The Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins, 6 analog inputs. We supply 12V to the Arduino using a battery or an AC-DC adapter to power it. This microcontroller can be programmed to read sensor inputs, make decisions based on that data, and control the outputs that control the movement of the robot.

- Voltage Regulator - LM7805

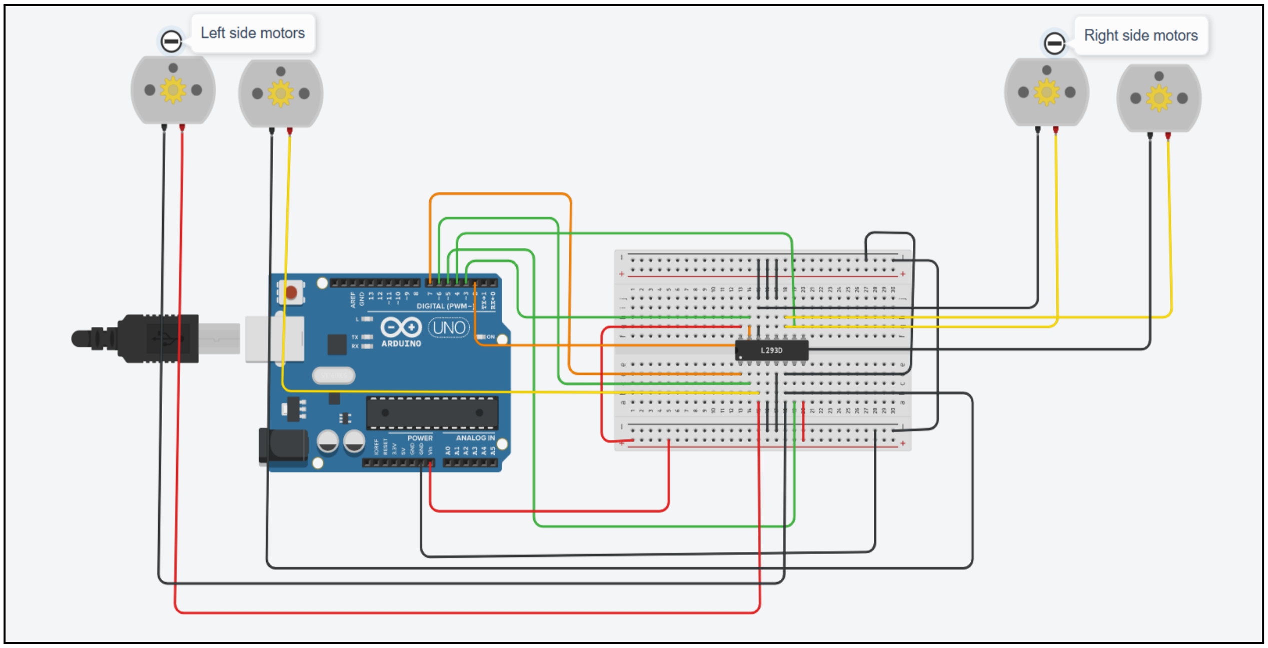


A voltage regulator is a circuit that creates and maintains a fixed output voltage, irrespective of changes to the input voltage or load conditions. LM7805 voltage regulator is used here to provide constant and lower voltages to voltage-sensitive components.

- Motor Driver - L298N

We use motor drivers to give high power to the motor by using a small voltage signal from a microcontroller. By sending signals to L298N, the Arduino can control the speed and direction of the motors.

Interfacing of Arduino with motor driver -



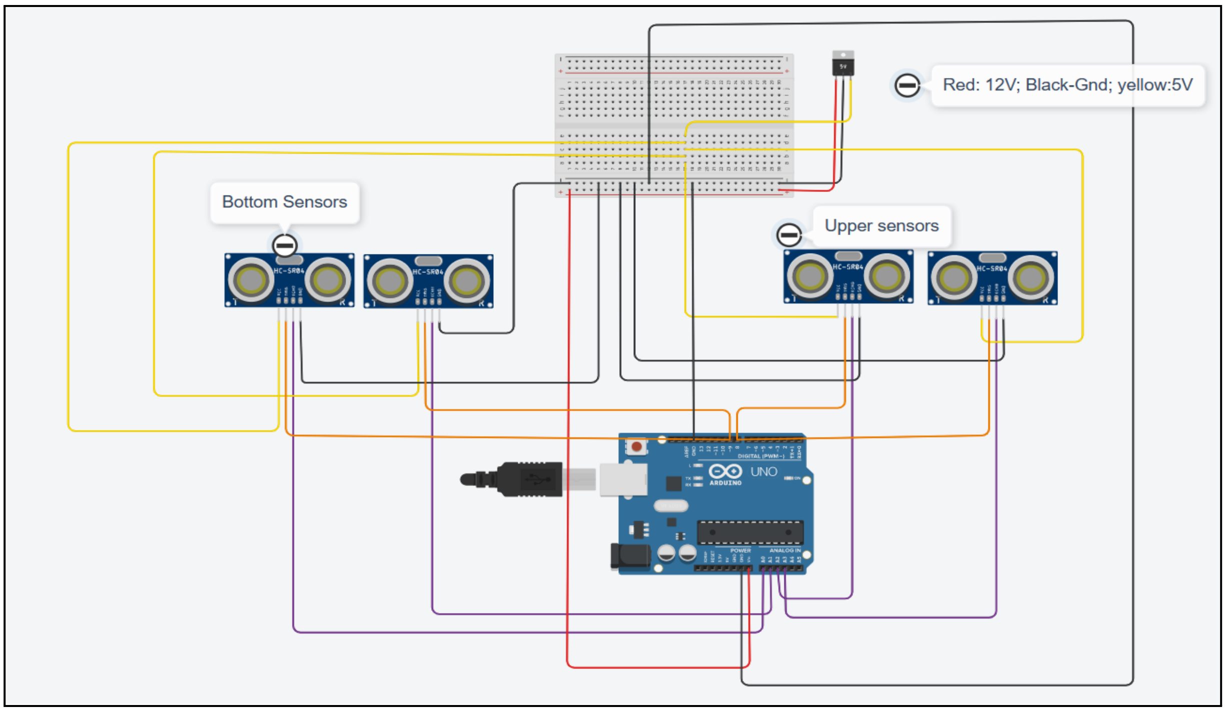
- Ultrasonic Sensor - HC-SR04

Ultrasonic sensors work by emitting high-frequency sound waves that bounce off to objects and return to the sensor. By measuring the time it takes for the sound waves to travel to the object and back, the sensor can determine the distance between the sensor and the object. HC-SR04 used here provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm.

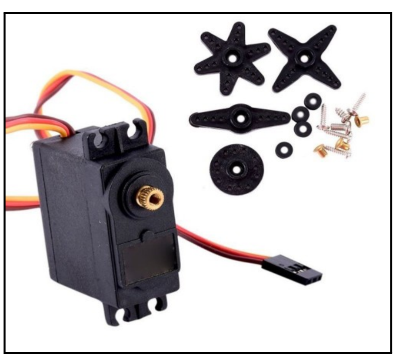
Ultrasonic sensors used in garbage collecting robots execute the following steps for calculating distance

1. Transmission of Sound wave
2. Reflection of Sound wave from the Object
3. Detection of the returning sound wave
4. Calculation of the distance using speed of sound and time taken
5. Use of distance measurement for controlling the movements of robot

Interfacing of Arduino with ultrasonic sensor -



- Servo motor - MG995



The angle control in the gripper mechanism is achieved by attaching and controlling servo motors to the Arduino. It involves programming the Arduino to send specific signals to the servo motor as target angle ad then the servo rotates the gripper to that angle. This allows the trash collecting robot to grasp and release objects as needed.

- Other components - Breadboard, resistors, LEDs, jumper cables, Soldering iron

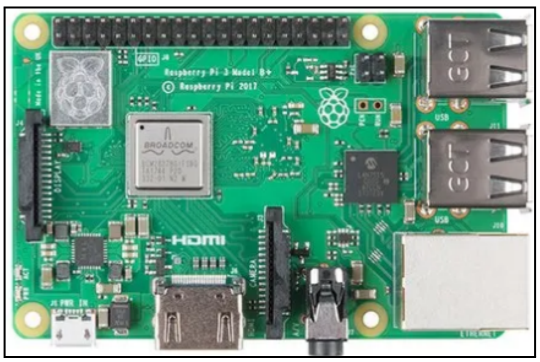
Configuration and Running the code:

After successfully compiling in the Arduino IDE, the code to interface motor driver, sensors& servos is uploaded to the Arduino and powered (+12V). Initially, the robot starts moving forward, if it finds an obstacle at a distance of 20 cm it stops and adjusts the position, then the gripper becomes active to pick up and drop the waste into the bin and then continues the path. If both the bottom and top sensors are triggered, it detects a wall and to avoid collision with the wall, the robot stops and takes a turn

2. Version 2

In addition to the components used in version 1, the following modules are used for image processing

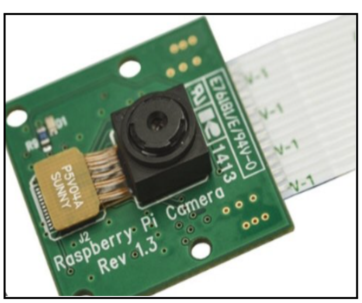
- Raspberry Pi 3B+

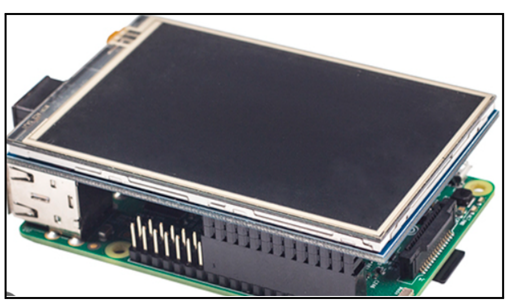


The Raspberry Pi is a very affordable computer that runs Linux and has a set of GPIO pins that allow us to control electronic components for physical computing and investigate the Internet of Things. We use it to implement computer vision and recognize the object using the machine learning models by using a real-time camera (IoT).

- 3. 5 Inch LCD Display and Camera module

The HDMI output is connected to the monitor using an HDMI cable to run the terminal of the raspberry pi, the LCD screen is attached to the display output, and the camera module particular to the raspberry pi 3 model is connected to the camera port of the raspberry pi and is used for real-time imaging





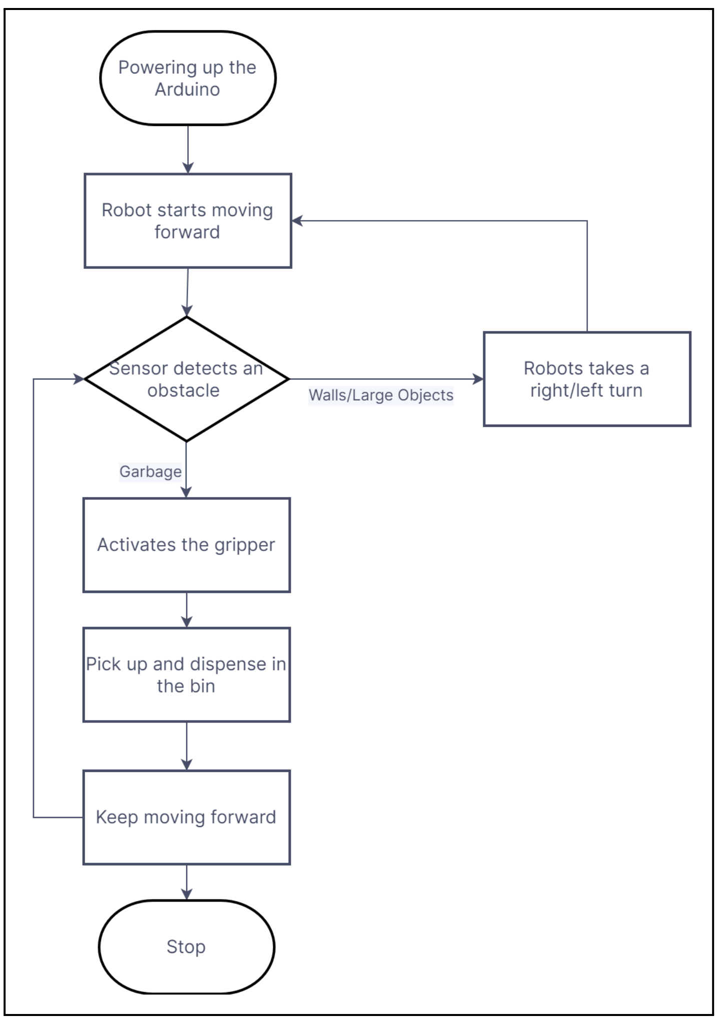
Configuration and Running the code:

The Raspberry Pi is powered up by plugging in a 2.5A power source, and it is then configured by installing the Linux operating system on a microSD card and connecting to a wifi or ethernet connection.The terminal is opened in the monitor and the object detection code(.py) file is made to run in the terminal which gets the input from the camera module and the name of the garbage is displayed in the LCD screen and the output is made ‘1’ if it's a garbage else ‘0’ and it is communicated to the Arduino.

Algorithms

1. Version 1

An Indicative diagram of the logic used is ahown below -



2. Version 2

Sequential steps followed are,

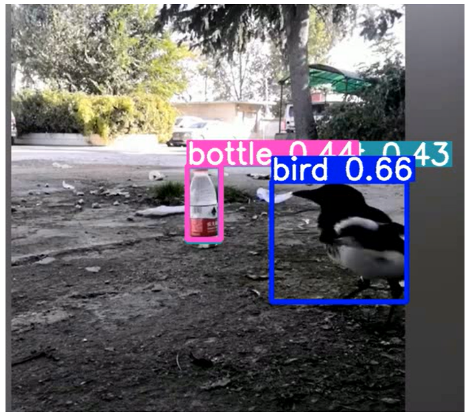
1. **Initialization:** The garbage collector program initializes by loading all the required libraries and dependencies on the Raspberry Pi. It then connects and configures the camera module.

2. **Movement:** The bot moves according to the defined path in the open ground as programmed.The wheels of the bot are attached with the servo motors and they are programmed accordingly to move in different directions depending on the requirement. Bot is also attached with a gripper that can facilitate the collection of garbage from the ground.

3. **Image capture:** The camera module takes pictures of the environment around it. The garbage collector program processes the captured images to identify and locate garbage and debris. The camera module has a sensor that captures an image of the environment in front of it. The sensor is made up of millions of tiny photosensitive elements called pixels. The camera module processes the captured image using built-in hardware to convert the analog signals from the sensor into digital signals that can be processed by the Raspberry Pi.

4. **Object detection and recognition:** The garbage collector program uses computer vision algorithms to detect objects that match the appearance of garbage, such as wrappers, cans, and bottles. The program uses machine learning techniques to recognize different types of garbage based on their shape, color, and other features. The programme involves several stages of image processing and analysis, including preprocessing, feature extraction, object localization, classification, and tracking. The program uses computer vision algorithms to analyze the images captured by the camera module, identify regions of interest that may contain garbage, determine the precise location of each object within the image, classify the objects as garbage or non-garbage using machine learning algorithms, and track their movement to ensure they are properly collected and disposed of.

For achieving this we are using the YOLOV5 model in computer vision.It is a state-of-the-art object detection algorithm that uses a deep neural network to detect and classify objects in real-time. YOLOv5 uses a single stage detector that simultaneously predicts the bounding boxes and class probabilities for all objects in an image, making it more efficient than two-stage detectors. It also uses a smaller network architecture and a novel training technique called self-supervised pretraining, which helps to improve the accuracy of the model.An example of picture of object detection in our model is shown below,

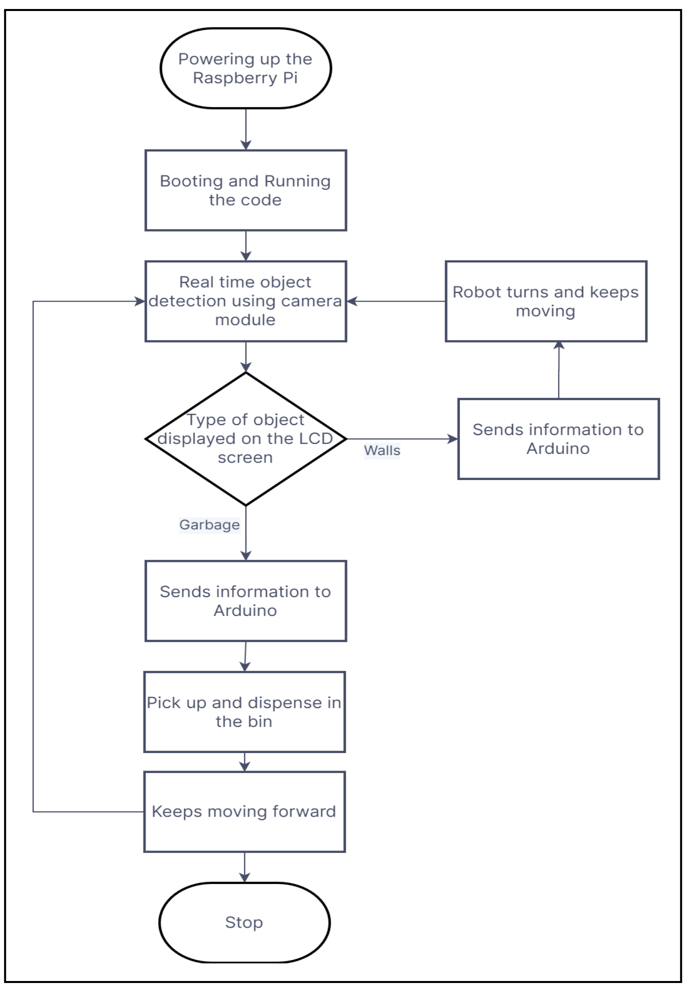


5. **Garbage collection:** Once the garbage collector program has detected, recognized and localized the garbage, it can trigger the appropriate actions to collect and dispose of it. The bot has an attached gripper which gets activated with the programme written in Raspberry pi.

6. **Continuing movement:** The garbage collector program continuously moves in the environment to detect new garbage and repeat the above steps for each new object it identifies.

7. **Shutdown:** Once the garbage collection task is complete and the bot is turned off, the program shuts down the camera module and releases any resources that were used during the process.

Indicative diagram -



Prototyping and Testing

A prototype of the proposed idea was built and tested in various scenarios :

Steps of garbage collection -




The bot was able to navigate through all given layouts and successfully collected the trash in its way.

Cost Analysis

The proof of concept price was found to be Rs. 27856 as shown in the table below. This can be brought down if the production is ramped up and better efficiency can be attained at a lower pr

Sl. No.	Component	Price
1.	Arduino Uno R3 With ATMEGA328	850
2.	Lipo Battery + Charger	2425
3.	Wooden chassis + Gripper	2400
4.	Soldron 25W	300
5.	64GB Micro SD card	950
6.	Digital Multimeter DT830D	200
7.	S3003 Servo Motor(4)	1200
8.	HC-SR04 Ultrasonic Sensor(4)	85*4=340
9.	1620 LCD Display with I2C Soldered	300
10.	DC center shaft motor(4)	156*4=624
11.	DC motor wheel(4)	30*4=120
12.	Raspberry Pi	10000
13.	Camera module	2850
14.	3.5 Inch LCD Tft Touch Screen Display for Raspberry pi	1362
15.	L298N 2A Dual H Bridge Motor Driver Module(2)	148*2=296
16.	LM7805 - Voltage regulator(2)	26
17.	Ball Caster wheel	43
18.	12V 2A Power Adapter	170
29.	Breadboard,LED,Jumper wires,Soldering wire	436
	Total	27856/-

Future Aspects

The design proposed in this project can be implemented successfully in several indoor and outdoor environments thereby eliminating the need for manual labor. There are several features that weren't included in the current prototype due to time constraints, location constraints etc and can be added in the future. Some of them are given below -

- Waste Segregation: Using sensor modules (Example: metal - nonmetal segregation can be done using an Arduino metal touch detector) or image processing, classifying waste into different categories and dispensing into separate compartments in a bin can be done on the bot itself.
- Level of garbage in the bin: A feature can be added to exhibit what is the volume percent/ weight of the garbage currently in the bin and howmuch more can be collected.
- Disposal at a specified location: The bot can be programmed to dispose all the collected garbage at a predefined location once the bin is full.
- The bot can be improved to operate in more complex outdoor environments by improving the mechanical design and navigation algorithm.

Conclusion

Write a summary

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