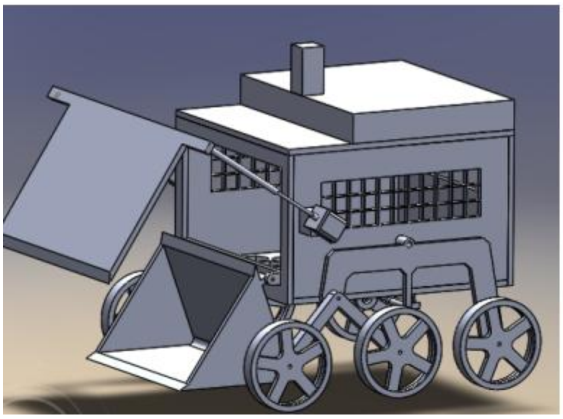
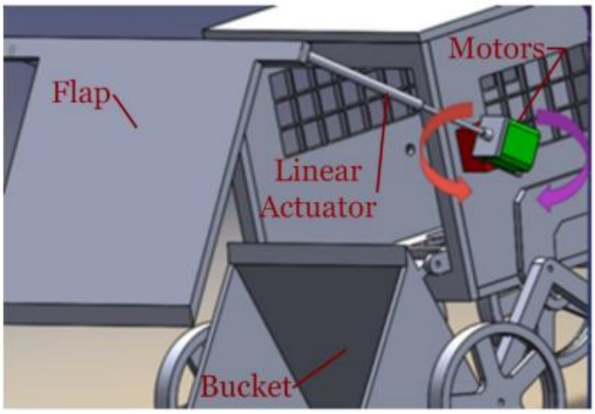
Autonomous Trash Collection Robot Using YOLO-Based Real-Time Object Detection





1. Overview

This project focuses on the design and development of an autonomous trash collection robot capable of detecting, identifying, and picking up waste materials in outdoor environments. The robot integrates mechanical design, electronics, and computer vision to perform trash detection and collection without human intervention.

The proposed system combines intelligent perception (via YOLO object detection) and precise robotic motion control to enable efficient environmental cleanup. It can be deployed in areas like parks, campuses, or streets to assist in maintaining cleanliness and reducing manual labor requirements.

2. Objectives

- To design a mobile robot capable of navigating and cleaning outdoor environments autonomously.
- To implement real-time trash detection using YOLO (You Only Look Once) deep learning architecture.
- To design and simulate robotic arms and collection mechanisms capable of grasping trash items of various shapes and sizes.
- To integrate sensors and path-planning algorithms for autonomous navigation and obstacle avoidance.
- To validate robot motion and stability through simulation in SolidWorks/ANSYS and incremental motion studies in ABAQUS.

3. System Design

Mechanical Design

The robot’s structure features a six-wheeled rocker-bogie mechanism, providing enhanced stability on uneven terrains. The collection mechanism consists of:

- A rotating flap and bucket system designed to scoop and store trash.
- Robotic arms with servo-actuated joints, capable of extending, gripping, and releasing collected waste.
- The design was modeled and analyzed using SolidWorks for motion simulation and ANSYS for static and buckling performance of key structural components.

Simulation Studies

- ANSYS: Used for stress and buckling analysis of robot arm components and chassis under varying loads.
- ABAQUS: Simulated the incremental motion and kinematics of the arm mechanism during trash pickup operations.
  These simulations ensured mechanical robustness and validated design feasibility before fabrication.

4. Electronic and Control System

The robot is powered by Raspberry Pi 4 (for high-level processing) and Arduino UNO (for motor and sensor control).
Key components include:

- Ultrasonic sensors for obstacle detection and distance measurement.
- Camera module for vision-based trash identification.
- GPS and magnetometer for real-time location tracking and orientation.
- Servo and DC motors for wheel and arm actuation, controlled via motor driver circuits (L298N, TB6600).

The control logic combines autonomous navigation with object-following behavior, allowing the robot to move toward detected trash, collect it, and deposit it in an internal bin.

5. Computer Vision and AI Integration

The perception module utilizes YOLOv4-Tiny for real-time trash detection due to its high accuracy ($\approx$95%) and fast inference time ($\approx$5 ms).

- Dataset: A custom dataset derived from TACO (Trash Annotations in Context) containing outdoor litter images.
- Frameworks: TensorFlow, Keras, OpenCV for training and deployment.
- Deployment: The trained model is converted to TensorFlow Lite and deployed on Raspberry Pi for live detection through the onboard camera.

The robot identifies and localizes trash objects in its camera feed, calculates the centroid, and navigates toward them. Once within reach, the mechanical arm performs a pickup operation.

6. Path Planning and Operation

A hybrid control algorithm enables the robot to navigate within a predefined workspace using:

- GPS-based coordinate boundaries.
- A* or random walk path planning for coverage.
- Real-time obstacle avoidance using front and side ultrasonic sensors.

The robot continuously scans the area, detects trash, approaches it, performs pickup using the flap/arm, and deposits it in the onboard bin. When the bin is full (detected using an IR sensor), it returns to a designated disposal point.

7. Expected Outcomes

- A fully autonomous prototype robot capable of trash collection in outdoor conditions.
- Real-time detection and collection of objects using deep learning-based vision.
- Validated mechanical and control system performance through simulation and testing.
- Potential scalability for municipal cleaning and waste management automation.