AUTONOMOUS WASTE COLLECTING DEVICE FOR SUGANDHA POINT OF COX'S BAZAR SEA BEACH

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A Final Year Design Project (FYDP) submitted to the Department of Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of BSEEE

Department of Electrical and Electronic Engineering
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Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
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3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I/We have acknowledged all main sources of help.

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Ethics Statement

Abstract/ Executive Summary

The issue of waste pollution of the coastal territories is also increasingly becoming a rising problem in Bangladesh, especially at the most popular sites like the Sugandha Point of the Cox's Bazar Sea Beach where tons of plastic and solid waste are becoming a daily occurrence and current means of clean-up is based mostly on manual labor. In this project, the proposal is to design and develop a cheap yet fully autonomous waste collector with the creation of a particular device designed to perform effectively in sandy and salty beaches. The proposed system will include an autonomous rover to identify typical wastes along with AI based computer vision, GPS based covering, ultrasonic and infrared sensors to avoid obstacles and a mechanical mechanism of waste collection in the form of a shovel. Once the waste is detected with the help of a camera and trained machine learning model, the rover is capable of autonomously picking a piece of garbage and placing it into an on-board container, which is emptied at a designated dumping point once full. Various design solutions have been considered, such as a robotic arm and a conveyor belt system, and the shovel mechanism has been chosen because of the simplicity of the mechanism, its lasting capacity, energy- efficiency, and its application in non-even sandy areas. There are experimental findings to prove that the device can be effectively used to clean a predetermined beach area with reducing the cost of operation and less human intervention. The above system can serve as a viable solution to sustainable beach cleaning, and it can place autonomous robotics in an environmentally-sustainable context, especially in developing nations.

Keywords: Waste Management; Raspberry Pi; YOLO; Classification.

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1.1 Introduction

Pollution of coastlines has become an environmental crisis especially in most of the tourist spots that have heavy traffic such as Cox's Bazar in Bangladesh. One of the most important destinations of millions of tourists every year, Sugandha Sea Beach is degraded seriously because of the accumulation of a great number of micro and macroplastic litter, which is estimated by approximately 368.68 ± 10.65 microplastic pieces per kilogram of soil [1]. Although automated systems like the Interceptor by the Ocean Cleanup prove the feasibility of automation [2], the systems cannot be affordable or applicable to a developing country due to its economic and contextual constraints. Waste management in Bangladesh remains largely manual and thus inefficient, non-scalable, and not very safe to the workers [3].

The project proposes a localized, cost effective and wholly autonomous waste-gathering apparatus that is specifically designed to meet the requirement of the unique sandy soil and environment of Sugandha Point. The proposed system will fill the gap between the costly industrial solutions and manual cleanups by incorporating advanced robotics and AID-driven computer vision (YOLOv11n), as well as by IoT-based monitoring. This project does not only fill a pressing research gap on affordable autonomous systems, but also supports Global Sustainable Development Goals (SDGs) to protect ecological and economic worth of the longest natural sea beach in the world.

1.1.1 Problem Statement

Sugandha Sea Beach is a tourist attraction site in Bangladesh, which is experiencing extreme environmental degradation as a result of poor waste disposal. The beach has millions of visitors every year and it is littered with macro and microplastics that are aggravated by the lack of proper waste management infrastructure. Studies show that the Cox Bazar beaches are densely covered with plastics as 368.68 +/-10.65 microplastic items/kg of sediment has been reported as a result of both tourism and fishing practices [1]. Marine plastic pollution is a rising issue in the world with 1923 million metric tonnes of plastics flowing into water bodies each year and therefore innovative solutions to waste collection are required [2]. The Interceptor of the Ocean Cleanup or beach-cleaning robots in Europe show the possibilities of autonomous systems, but they remain expensive and unsuitable to the context of developing countries. The existing initiatives in Bangladesh are based more on manual cleanups, which are labor intensive and have limited scalability as observed in the research on evaluating the challenge of cleanups of coastal wastes [3]. The gap in the research is the low cost, localized autonomous waste collection systems to suit the high-tropical beaches such as Sugandha where monsoons and tourist numbers increase littering during the season. This project will be essential to protect the ecological and economic importance of Cox’s Bazar, which is in accordance with global sustainable development principles and globalization of the waste management industry that is seeking automation. Through this gap, the autonomous waste collecting machine will help to improve the effectiveness of cleaning up, minimize the degradation of the environment, and establish a model of scale to other regions around the globe.

1.1.2 Background Study

The increasing issue of pollution of the coast, especially in Sugandha point of Cox Bazar Sea Beach, requires new approaches such as the suggested Autonomous Waste Collecting Device that relies on robotics, AI, and IoT to collect garbage effectively. There are a number of autonomous waste collection systems that have been pointed out in the existing research. An example of such a project is The BeBot, which is an environmentally friendly and silent way of keeping beaches clean. It is a completely electric robot that is able to execute various tasks, such as sifting through sand up to a depth of 10 cm, raking of seaweed, and flattening beaches as well as carrying loads of the waste that was gathered. It attacks a variety of solid waste materials that are usually encountered in beaches including plastic bottles, cigarette butts, packaging, bottle tops, cardboard and cotton buds. The BeBot is able to clean up an area as large as 3,000 square meters in an hour and its operation is remotely controlled with the capability of reaching a range up to 150 meters [4]. Nevertheless, it is less efficient at large debris, and without further development does not use advanced AI-based waste recognition, but needs a human operator. In another case, Kumar et al. suggested the use of the so-called Eco Beach Cleaner, which is a semi-autonomous, solar-powered equipment that is aimed at gathering plastic waste to save aquatic life. The system incorporates a conveyor belt system to collect the rubbish into a storage unit, and it has been reported that it would be capable of collecting up to 10 kg of garbage per hour. It is equipped with rudimentary obstacle avoidance sensors, but manual control to navigate, thus reducing its self-driving. The fact that the device uses solar energy makes it more environmentally friendly, but its inability to perform its functions in the low-light environment and its failure to handle fine debris such as cigarette butts highlights the necessity of fully autonomous systems with high-quality detection systems [5]. In other studies, Bai et al. introduced a deep learning based garbage collecting robot that works in grassy environments, which can be transferred to beach applications. The robot employs a convolutional neural network (CNN) to attain an accuracy rate of 95 percent recognition of different kinds of garbage and a robotic arm to collect the garbage precisely. It has a minimal power consumption of about 50W when powered on but the wheeled movement mechanism is less suitable over sandy or rough surfaces and it has not been tested under coastal conditions [6]. And finally, another project is called The WasteShark, which is an autonomous surface vehicle (ASV) that will be used to gather floating debris in harbors, rivers, and canals. It is similar to the robotic vacuum, traversing the surface of water and storing waste in a storage compartment. The machine is GPS and obstacle avoidance sensor-based and can gather as much as 500 kg of garbage daily [7]. Nonetheless, it lacks a design that can be used in sandy geographical locations, so it can only be used in water bodies but not in beaches.

Although these innovations are enlightening, there is a gap in the research in making a fully autonomous machine which can process various types of waste in sandy beaches such as Sugandha Point of Cox bazar Sea Beach. The existing solutions are mainly focused on waters (WasteShark) or small-scale cleaning of beaches (BeBot) though none of them offers a fully autonomous system that could address mixed waste (plastic, glass, organic debris) in dynamic sandy beaches such as the Sugandha point. Furthermore, majority of the devices do not have AI-based waste detection, Multi-terrain mobility, and large-capacity storage.This project will fill this gap by coming up with an autonomous waste collector with AI-based waste detection, Multi-terrain mobility, High-capacity storage and Real-time monitoring via IoT.

The choice of Sugandha Sea Beach as the site of this project is based on the fact that it is a highly tourist attraction location with massive waste management issues such as plastic pollution and organic waste collection. Current autonomous cube-cleaning systems are not flexible to various landscapes and waste materials, which represent a research gap. The purpose of this project is to design a multi-terrain, AI-driven, waste collector based on the requirements of Sugandha and provide an effective method of cleaning the premises, replacing a manual cleaning system. With the implementation being successful it may be used as a guideline on how to expand this to the rest of the polluted coastal regions in Bangladesh and not only solve the issue on the environment but also the economy at large.

1.1.3 Literature Gap

An examination of the current literature reveals that there exists a significant gap in the development of an entirely autonomous AI-driven waste collection system that can survive in the busy and constantly evolving tropical beach conditions like those that are present in the Sugandha Point. Most of the waste-cleaning solutions in the world today are not quite appropriate to these conditions. As an illustration, the BeBot system is heavily reliant on remote manual control and no sophisticated AI is implemented in detection of waste [8]. In the same way, the Eco Beach Cleaner has problems with gathering small pieces of rubbish and it is not reliable in low-light conditions [9]. Moreover, the majority of deep-learning models that have been trained to detect waste have been evaluated on a relatively stable surface, such as a grass field or an urban road [10]. Consequently, little is known on the systems that can move efficiently in several terrains, including loose and shifting beach sand that are subjected to high salinity like the one along the Bay of Bengal. In addition, no low-cost and scalable autonomous systems that use real-time IoT monitoring together with AI-based waste sorting to handle mixed waste types such as plastic, glass, and organic substances are evident, which are prevalent in developing nations [11]. Hence, there is no available robust locally-appropriate solution that would be able to minimize the reliance on the manual workforce and at the same time not be as expensive as the industrial robotic systems. This brings to focus the consideration of having a waste collection system that is uniquely tailored to the environmental and economic factors of Cox's Bazar [12].

1.1.4 Relevance to current and future Industry

The Autonomous Waste CollectingDevice at SugandhaPoint of Cox Sea Beach has great significance in the current and prospective industrial trends, specifically in the aspects of environmental engineering, robotics, artificial intelligence (AI) and intelligent infrastructure. Due to the blistering development of international tourism, urbanization and industrial activity, the amount of solid waste produced in the coastal and urban setting is rising at a pace never before seen. The traditional methods of waste management that are highly manual in nature cannot handle this magnitude and hence the environmental degradation, poor use of resources and rising operation costs. As a result, all industries across the world are moving to capitalize on automation and smart systems that have the capabilities of streamlining the process of picking up, processing and disposing of waste materials.

The autonomous waste management technologies have several benefits in the present industrial environment. With AI-based trash recognition, IoT-powered sensorization, and all-terrain navigation, the systems similar to the proposed device will be able to work with minimal human intervention, which will enable them to collect waste in high-traffic places like Sugandha Sea Beach, continuously, reliably, and efficiently. This does not only enhance operational productivity but also increases safety since the workers do not encounter the potentially dangerous wastes as well as extreme environmental conditions. Additionally, the opportunities to monitor and collect data in real time enable industries to monitor the trends of waste accumulation, to optimize the collection routes and to make data-driven decisions, which are becoming more appreciated in both municipal and private waste management industries.

In the future, the industry is rapidly shifting to the principles of Industry 4.0 that is characterized by automation, intelligent technologies, and environmentally friendly operations. Smart autonomous equipment is the future of industrial devices, which will allow predictive analytics, intelligent navigation, and effective use of resources. Waste management solutions supported by AI may considerably minimize the operation costs, energy usage, and carbon footprint and enhance the general sustainability of the environment. Moreover, machine learning and internet of things technologies can be integrated, which means that these systems can be adjusted to various environmental conditions and types of wastes as well as to challenges related to the terrain, thereby being very versatile and flexible to different industrial needs.

The new system is also in line with the new market requirement that is focused on sustainable and environmentally friendly industrial solutions. Other sectors of the economy, including tourism, municipal waste management, environmental services and robotics manufacturing are also putting their money in technologies that can be less harmful to the environment and allow them to stay efficient in their operations. The autonomous garbage collection devices do not only help to create a cleaner environment but also provide an example of smart and green technologies that can be implemented in street life of the urban areas, industrial facilities, ports, and rivers and other coastlines. This project will help fill the void between technological invention and the industrial implementation, especially in developing countries where prices, scalability and environmental flexibility will matter.

To sum up, the creation of the autonomous waste gathering device can be considered very topical to the industrial needs of the time, efficient, automated, and sustainable waste management systems and can be successfully adopted in future. Its combination of robotics, AI, IoT, and multi-terrain mobility are the epitome of the type of intelligent automation that more industries around the globe are showing an interest in and so the project is not only a potential remedy to the current issues, but a blueprint of how environmental management in the context of sustainability and technology-driven approaches can be done in the future through intelligent automation.

1.2 Objectives, Requirements, Specification and constant

1.2.1. Objectives

- **i.** Design and Implementation of an Autonomous Waste Collection Device for Sugandha Point of Cox's Bazar Sea Beach.
- **ii.** To collect 10 kg of waste per day from Sugandha Beach by one device.
- **iii.** Design the device in such a way that it is capable of handling different types of waste found at sea beach.
- **iv.** Minimize the need of manual labor and reduce the cost.

1.2.2 Functional and Nonfunctional Requirements

Functional Requirements:

Table-1: Functional Requirements

Parameter	Details
Amount of Waste Collected	8-10 kg per day
Maximum Size of Waste	50 cm in diameter
Device Height	0.5-0.6 Meter approximately
Device Weight	10-12 kg approximately
Storage Capacity	5 liters of waste

Device Dimension	(30 inches long × 20 inches wide × 20 inches high)
Area Covered per Unit Time	200 square meters per hour
Energy Provided by Battery	0.115 KWh maximum
Operating Time on Full Battery	2-3 hours of continuous operation
Autonomy	Fully Autonomous or Semi-Autonomous

Non-Functional Requirements:

i. **User-Friendly Interface:**
   a. Provide intuitive controls and feedback mechanisms for operators to monitor performance and intervene if necessary.

ii. **Maintenance Accessibility:**
   a. Design components for easy access to facilitate routine maintenance and repairs.

iii. **Durability and Reliability:**
   a. Ensure long-term operation with minimal downtime through robust design and quality components.

iv. **User Training and Support:**
   a. **Training Programs:** Provide comprehensive training for operators to ensure safe and efficient use of the robot.

v. **Customer Support:** Offer accessible support services to address operational issues and gather user feedback for continuous improvement.

1.2.3 Specifications

Table-2: Specifications

Sub-System	Component	Specifications

1. Mobility & Chassis Subsystem	Chassis Frame	- Material: Steel / Stainless Steel (Corrosion-resistant) - Coating: Powder or colour coated for saltwater protection
	Driving System	- Type: Rubber tracks /wheel - Motors: 4 DC gear motors - Suspension: Trailing Arm Suspension (with Spring or Rubber Damper)
	Steering	-Differential drive (skid-steering) - PID control for smooth turns
2. Waste Collection Subsystem	Conveyor Belt	- Material: Rubber Belt
	Picking Hand or Suction Mechanism	- Gripper Arm with Rubber Pads - Suction pump
	Storage Bin	- Capacity: 10L (detachable) - Material: UV-resistant HDPE - Auto-unload: Hinged bottom door
3. Navigation & Sensing Subsystem	Sensors	- Ultrasonic : (obstacle avoidance) - Infrared : (Beach edge and obstacle detection)
	Positioning	- GPS : (For detecting location)
	Vision System	- Camera - AI Model: CNN for waste classification
4. Power & Energy Subsystem	Battery	- Type: Li-ion - Runtime: 3–4 hours maximum - Energy Provided: 1 KWh maximum - BMS: Overcharge/discharge protection
	Solar (Optional)/ May add a power converter or a power supply unit	- Panel: 10W - Charge Controller
5. Control & Communication Subsystem	Controller	- Main Processor (Jetson Nano / Raspberry Pi / Teensy) - Secondary: Micro-Controller (motor/sensor control)
	Motor Drivers	-To control the DC motor's direction and speed through input control signals

	Connectivity or Communication	- Wi-Fi: Local control - GSM: Remote alerts
6. Software & AI Subsystem	Autonomy Stack	- Path Planning
	Waste Detection ML	- Model: CNN trained on the beach waste dataset -Sensor Fusion Software
	Firmware	- (C++): Motor/sensor control - (Python/C++): Navigation/Waste detection
7. Safety & Environment Subsystem	Emergency Stop	- Hardware: Physical kill switch - Software: Remote E-stop (GSM/Wi-Fi)
	Anti-Theft	- GPS Geofencing + tamper alarm

1.2.4 Technical and Non-technical consideration and constraint in design process

Development and operating of an independent waste collection system within Sugandha Point requires an in-depth analysis of technical and non-technical conditions to achieve the efficiency and sustainability of the developed system in a natural environment of the coastline.

Technical Constraints and Technical Considerations:

- **Mobility and Terrain Adaptability:** The device should move through the movable and changing sandy area of the Sugandha Beach that is characterized by different levels of moisture and changing densities. This necessitates a strong driving system like rubber tracks or wheels that are driven by high-torque DC gear motors and fixed to special suspension, such as trailing arm suspension with dampers.

- **Environmental Resilience:** The hardware is exposed to extreme salinity, high humidity, and gritty sand in the location of operation, which is a coastal zone. The design considerations involve using corrosion resistant materials (i.e. stainless steel or powder coated frames) and fully sealed and weatherproof enclosures of all delicate electronic parts.

- **AI-based Detection and Processing:** One of the central technical specifications is a vision system that can classify waste in real-time (e.g. plastic, glass, organic) among natural beach litter. This is limited by the requirement of lightweight AI models like YOLOv11n that can be implemented efficiently with a main processor such as a Raspberry Pi or Jetson Nano and does not require too much power consumption.

- **Power and Energy Management:** The system is limited by the battery capacity, which means that there should be a balance between the weight and the operational time. The design objective is 2-3 hours of constant running time on one charge with the peak power consumption of some 78-80 Watts.

- **Autonomous Navigation and Safety:** To be completely autonomous, the device should contain a sensor fusion stack, i.e. GPS to obtain macro-localized data and ultrasonic/infrared sensors to obtain micro-navigated and obstacle-avoided data, respectively, providing the device with the means to navigate safely within a 200 m^2/h area.

Non-Technical Considerations and Constraints:

- **Economic Feasibility and Scalability:** One of the non-technical limitations is the creation of a low-cost solution that is affordable by local municipalities in Bangladesh. The project should narrow the disparity between the high cost of international industrial robotics and the small budgets of the developing countries.

- **Public Safety and Privacy:** The deployment of a robot in the high-traffic tourist region creates some ethical responsibilities that are related to the safety of pedestrians and the privacy of data. The system should have physical kill switches where emergency stops are involved and also the cameras by AI should be used in a very strict way to detect the waste and not to gather personal facial information.

- **Socio-Economic Impact:** The design should pay attention to its influence on the local manual labor. Instead of just removing the workers, the project is expected to add to the current cleanup operations and, perhaps, establish additional technical maintenance jobs to the local population.

- **Maintenance and Usability:** The device should be easy to use by the local operators and be designed in a way that allows easy access by ordinary users when it comes to routine diagnostics and replacement of parts without any particular tools.

- **Legal and Cultural Conformance:** The project should be in line with the environmental protection laws in the country including Bangladesh Environmental Conservation Rules and historical and cultural sensitivity of the beach by sustaining the beauty and leisure value of the beach.

1.2.5 Applicable compliance, standards, and codes

The self-governing garbage-gathering equipment at the Sugandha Point of Cox Bazar is also meant to contain the ever increasing problem of beach pollution in a sustainable and efficient way. In order to make sure that the device is safe and will be effective in such a dynamic environment, it is built in accordance with a range of standards and codes. These are the navigation, waste detection, transparency, ethical design, safety, sustainability and environmental protection guidelines. Through these standards, the project is projected to save the local ecosystem, reinstate the public's trust and also add to the general cleanliness of one of the most tourist destinations in Bangladesh.

i. **IEEE 1872-2015** guides the autonomous device’s navigation and waste detection, ensuring reliable performance in Sugandha Point’s dynamic beach environment [9].

ii. **IEEE 7001-2021** ensures transparent decision-making (e.g., logging waste collection choices), fostering public trust in a busy tourist area [9].

iii. **IEEE P7007** promotes ethical design, minimizing environmental harm (e.g., protecting marine life) and ensuring safe operation around beachgoers [9].

iv. **IEB Code of Ethics** prioritizes safety (e.g., collision avoidance) and environmental health, supporting the project’s goal of reducing beach pollution [11].

v. **IEB Sustainability Guidelines** encourage eco-friendly materials and waste segregation, addressing Cox’s Bazar’s plastic pollution sustainably [11].

vi. **BNBC Environmental Section** ensures compliant waste handling to prevent secondary pollution.

vii. **ECR 1997** protects Cox’s Bazar’s ecosystem by ensuring waste collection avoids sand erosion or biodiversity harm.

Reason for Choosing These Standards:

In order to make the autonomous waste-collecting device at Sugandha Point, Cox’s Bazar Sea Beach safe, sustainable, and adhering to the engineering best practices, the following standards and codes are directly related:

i. **IEEE 1872-2015 (Standard Ontologies for Robotics and Automation)**: This standard offers a guideline to establish ontologies of robot systems, which is essential to the autonomous movement and detection of waste by the device [9]. In our project, it means that the device will be able to detect and retrieve wastes (e.g. plastic bottles, wrappers) reliably when it comes to moving around the dynamic beach environment, avoiding any obstacles such as people, rocks, or relatively low tides. Following this criterion, the control algorithms of the device can be designed in such a manner that they are able to cope with more complicated tasks, e.g., separating waste and natural debris (e.g., seaweed), which contributes to the higher efficiency of the work.

ii. **IEEE 7001-2021 (Standard for Transparency of Autonomous Systems)**: This requirement stipulates openness in the work of the autonomous systems, which is paramount to the credibility of the population in a high-traffic tourist site such as Sugandha Point [9]. In the case of our device, it will involve establishing systems to record and justify the decisions, including the reason behind picking this or that item or ignoring it. Such transparency will provide accountability so that the beach authorities and the visitors can know what the device is doing and there are no fears of an autonomous device that goes about its business in a busy public environment.

iii. **IEEE P7007 (Ontological Standard for Ethically Driven Robotics and Automation Systems)**: Ethical in nature, this standard makes sure that the device is responsibly used and that its use will not cause many harmful effects to the environment, but be safe [9]. In our project, it will be used to direct the design to prevent destabilizing the fragile coastal environment of Cox's Bazar (e.g., the nesting location of marine turtles) and to promote safe use with beach users. As an example, the equipment should not be characterized by dangerous maneuvers or risky work with waste, which can jeopardize humans or wild animals, and this concept is consistent with the ethical principles of engineering.

iv. **IEB Code of Ethics**: The Institution of Engineers, Bangladesh (IEB) Code of Ethics is focused on the protection of the environment, health, and safety of people [11]. In our project, this code will make sure our device is made with safety mechanisms such as collision avoidance sensors and emergency stop machinery in order to safeguard tourists and workers on the beach. It also makes the project objective of decreasing plastic pollution, to make the beach cleaner and healthier, which is vital to the ecological equilibrium and tourism of Cox's Bazar.

v. **IEB Guidelines for Sustainable Engineering Practices**: These principles encourage green engineering, which is crucial in the solution to the plastic pollution crisis at Cox's Bazar [11]. In our project, they promote the application of materials, which are environmentally friendly in constructing the device (e.g., recyclable plastics or corrosion resistant alloys used in coastal environments) and also incorporating waste segregation features so that they can be easily recycled. This makes sure that the device does not just collect waste but also promotes sustainable waste management practices that will be in line with the local environmental objectives.

vi. **BNBC Environmental Engineering Section (Bangladesh National Building Code)**: The environmental engineering department of the BNBC has guidelines on waste management and pollution control although it is mainly applicable to buildings. In the case of our project, it helps in ensuring that the device manages waste in a way that does not cause secondary pollution like the leakage of the collected waste when transporting it. This is essential in keeping the Sugandha Point clean and preventing the pollution of the beach and surrounding waters which is in line with the national standards of protecting the environment.

vii. **ECR 1997 (Bangladesh Environmental Conservation Rules)**: These laws are used to regulate the disposal of waste materials in order to conserve the ecosystems in Bangladesh especially the coastal sensitive regions such as Cox's Bazar. In our project ECR 1997 would make the device harvest some waste without polluting the environment, e.g., sand erosion caused by heavy treads or disruption of marine life (e.g., crabs, birds). It requires that the operations of the device must be in line with legal provisions regarding waste disposal and handling procedures to ensure that the project positively impacts on the ecological well-being of the beach.

Criteria Development for Autonomous Waste Collecting Device:

In order to come up with requirements of the autonomous waste-gathering machine in Sugandha Point of Cox's Bazar, as per good engineering practice, conform to IEEE, IEB, and NSP standards:

i. **Safety:** Supply with collision avoidance sensors and emergency stop complying with IEB Code of Ethics and IEEE 7001-2021, made of non-toxic materials[11] [9].

ii. **Sustainability:** Consumption eco-friendly and corrosion-resistant materials and energy-saving systems (e.g., solar power) according to IEB Guidelines and ECR 1997, waste sorting to be recycled [11].

iii. **Reliability:** Be able to detect and navigate through dynamic conditions (e.g. tides, sand) correctly per IEEE 1872-2015, aiming at 95% uptime [9].

iv. **Transparency:** Documents the decisions of logs (e.g., waste selection) and provides a monitoring interface based on IEEE 7001-2021 in order to earn the trust of the population [9].

v. **Ethical Responsibility:** Do not damage the ecosystem (e.g., no sand erosion, do not harm marine life) and be not noisier than 60 dB according to IEEE P7007 [9].

vi. **Regulatory Compliance:** Avoid the waste leakage, meet BNBC and ECR 1997 regulations of handling the waste and protecting the environment.

vii. **User-Centric Design:** User needs must be easy to maintain and simple controls must be provided to the operators.

1.3 Systematic Overview/Summary of the proposed project

The project proposal will focus on the creation of a completely autonomous and AI-built waste collection system specially designed to suit the high-density and hostile environment of the location of Sugandha Point on the Cox's Bazar Sea Beach. The system aims at removing the gap between manual cleaning which is labor intensive and international industrial robotics that are costly and contextually out of place.

System Architecture and Operation:

The project employs a mechanical design called shovel (Design Approach-1) based on the reason that it is the best solution since it can withstand sandy salty conditions and it consumes less power than a robotic arm or conveyor system. The working workflow will be the following:

i. **Navigation and Localization:** The robot will have a combination of GPS macro-localization over a fixed area of 200 m 2 of cleaning, and a set of sensors, such as ultrasonic sensors and infrared sensors, to provide micro-navigation and real-time obstacle avoidance.

ii. **Intelligent Detection:** The camera faces forward to shoot images that pass through a CNN with YOLOv11n. This AI model can categorize waste as plastic bottles, wrappers and organic debris with high levels of confidence (0.78 to 0.92).

iii. **Collection Mechanism:** When waste is detected the rover will position itself and open a 5-liter detachable storage bin with a servo-controlled shovel which will collect the rubbish.

iv. **Automated Dumping:** The device has a load sensor that measures the weight of the bin; when the bin becomes full or full of its route, it drives itself back to a dumping station and the resultant waste is unloaded using a tilting actuator.

Key Technical Specifications:

i. **Performance Targets:** The device will be designed to gather 8-10 kg of garbage daily.

ii. **Power System:** The system runs on a 12V 15Ah Lithium-ion battery, and can operate continuously 2.1 to 3.6 hours, depending on the load, to cover the area assigned to it on one charge.

iii. **Durability:** The chassis is produced of stainless steel which does not corrode easily or powder-coated metal frames in order to survive the salinity and humidity of the Bay of Bengal.

Sustainability and Impact:

The project will include IoT-based real-time monitoring of remote data-driven management and is developed in a manner that is highly scalable. The project is expected to lessen the destruction of the environment through the provision of a local solution through the offer of cost-effective methods to protect the ecological and cultural value of the coastal areas of Bangladesh.

1.4 Conclusion

The suggested autonomous waste-gathering machine is a strategic technological reaction to the growing crisis of plastic pollution at Sugandha Point, Cox Bazar. This project is able to overcome the constraints of the current semi-autonomous and contextually inappropriate global systems by integrating AI-based waste detection, strong multi-terrain mobility, and real-time IoT to a single and cost-efficient system. The design is based on strict international and national standards, such as the IEEE 1872-2015 standard of navigation and the ecological sensitivity and public safety of operation, which are guaranteed by the Bangladesh Environmental Conservation Rules (ECR 1997).

According to technical assessments, one unit with an optimized collection mechanism using a shovel and a 12 V Li-ion power supply can successfully handle up to 10 kg of waste per day and cover up to 200 m 2 per hour. Outside its immediate effect on the environment, an important contribution of the project is that the model can be expanded and cost-effective to coastal management in developing areas to show that intelligent automation can be localized and sustainable. In the end, this device will be a stepping stone to make Cox Bazar a smart and a green tourism destination that will not only preserve its biodiversity to discoverers of the future generations but also act as a model of autonomous environmental engineering in Bangladesh.

Chapter 2: Project Design Approach [CO5, CO6]

2.1 Introduction

Designing a useful independent waste collection in a dynamic coastal zone such as Sugandha Point needs a procedural search for workable mechanical solutions. It is not only the task of the implementation of functional waste collection but ensures the durability of sandy, wet and saline conditions, energy efficiency, and strict budgetary limitations. In order to have a strong and viable final product, it is important to factor and consider various engineering strategies. This chapter rationally outlines three mechanical design ideas, developed to achieve the main project goals. All the methods are outlined with a detailed description of the method, and the main comparison analysis involving the main variables of performance, cost, reliability and user acceptance has been conducted. This process aims at determining the best design which to put it in a balance between technical and real-life applicability on sustainable cleaning of beaches.

2.2 Identification of Multiple Design Approaches

In order to come up with a successful autonomous waste collection system at Sugandha Beach, three different mechanical design schemes were conceptualized, all of which use a fundamentally different approach to the collection of the debris. These solutions have been designed to investigate degrees of complexity, efficiency, and the appropriateness to the harsh coastal environment.

2.2.1 Design approach 1 (With Shovel Mechanism)

Under this method the self-propelled beach-cleaning machine is positioned or operated manually or begins at a predetermined station. Onboard systems are started upon booting, and they comprise power, navigation, sensors, and waste detecting modules. The gadget employs mixture of GPS as a means of localization. Obstacle detection and avoidance is done by ultrasonic or IR sensors and optional LiDAR/vision. The device investigates an area of 200 m 2 of predefined beach on its own. The forward facing camera has its images processed by a lightweight image classification algorithm(e.g., YOLO model, MobileNet, or custom CNN). The technology recognizes the typical wastes (plastic bottles, wrappers, cans, etc.). The coordinates of detected wastes are determined and transformed into movement instructions to be collected. The rover then aligns itself with the waste by fine-tuning it. A shovel is lowered and scoops the waste by use of a servo-controlled shovel mechanism. The shovel picks up and directs the waste into a collection box on the chassis of the device. The sensor (weight sensor) is put under the garbage box.When the box has accrued a certain weight limit, this sensor prevents the accumulation of extra trash. When the device reaches capacity or completes coverage, it is therefore able to reverse to its dumping station with the aid of GPS and dead reckoning. A waste box is lifted and tilted at the station by a servo or linear actuator. Waste is thrown in an encased trash container. Once the weight sensor is reset and the system records the journey after unloading. Provided that there is battery and time, the rover goes back to route. Otherwise, it goes back to base, requests that it be charged or serviced by humans, and enters the standby state.

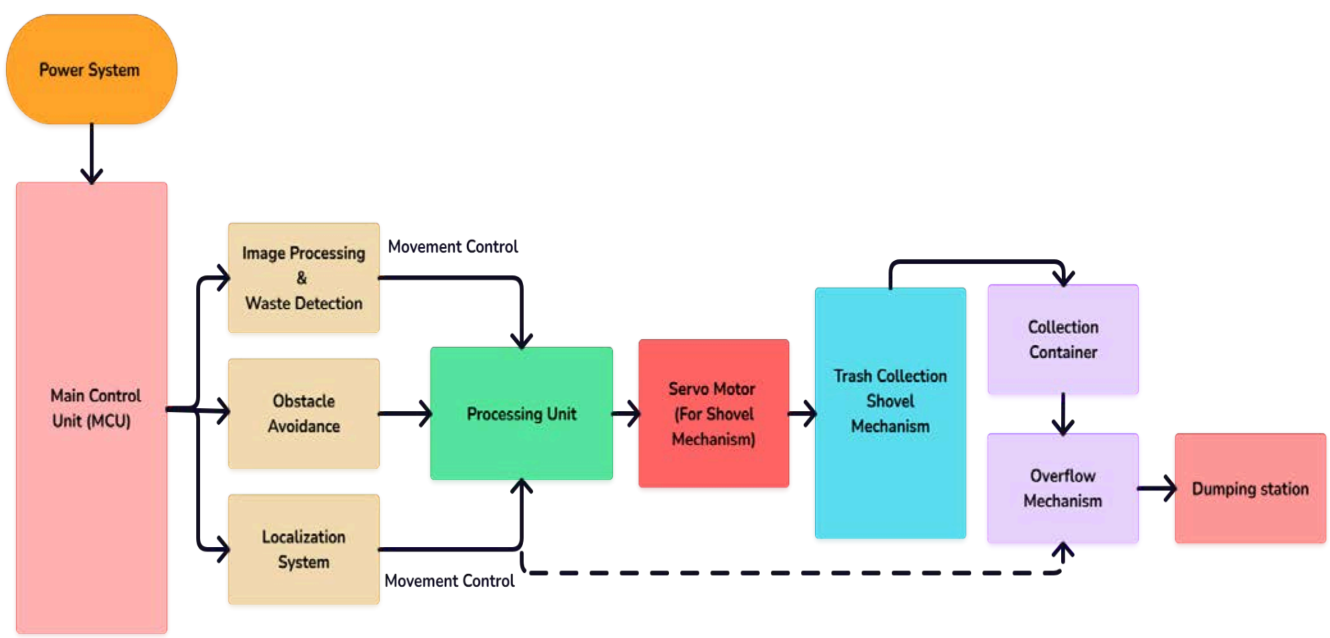


Figure 1 : Block Diagram of Shovel Mechanism

2.2.2 Design Approach 2 (With Robotic Arm Mechanism)

This approach is more or less the same as Approach 1, in which an autonomous cleaning device on the beach moves within a 200 m 2 area guided by GPS and obstacle-detection sensors to detect and collect garbage. Nonetheless, the outstanding difference is the waste collection mechanism. This device turns to a 4DOF robotic arm as opposed to a shovel system (as in Approach 1). The arm itself retrieves a waste which has been identified by onboard image processing (e.g., YOLO model or MobileNet) and puts it into a collection container. Once the container is full, the emptying happens at the base station through an actuator mechanism and the device either goes back to work or goes into a standby depending on the battery.

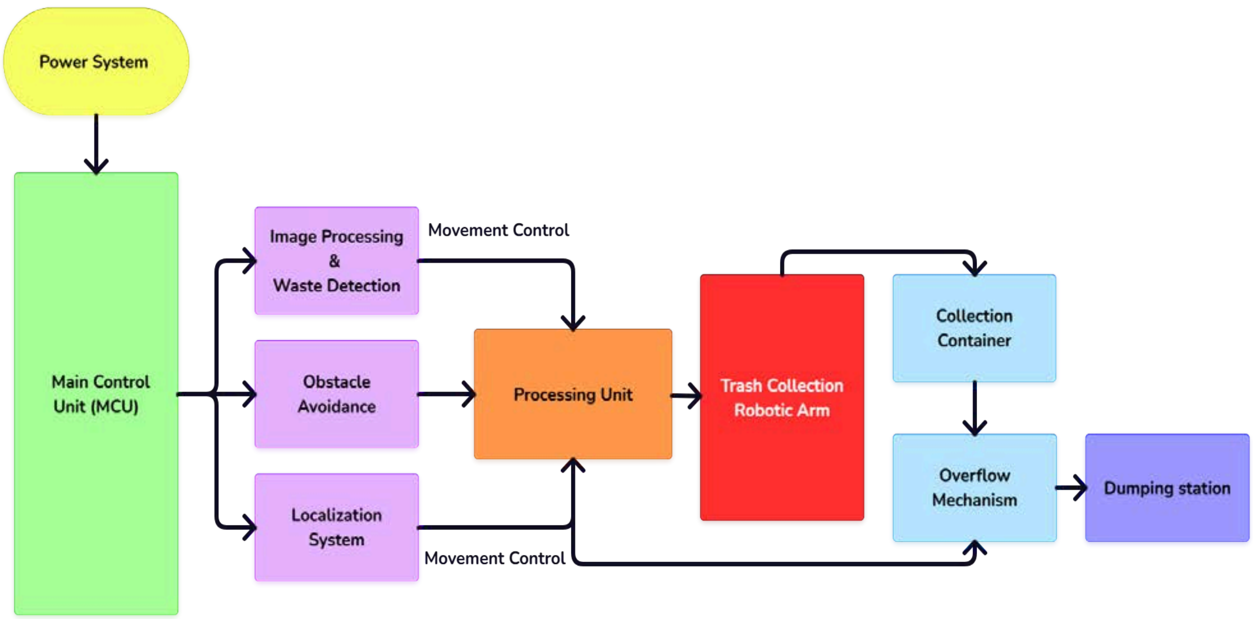


Figure 2: Block Diagram of Robotic Arm Mechanism

2.2.3 Design Approach 3 (With Dual Conveyor Belt Mechanism)

This solution is similar to Approaches 1 and 2 in terms of their operational framework, which involves autonomous navigation, obstacle avoidance, image-guided waste localization, and returning-to-station behavior. Nevertheless, the main distinction is in the waste collection system. This design is based on the idea of a dual conveyor belt system instead of relying on a shovel (Approach 1) or a robotic arm (Approach 2). The former transfers the garbage on the floor to the first conveyor, and the second conveyor is linked to the onboard collection box. None of the other processes like localization, dumping, and system reset is changed.

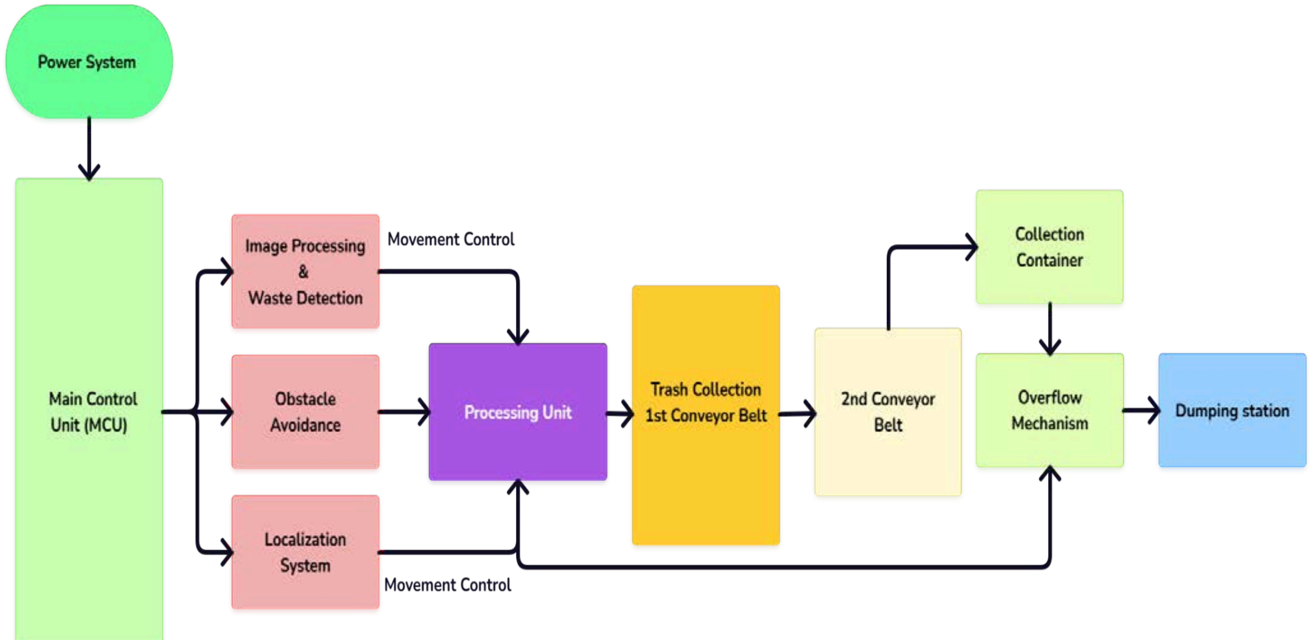


Figure 3: Block Diagram of Dual Conveyor Belt Mechanism

2.3 Description of Multiple Design Approach

Both of the designs have been developed into a common platform that can include a mobile chassis, navigation sensors, an AI-based vision system, and a control unit. The major point of difference is the waste collection subsystem.

2.3.1 Design approach 1 (With Shovel Mechanism)

Under this method, the autonomous beach-cleaning vehicle will be either placed manually or initiated at a specified station. When booting, onboard systems are started, such as the power, navigation, sensors and waste detection modules. The device incorporates a mix of a GPS to localize. Obstacle detection and avoidance is done by ultrasonic or IR sensors and optional LiDAR / vision. The device is free-roaming that investigates a designated 200 m 2 area on the beach. A forward-facing camera runs the images through a lightweight image classification algorithm(e.g. YOLO model, MobileNet, or custom CNN). The machine detects the types of waste that are most common (plastic bottles, wrappers, cans, etc.). Waste coordinates are identified, and transformed into movement instructions that are collected. The rover moves itself in front of the waste with fine tuned movement. A shovel mechanism is a servo-controlled device that drops and scoops the waste. The shovel raises and directs the garbage into a collection box which is placed on the machine chassis. Under the waste box a load sensor (weight sensor) is placed, which stops the continuation of receiving more trash when it reaches a predefined weight limit. When the Device is old enough or when the coverage is complete it autonomously returns to its Dumping station by GPS and dead reckoning. A servo or a linear actuator is used to lift and tilt the waste box at the station. Waste goes into a predetermined waste container. Once unloaded, the weight sensor is re-set and the system records the journey. In case there is enough battery and time the rover returns to its course. Otherwise it goes back to base, is asked to recharge or be maintained by humans and enters standby.

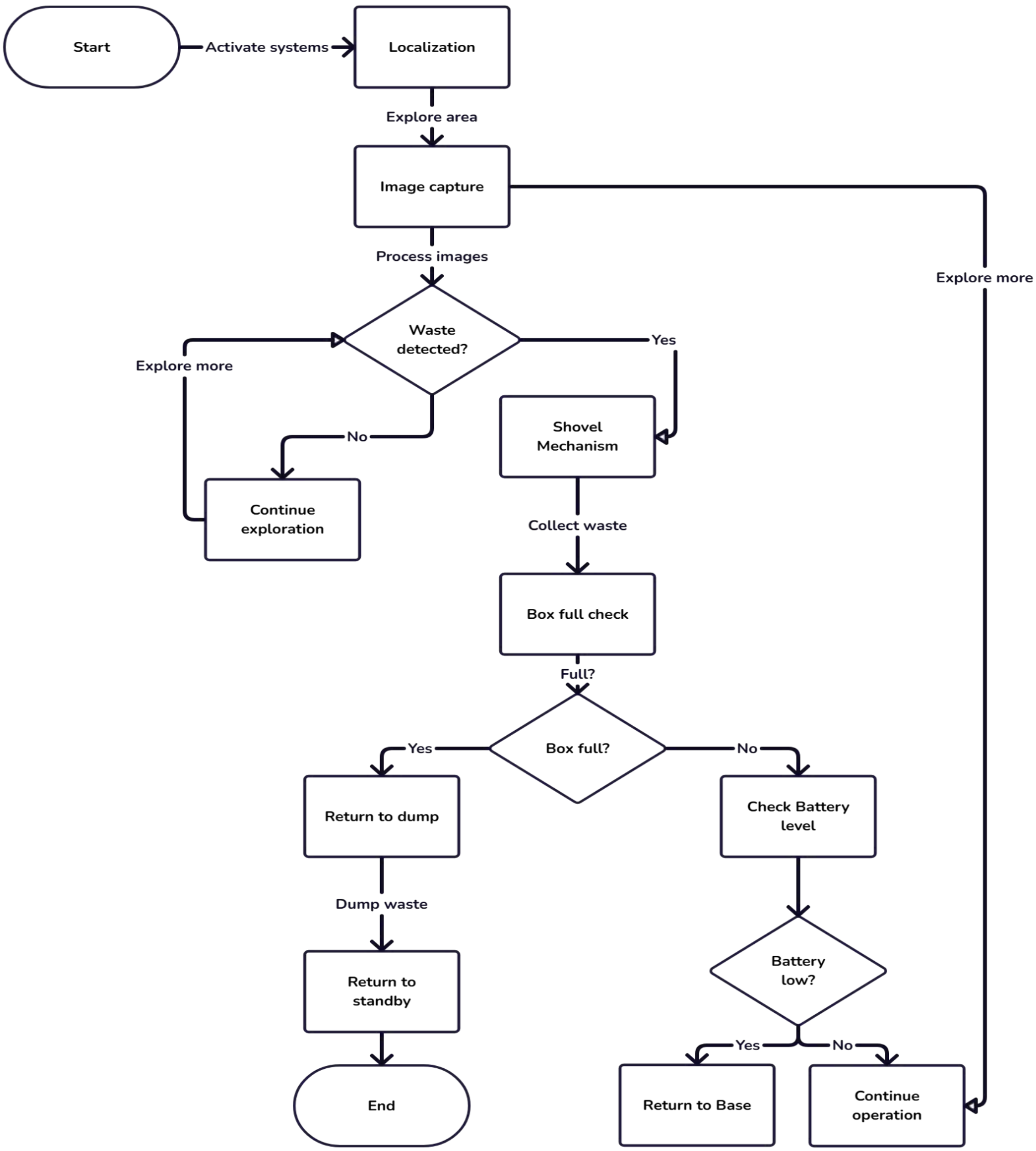


Figure 4 : System Flowchart for Design Approach 1

2.3.2 Design approach 2 (With Robotic Arm Mechanism)

This approach is more or less the same as Approach 1, wherein an autonomous cleaning machine is sent to clean a 200 m 2 zone with the help of GPS and obstacle detection sensors to detect and pick up garbage. The major difference, however, can be seen in the collection of waste. As opposed to Approach 1, which uses a shovel system, this device uses a 4DOF robotic arm. The arm picks up the waste accurately based on waste visible on the board image (e.g., YOLO model or MobileNet) and puts it in a collection container. The container is emptied at the base station via an actuator mechanism when full and the device either re-initiates or goes into standby depending on the battery status.

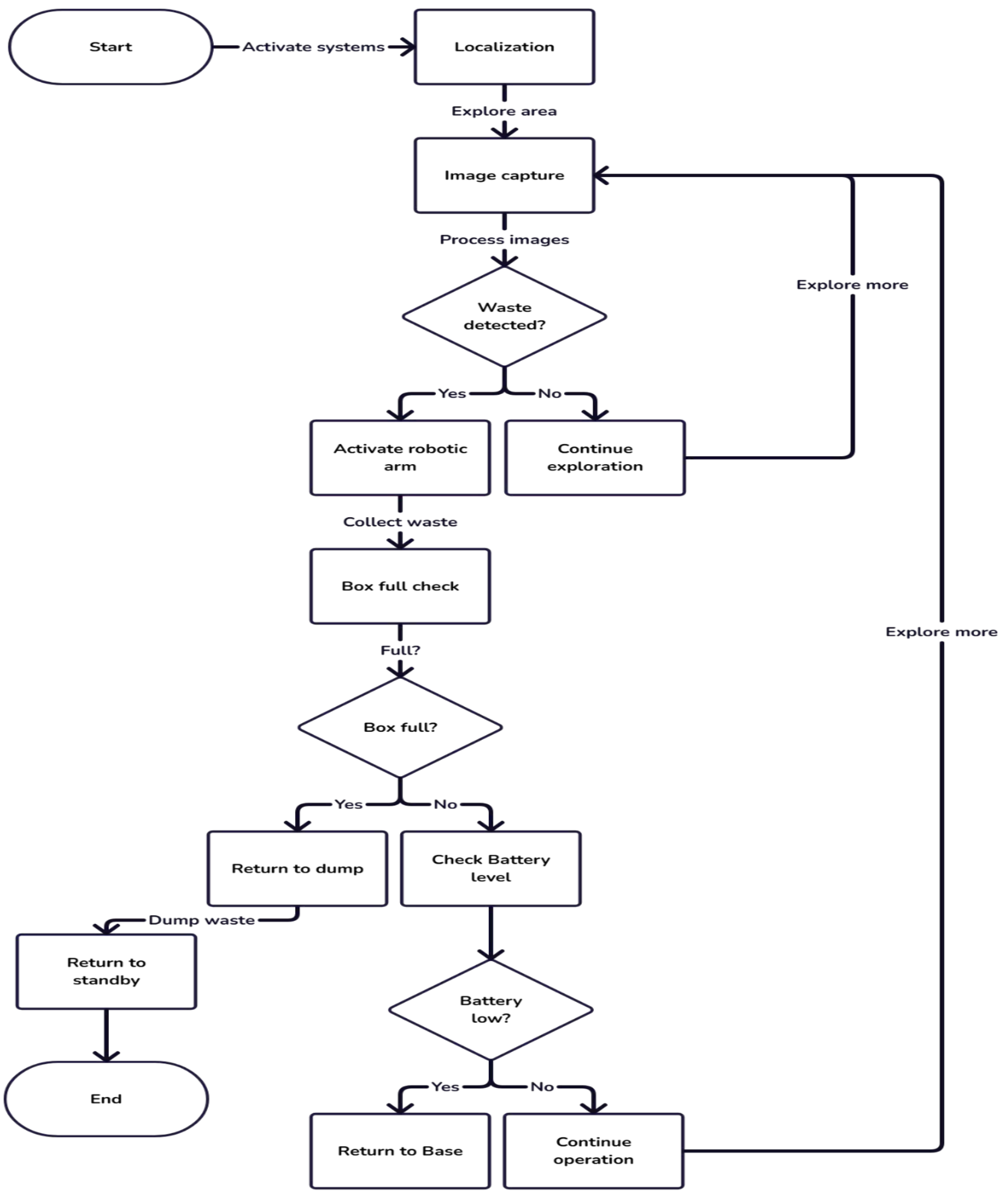


Figure 5: System Flowchart for Design Approach 2

2.3.2 Design Approach 3 (With Dual Conveyor Belt Mechanism)

This method is based on a very similar operation pattern as Approaches 1 and 2, encompassing autonomous navigation, avoidance of obstacles, image-guided waste sensing, and turnaround-to-station behavior. Nevertheless, the main dissimilarity is associated with the waste collection mechanism. Unlike Approach 1 (shovel) or Approach 2 (robotic arm), this design employs a 2-conveyor belt system. First is a collection of waste on the ground by the first conveyor and the second one is transfer of the waste into the onboard collection box. Other processes like localization, dumping and reset of the system are not changed.

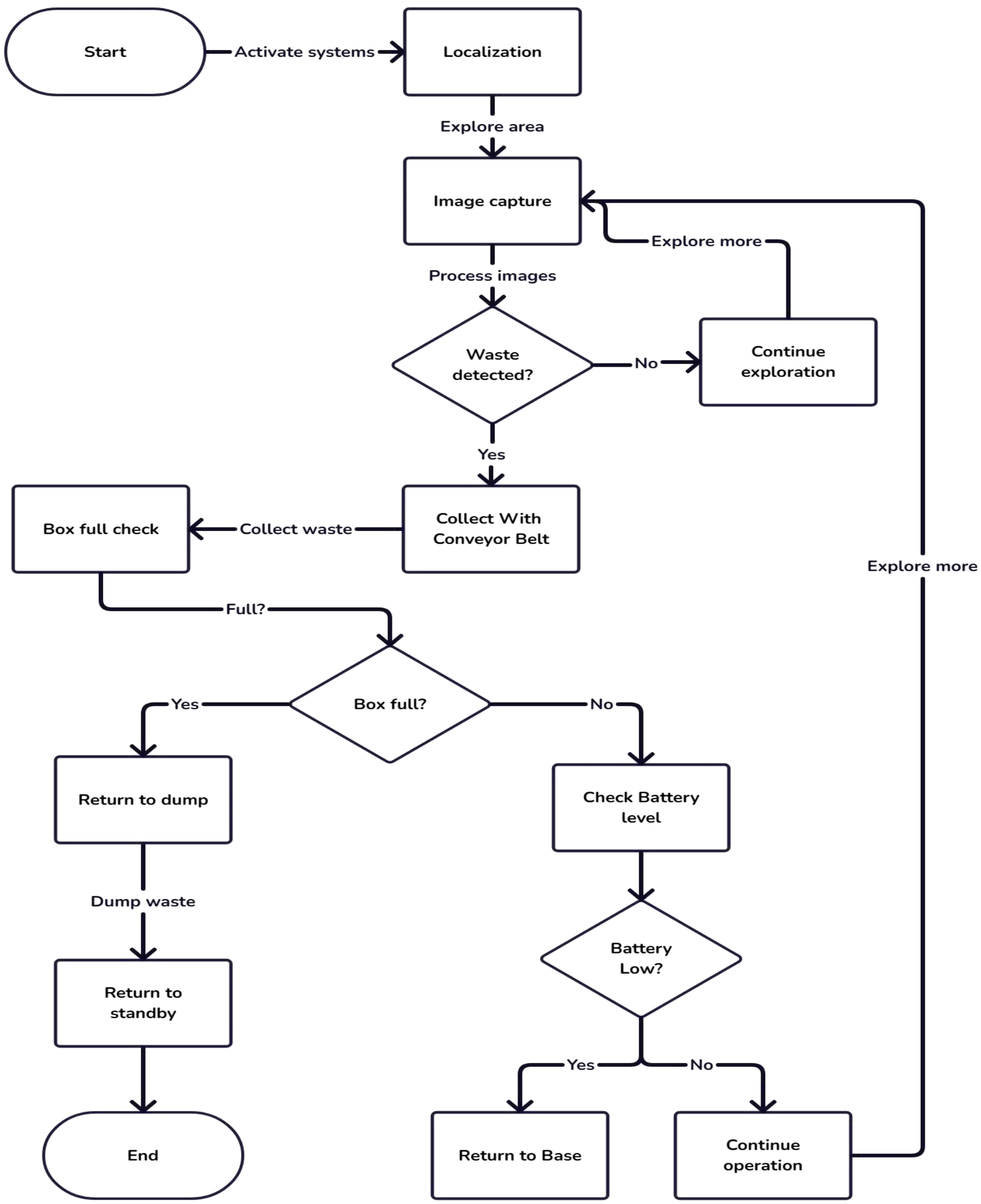


Figure 6: System Flowchart for Design Approach 3

Comparison:

Approach 1, where a shovel system is driven by a servo-motor, is the most viable and balanced approach and solution to an autonomous beach-cleaning robot among the three approaches to the design. It has a less complex mechanical design, reduced use of power and quicker operations than the robotic arm in Approach 2 and dual conveyor in Approach 3. Although the robotic arm is highly precise in collecting various waste items, it contributes to high complexity, reduces the rate of operation and increases energy requirements, thus it is not applicable in rough and sandy beach conditions. Equally, the conveyor belt system used in Approach 3 can provide high throughput yet might not be effective in uneven terrain as well as with scattered or embedded waste that might be hard to collect. On the other hand, the shovel system of Approach 1 is strong, convenient to take care of, and suitable to scoop common litter off the beach promptly and effectively. This is why Approach 1 is the most trusted and inexpensive option; and it is applicable in the scenario of working on the territory of 200 m^2 with the emphasis made on the practical use and the ability to perform in a stable way.

2.4 Analysis of multiple design approaches

In a bid to come up with the most potent and brilliant engineering solution to the Sugandha Point waste collecting device, three possible designs, namely: the Shovel Mechanism, the Robotic Arm Mechanism and the Dual Conveyor Belt Mechanism, were compared rigorously to ensure that the best among them was selected. This analysis has opposed every strategy with harsh technical and economical limitations, such as, cost viability, power utilization, mechanical consistency, and environmental flexibility. This was to find the design combining performance needs and practical constraints of operating in a salty, sandy coastal environment.

Comparative Analysis of Design Alternatives:

Table-3: Comparative Analysis of Design Alternatives

Criteria	Design Approach 1: Shovel Mechanism	Design Approach 2: Robotic Arm Mechanism	Design Approach 3: Dual Conveyor Belt Mechanism
Cost Analysis	Lowest (Estimated 43,000 – 60,000 BDT). Most budget-friendly due to standard components.	Moderate to High (Estimated 47,000 – 65,000 BDT). High cost due to precision servos.	Highest (Estimated 49,000 – 72,000 BDT). Most expensive due to structural complexity and motor requirements.
Collection Efficiency	High. Effective for bulk collection of loose waste and sand mixture.	Moderate. High precision but misses small debris buried in sand; slow cycle time.	High. Continuous intake allows for high volume, but efficiency drops on uneven terrain.

Energy Efficiency	High. Actuators only consume peak power during the scoop cycle.	Moderate. Servos require constant holding torque, draining power continuously.	Low. Motors must run constantly to drive the belts, leading to rapid energy depletion.
Sustainability	High. Lowest energy footprint and fewer materials required for fabrication.	Moderate. Higher energy demand and electronic waste potential from damaged servos.	Low. High energy consumption reduces battery life; rapid belt wear generates material waste.
Maintainability	Excellent. A simple open mechanical structure is easy to clean and repair locally.	Poor. Complex joints are difficult to troubleshoot; sand ingress ruins servos.	Fair. Belt tensioning and alignment require frequent skilled maintenance.
Usability	Simple. Operates on basic "detect-scoop-dump" logic.	Complex. Requires sophisticated operator oversight or complex autonomy.	Moderate. Simple controls but requires constant physical adjustment for terrain height.
Operational Complexity	Low. Tolerant of minor positioning errors.	High. Requires precise coordinate calculation and inverse kinematics.	Moderate. Requires synchronization between vehicle speed and belt speed.
Public and Expert Validation	Preferred (54.8%). Selected by majority for reliability and simplicity.	Least Preferred (21.4%). Viewed as overly complex for the task.	Neutral (23.8%). Acknowledged for speed but criticized for cost/maintenance.
Mechanical Complexity	Low. Single primary axis/linkage.	Very High. 4+ Degrees of Freedom (DOF) requiring precise synchronization.	High. Requires complex roller assemblies, tensioners, and gearing.
Accuracy & Precision	Coarse. Scoops area around the object	Fine. Can pick specific small items	Area-based. Sweeps a path regardless of specific object location.
Risk Management	Low Risk. Failure of one part usually doesn't cause catastrophic system failure.	High Risk. Failure of one joint renders the arm useless; prone to jamming.	Moderate Risk. Belt jamming or tearing stops collection entirely.
Serviceability	High. Parts are accessible and standard.	Low. Specialized knowledge required to replace/calibrate motors.	Moderate. Changing a belt requires significant disassembly.
Speed	Moderate. Discrete cycles (Stop -> Scoop -> Move).	Slow. Discrete cycles (Stop -> Calculate -> Grasp -> Move).	Fast. Continuous collection while moving (High theoretical throughput).

Average Power Consumption	~76 – 80 Watts	~82 – 85 Watts	~130 – 142 Watts
Peak Power Draw	Moderate. Spikes only during lifting of heavy loads.	Moderate. Spikes during multi-joint movement against gravity.	High. Significant surge current required to start belts under load.
Battery Capacity Required	Standard. Compatible with standard Li-ion packs for required runtime.	Standard to High. May require larger packs to offset holding torque drain.	High. Requires high-capacity, high-discharge batteries to sustain operation.

The final choice is the Shovel Mechanism as the most promising option based on the thorough evaluation of such variables as cost, energy efficiency, and maintenance needs. Although the Conveyor Belt has a greater throughput and the Robotic Arm is more precise, they have too much power consumption, high cost, and mechanical weakness to be used in such an application. The Shovel Mechanism is the most appropriate to the project requirements as it is a sustainable, affordable, and strong device that can resist the severe environment of Cox Bazar and achieve the main goal of an autonomous waste collection.

2.5 Conclusion

Three mechanical design methods of the autonomous waste collection device Shovel Mechanism, Robotic Arm Mechanism, and Dual Conveyor Belt Mechanism were reviewed in the light of cost, energy efficiency, reliability, maintainability and the ability of the device to work in the environment of sandy coasts. Although the robotic arm is very precise and the conveyor belt allows continuous collection, both methods have a drawback in their higher power requirements, complexity of the mechanical process and inability to operate in saline water and irregular beach waves.

The Shovel Mechanism has the best balance of performance and being practical. Its minimal design, low energy consumption, ease of maintenance coupled with high resistance to sand ingress, renders it very suitable in the long-term operation in coastal settings. Based on the technical feasibility, environmental flexibility, and economic considerations, the shovel-based design is chosen as the most efficient answer to the autonomous collection of wastes at the Sugandha point.

Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

3.1 Introduction

Designing and implementing an autonomous engineering system is a successful task that demands the selection and effective application of the modern engineering and information technology (IT) tools carefully. In such multidisciplinary projects as the Autonomous Waste Collecting Device at Sugandha Point of Cox's Bazar Sea Beach, those tools are extremely important to guarantee the accuracy, effectiveness, and reliability of the system. Current software and hardware allow engineers to do virtual modeling and simulation, embedded programming, and machine learning creation to do design verification and optimization.

The project has several subsystems such as mechanical structures, electronic circuits, embedded control units, and smart waste detecting algorithms. The subsystems require custom tools to analyze, develop and test. The chassis, shovel mechanism, robotic arm and conveyor system are mechanical parts that need to be accurately modeled and analyzed in 3D. Likewise, circuits with the sensors, actuators, motor drivers and microcontrollers are also to be verified by circuit simulation so that operation is assured to be reliable. To realize control logic and system behavior coordination, embedded software tools are required, and machine learning platforms are needed to make waste recognition in the real world beach setting intelligent. It is possible to compare the alternative approaches to the design, fast adjustment in case of failures, and identify the design constraints at an early stage with the help of the choice of the modern engineering and IT tools. Through the combination of computer-aided design software, simulation of circuits, embedded programming systems, and machine learning systems, the suggested system can be assessed extensively before it is fabricated. This systematic method will save a lot of time to develop, it will save a lot of cost and surely even improve the performance of the entire system.

Thus, the choice and use of the current engineering and IT tools employed during the project are demonstrated in this part. All the tools were selected depending on functionality, cost-effectiveness, compatibility, and applicability of the tool in real-time autonomous working in coastal areas like Sugandha Point, Cox Bazar.

3.2 Selection of Modern Engineering/IT Tools

In the design, development and testing of any engineering projects, it is important to select the appropriate modern engineering and IT tools. With the help of these tools, we can work on simulation, modelling, code, and train AI models, which is more convenient to compare the various design variants of a project and to make a fast change in case of a fault. This means that in the case of our design like a shovel, robotic arm or a conveyor belt we decide which one is best by comparing. With the integration of mechanical CAD software, circuit simulators, embedded program platforms, and ML platforms we can be confident that the device will be efficient and reliable well before it is physically constructed. This technique assists in minimizing the development time as well as expenses.

i. **3D-Modeling:**

- **Selected Tool:** Fusion 360
- **Alternative Tools:** SolidWorks, AutoCAD.
- **Justification for Selection:** Fusion 360 provides integrated 3D modelling and simulation at lower cost and with cloud collaboration, unlike SolidWorks (expensive) and AutoCAD (lacks advanced 3D simulation).

Fusion 360: The primary CAD software to be used is Fusion 360 that is used to design the mechanical components of the device. It enables us to build the 3D models of the chassis, shovel, robotic arm and conveyor belt in great detail, and thus it will be easier to compare the various designs. With its motion analysis and stress testing capabilities, we will be able to verify that the chosen design could withstand the actual opportunity such as lifting garbage and traveling through the uneven sands of the beach of Cox-Bazar. This assists us to make sure that the design is robust, effective and environmentally acceptable. Through Fusion 360, we can reduce the amount of mistakes made during prototyping and create correct designs that are ready to be made into products.

ii. **Circuit Simulation:**

- **Selected Tool:** Proteus
- **Alternative Tools:** Multisim, LTSpice.
- **Justification for Selection:** Proteus offers combined circuit and microcontroller simulation, whereas Multisim is costly and LTSpice lacks embedded system support.

Proteus: Proteus is decided to be used in simulating the electronic circuits and microcontroller systems where navigation, sensing, and movement are controlled. Our machine has such parts as sensors (ultrasonic, IR, GPS), actuators (DC motors, linear actuators, servos), and controllers (Arduino and Raspberry Pi). Proteus also provides us with a secure testing platform on which we can experiment with these elements virtually and then put the actual hardware together. This assists us in confirming the signal processing, motor driver reaction and sensor reliability under various circumstances. Proteus allows mitigating the possibility of hardware failures and enhanced real-life system reliability by simulating the detection of obstacles, path correction, and waste collection.

iii. **Microcontroller setup:**

- **Selected Tool:** Arduino IDE
- **Alternative Tools:** PlatformIO, MPLAB X IDE.

- **Justification for Selection:** Arduino IDE is beginner-friendly and hardware-compatible, while PlatformIO is more complex and MPLAB X IDE suits PIC microcontrollers.

Arduino IDE: The microcontrollers that process commands such as motor control, obstacle detection and data communication are programmed using Arduino IDE. It offers a easy to code C/C++ platform and has numerous inbuilt libraries on sensors and motor drivers. In this project, it is not difficult due to the Arduino IDE to write and test control algorithms of navigation and shovel/conveyor movement. It also enables us to debug behaviour in real-time, upload firmware to the hardware, and to have a well-functioning communication between the mechanical and electronic components of the machine. This assists in maintaining the entire device in synchrony.

iv. **ML Compiling:**

- **Selected Tool:** Python
- **Alternative Tools:** C++ with OpenCV.
- **Justification for Selection:** Python is open-source, easy to use, and rich in libraries, whereas C++ requires more development effort.

Python: The primary programming language that we rely on developing the system of waste detection and classification is Python. We can learn to detect the presence of typical waste on a beach (plastic bottles, wrappers and cans) with the help of a convolutional neural network (CNN) using libraries such as OpenCV, TensorFlow and NumPy. The python can also be fitted effectively with the camera of Raspberry Pi enabling the learned AI model to identify waste in real time. Through the experimentation with the models in Python, we are able to trade-off between accuracy and processing speed, and ensure that the vision system operates effectively on the field.

v. **ML-Training:**

- **Selected Tool:** Google Colab
- **Alternative Tools:** Kaggle Notebooks, AWS SageMaker.
- **Justification for Selection:** Colab offers free GPU/TPU resources and easy collaboration, unlike Kaggle and SageMaker (costly).

Google Colab: The training of machine learning models is done on Google colab which is our cloud-based platform. Because it offers free GPU/TPU acceleration we can now train CNNs with large sets of beach wastage images without having to buy costly local hardware. Teamwork is also encouraged by Colab, meaning that several people can cleanse datasets, optimize hyperparameters, and assess outputs simultaneously. The models are trained and then transformed to lightweight formats which are then deployed on the Raspberry Pi and can be used in real-time. This will have the advantage of optimising and making our AI system reliable before it is deployed to the real environment.

3.3 Use of Modern Engineering and IT Tools

The Autonomous Waste Collections Devices of Sugandha Point of Cox's Bazar Sea Beach should be developed with the combination of the modern engineering and information technology to achieve the accuracy, efficiency, and reliability. The tools are used in mechanical system design, simulation of electronic systems, embedded programmable systems, and waste detection using machine learning. With a systematic application of these tools, it can perform virtual testing, performance optimalization, and validation of the system before the actual implementation of the system, which helps to minimize the cost of developing the system and decreases the technological risk.

A. Mechanical Design and 3D Modeling

The basic computer-aided design (CAD) tool that is used in the development of a mechanical system is Autodesk Fusion 360. The chassis, shovel mechanism, robotic arm and conveying system are some of the critical components that are designed and modelled using it. Fusion 360 is parametric (modelling), assembly design, and with built-in motion and stress analysis features. These characteristics enable consideration of the load-carrying ability, mechanical motion and stability against the structural conditions in the actual situations of the beach in terms of uneven sand surface and the changing weight of the waste. Fusion 360 will be suitable in the process of iterative design and rapid prototyping compared to other tools, e.g., SolidWorks and AutoCAD because it provides cost-effective cloud collaboration with high-level simulation support.

B. Electronic Circuit Simulation and Validation

Proteus Design Suite is used in terms of electronic system design and verification. Proteus enables co-simulation in a virtual environment of an electronic circuit based system and a microcontroller based system. It is modeling sensor interfaces (ultrasonic, infrared and GPS modules), actuators (DC motors, servos and linear actuators), and motor driver circuits. Also, the logic in microcontrollers is put to test to check signal processing, motor response, and obstacle avoidance behavior. Proteus is chosen instead of Multisim and LTSpice because it supports system simulation which is an embedded system simulator; this can be used to identify design errors early before hardware is developed, where the reliability of the hardware can be ensured..

C. Embedded System Programming and Control

Programming microcontrollers that control motors, sensors and navigation is done using the Arduino Integrated Development Environment (IDE). The IDE is compatible with C/C++ and it has very rich libraries of interfaces to sensors, motor drivers and communication modules. Control algorithms are created and tested using Arduino IDE and used to coordinate the mechanical activities of waste collection, conveyor movement, and directional control. Its simplicity, support of real-time debugging and compatibility with hardware make it an appropriate platform in the development of the embedded system in a short period of time.

D. Machine Learning Implementation

Python is the main language of programming employed to perform smart activities of detecting and classifying waste materials. Python is chosen because it is an open-source language with good machine learning and computer vision libraries, which are OpenCV, TensorFlow, and NumPy. A convolutional neural network (CNN) is trained to detect typical wastes found in the beach including plastic bottles, wrappers, and cans given by the camera. Python can also be used to integrate well with the Raspberry Pi camera module, allowing real-time inference when the device is in operation. Unlike C++-based implementations, Python is also much faster to develop and model experimentation is much easier.

E. Machine Learning Training Platform

The cloud-based machine learning model training and optimization services are provided through Google Colaboratory (Colab). Colab offers public access to GPU and TPU resources which can be used to train deep learning models with large image data without the need to use high-end local hardware. The platform can be used to develop together, manage data sets, and hyperparameter tune. Once trained the optimized models are converted to lightweight formats and run on the Raspberry Pi in real-time. This will not only guarantee high detection rates but it is also computationally efficient in the field.

F. System Integration and Validation

The integration of CAD tools, circuit simulators, embedded programming platforms, and machine learning environments makes it possible to fully integrate and test a complete system. Subsystems, which are mechanical, electronic and intelligent are tested independently and then assembled to coordinate their working together. This multi-tool engineering technique is to make the autonomous waste collecting gadgets to fulfill the performance, reliability and environmental adequacies to operate in the Sugandha Point, Cox Bazar.

3.4 Conclusion

The availability and efficient use of the modern engineering and information technology tools contribute to the successful development of the Autonomous Waste Collecting Device of Sugandha Point of the Cox-Bazar Sea Beach. In this project, the application of the right tools was used in mechanical design, electronic simulation, embedded programming, and machine learning implementation to achieve the accuracy, efficiency, and reliability of the system.

The use of computer-aided design tools facilitated an accurate mechanical modeling and structural modeling to make sure that the device was capable of surviving the actual conditions in the beaches like irregular terrain and a fluctuating load of the waste. The circuit simulation tools helped to verify the electronic components and control logic at a very early stage, however and greatly minimised the chances of failure of hardware. Embedded programming platforms provided an easy way to coordinate sensors, actuators, and control units and machine learning frameworks provided intelligence in waste recognition and real-time decision-making.

The combined application of these modern tools also made possible virtual testing, alternative design comparison and fault detection before the implementation is done physically. This led to a reduction in development time and a reduction in cost and idealization of system performance. On the whole, it can be stated that the rigorous use of the modern engineering and IT solutions made the proposed autonomous waste collecting device much more robust, functional, and practical, which would allow deploying it to a real-world scenario to Sugandha Point, Cox's Bazar.

Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

4.1 Introduction

Arriving at the most efficient engineering solution to autonomous cleaning of the beach implied a strict optimization of the originally suggested design ideas to coordinate them with the particular environmental and operational conditions of the Sugandha Point. After the thorough comparative study of the Shovel, Robotic Arm, and Conveyor Belt mechanisms in relation to such important variables like cost, energy usage, and environmental conditions, the Shovel Mechanism was singled out as the most ideal candidate to use. Herein lies the transfer of the conceptual selection to practical refinement where it is now time to tweak the performance of the chosen subsystem, in this case the combination of the Raspberry Pi vision system and the high-torque actuation units to achieve optimal performance in the sandy terrain. Additionally, it reports on the experimental validation procedures used to test the accuracy to navigate, waste detection latency, and mechanical stability of the device which will guarantee that the synthesized solution is not only based on the theoretical design specifications but provides strong performance in the real-life experimental conditions as well.

4.2 Optimization of Multiple Design Approach

4.2.1 Design Approach 1: Shovel Mechanism Optimization

The shovel mechanism was represented as a strong and simple solution. The design was done in detailed 3D format which depicts a small chassis that has the frontal shovel assembly mounted onto linear actuators to provide lifting and tilting forces, and a waste storage bin located at the rear.

Electrical Circuit Simulation: Full Circuit simulation in proteus was created to test the essence of electronic systems.

i. Electrical Circuit Simulation

Obstacle Detection: Two ultrasonic sensors (HC-SR04) with variable resistors were simulated in a circuit. The output managed to show the messages of objects detected with the real-time distance measurements when an object entered the range of 50cm.

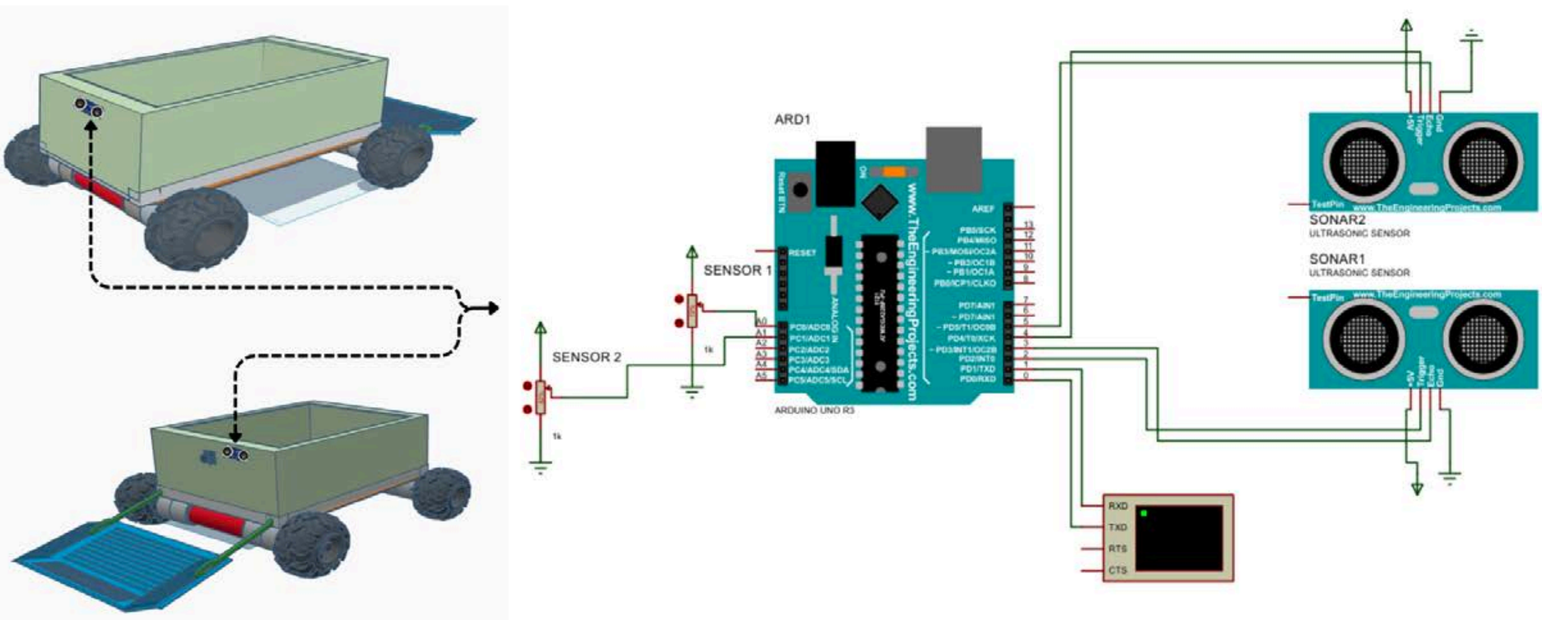


Figure 7: Circuit diagram for Obstacle Detection

This is the obstacle detecting circuit based on ultrasonic sensors. This sub-circuit has a variable resistor, and this is what enables us to adjust the detection range. In this case we have two variable resistors and when we lower the values of the variable resistors the system perceives that the object is coming nearer to the ultrasonic sensor.

Output:

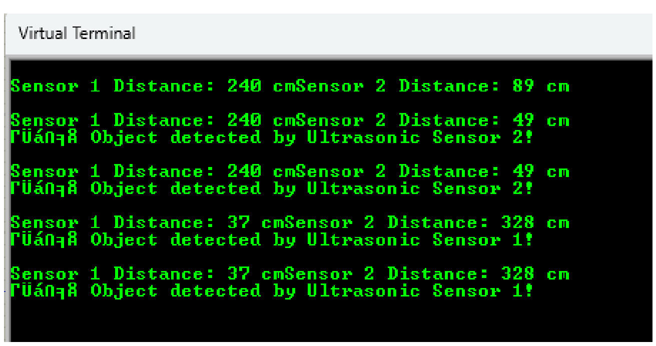


Figure 8: Software output for the obstacle detection subsystem

We can observe this when we see the output that when an object enters a distance of less than 50 centimeters of the sensor it will indicate the sensor 1 is active by displaying the text Object detected by Sensor 1. In the same way, when Sensor 2 is employed the display will give out a result of Object detected by Sensor 2. The output also gives the distance of the object in real time besides detection.

DC Motor RPM Control: A sub-circuit consisting of four DC motors (two on each side) powered by L298N motor drivers was put into test. The simulation with clock signals of different frequencies as speed control inputs proved that it was independent that the left and right motor pairs could be controlled independently in steering with the differential drive.

- **Simulation for DC motor RPM Control:**

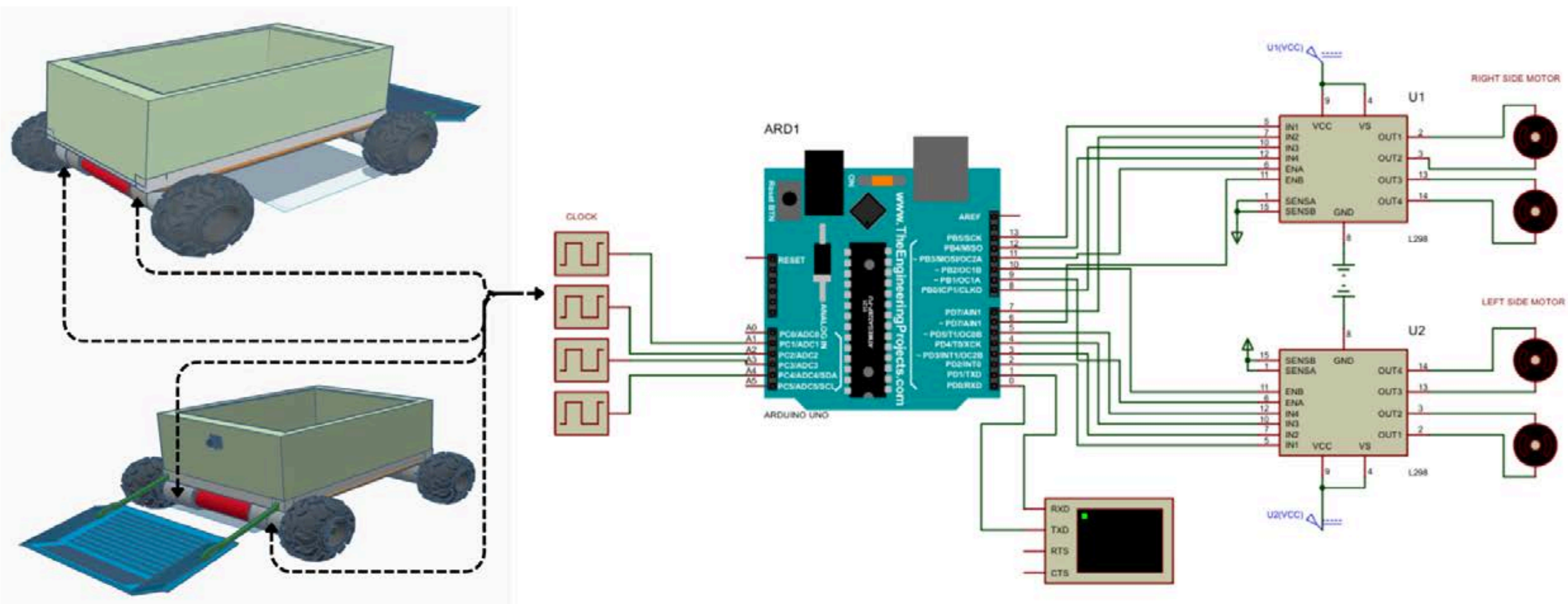


Figure 9: Circuit diagram for DC motor RPM Control

This is the sub circuit, wherein we demonstrate the control of the main Dc motor and enable us to vary the Dc motor. The system can use four clock signals each of which can supply various frequencies. These frequencies can vary such that the RPM of the motor varies as well. We have got two motors on the right hand and two on the left hand. As an illustration, when we wish to adjust the speed of the motors on the left side we only change the frequency of the corresponding clocks and thereby cause the motors to run quicker or slower. On the same note, the slower we slow down the two right motors, the more we will convert the device into the right direction. Conversely, reducing the speed of the two motors on the left will cause the device to rotate on the left.

Output:

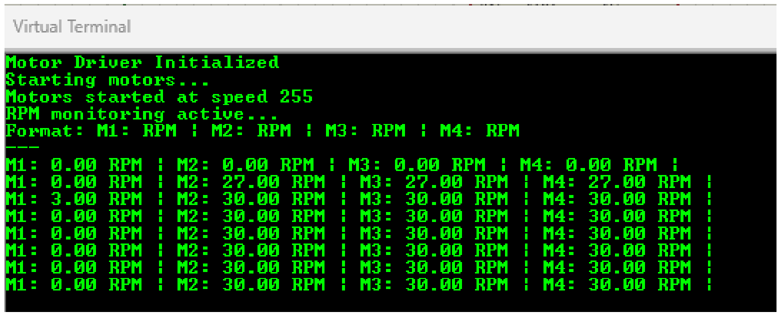


Figure 10: Software output for the DC motor RPM Control

This output indicates the variations of the rpm that we obtained when the frequency of the clock was altered.

Shovel Actuation: A circuit that drives two servo motors (which correspond to the lift and the tilt of the shovel) was attached. A manual push button acted as a simulation of waste detection, which caused the servo sequence to be triggered hence an output of Waste detected and collected.

- **Simulation for Shovel Mechanism Using Servo:**

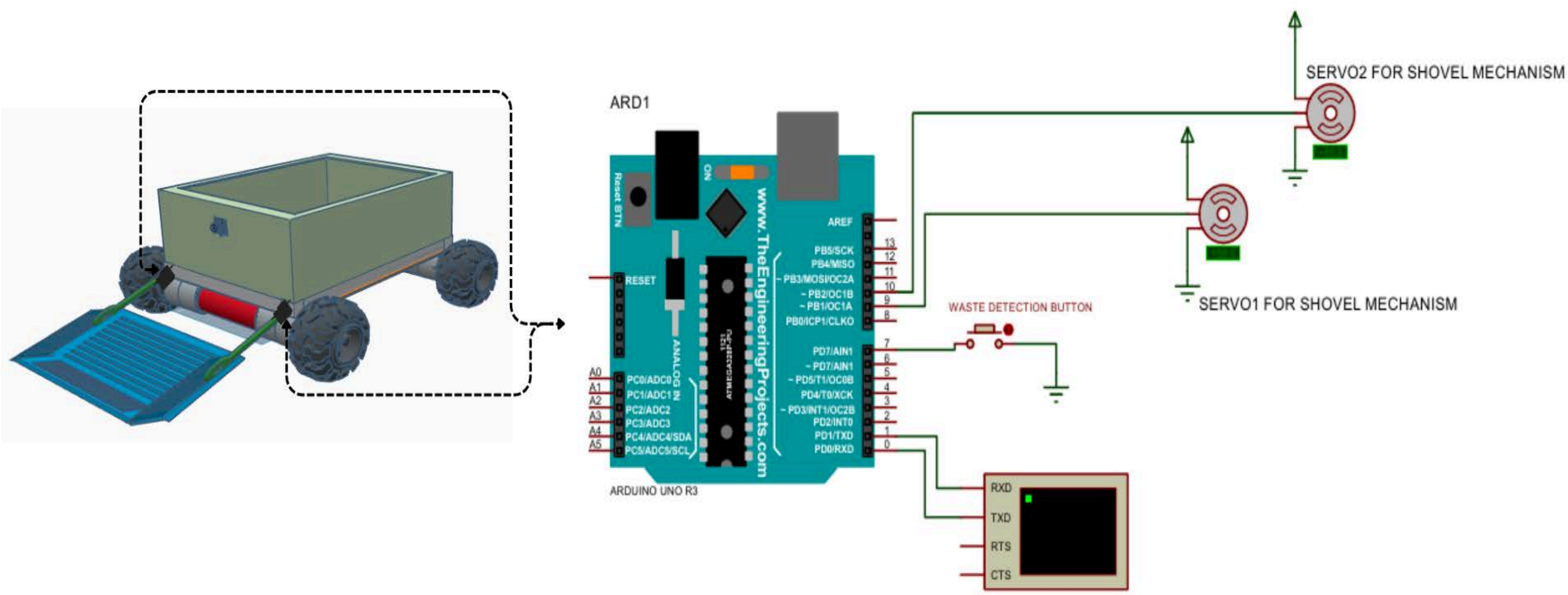


Figure 11: Circuit diagram for Shovel Mechanism Using Servo

This is our second sub-circuit. Where we used two servos which will be used as the shovel mechanism to pick up waste and we also used a manual push button for detecting waste.

Output:

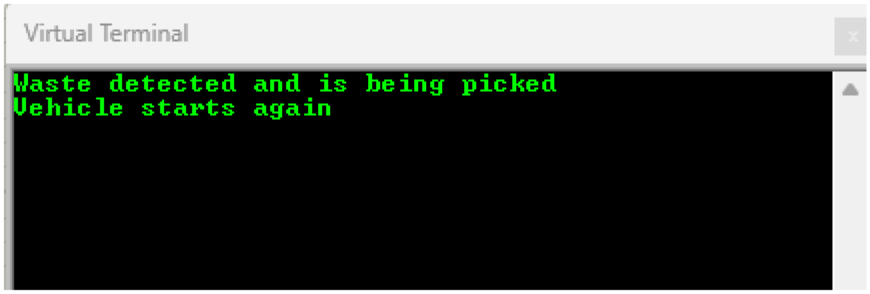


Figure 12: Software output for for Shovel Mechanism Using Servo

Similar to the output, once the push button is press the output will show Waste detected and collected. When the push button is released, the output will be changed to "Device starts again" which means that waste detection is not provided and the device is restored to its usual mode.

- **Main Circuit:**

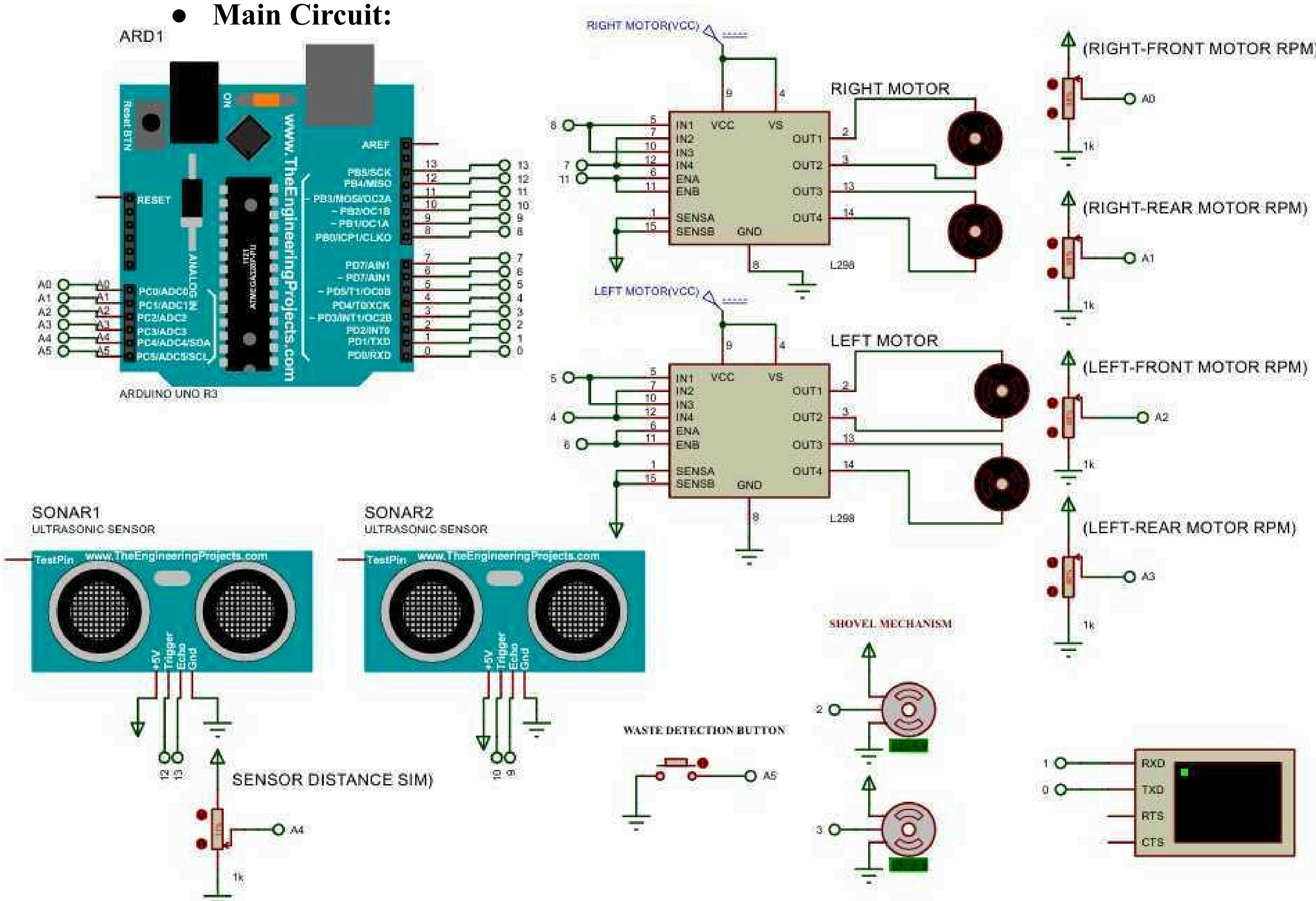


Figure 13: Circuit diagram for Main Circuit

This is a primary circuit that brings all the subcircuits together. In this case we employed two servo as shovel mechanism, variable resistors to vary the DC motor rpm and a push button which is employed as the waste detection. There were also two motor drivers, which were used to drive DC motors. In the case of object detection, we employed two ultrasonic sensors, which were used to detect the objects in front and back. We also employed manual switches in detection of objects.

Power Regulation: A buck converter circuit has been designed and calculated to step down 12V to 5 V. A switching frequency of 20kHz and a duty cycle of 42 percent was found to give stable operation using appropriate values of inductance (≈0.48mH) and capacitance (≈37.5µF).

- **Simulation for Buck converter:**

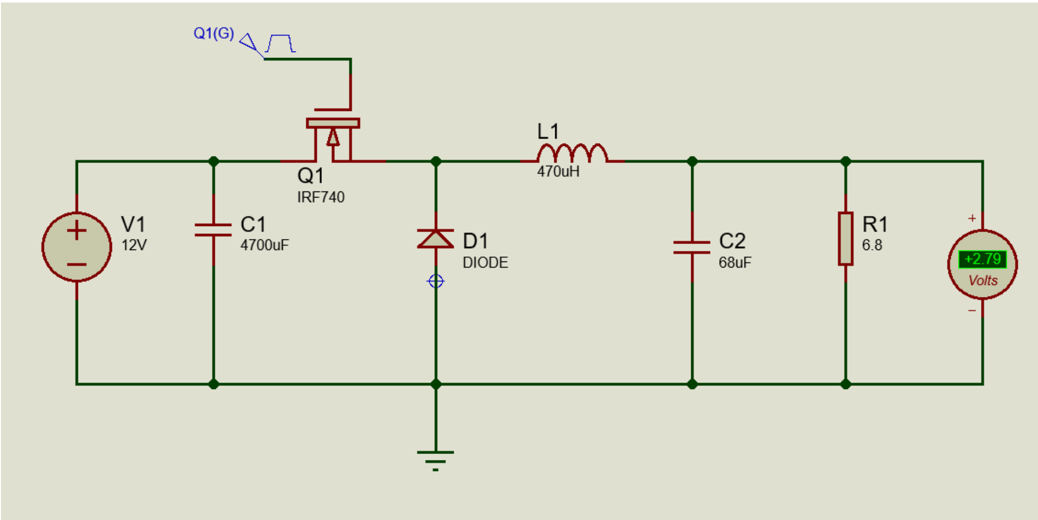


Figure 14: Circuit diagram for Buck converter

A buck converter is a variation of DC-DC converter that reduces the voltage of a higher voltage to a lower voltage but increases the current. It is merely a higher DC voltage (such as 12V) to lower DC voltage (such as 5V) which is accomplished efficiently with the aid of a switch (transistor), diode, inductor, and capacitor.

i. Buck Converter calculation:

For 12V to 5V,

New Pulse Generator Settings:
Frequency (Hz): Keeping it at 20k

The most important change is the duty cycle, which determines the output voltage.

- Formula: Vout = $(Duty\ Cycle\ (D)\ \times\ Vin)$
- Calculation: D = $(\frac{5V}{12V}) \approx 0.4167$

Pulse Width (%): 42

1. Inductor(L1):
    - Formula: L = $(\frac{Vout\times(1-D)}{fsw\times\Delta IL})$

      (Assuming inductor current ripple, ΔIL, is 30% of 1A, so 0.3A)
    - Calculation: L = $(\frac{5V\times(1-0.4167)}{20{,}000\ Hz\times0.3A}) = \frac{2.9165}{6000} \approx 0.00048$ H

2. Output Capacitor (C2):
    - Formula: C = $(\frac{\Delta IL}{8\times fsw\times\Delta Vout})$

      (Assuming output voltage ripple, ΔVout, is 1% of 5V, so 0.05V)
    - Calculation: C = $\frac{0.3A}{8\times20{,}000\ Hz\times0.05V} = \frac{0.3}{8000} = 3.75\times10^{-5}$ F

3. Load Resistor (R1):

   example, to draw 0.5A (500mA):

    - Calculation: R= $\frac{V}{I} = \frac{5V}{0.5A}$ =10Ω
    - Recommended Value: 10Ω

Power Analysis: There was a component-based power audit. A total peak draw of the system peaked at some 78W and consisted of a Raspberry Pi 4 (15W), four DC motors (24W), actuators (24W), sensors, and controllers. A 12V 15Ah Li-ion battery was selected to achieve the 2-hour operational goal, which would give it a projected operation time of 3.6 hours at a constant load of 50W.

ii. Power Calculation

Table-4: Power Calculation

Component	Quantity	Voltage (V)	Current (A)	Power (W)
Arduino Uno	1	5V	0.05 A	0.25 W

Raspberry Pi 4	1	5V	3 A	15 W
USB Camera	1	5V	0.5 A	2.5 W
DC Motors (for 4 wheels)	4	12V	0.5A	24 W
L298N Motor Driver	1	12V	0.1 A	1.2 W
Servo Motors (for shovel)	2	6V	0.5 A	6.0 W
Linear Actuator (waste dump)	1	12V	2 A	24 W
Sensors (Ultrasonic etc.)	2–3	5V	0.05 A	0.25 W
Voltage Regulators (losses)	1–2	—	—	~3–5 W
Total	—	—	—	~**76.2 W– 78.2 W**.

The device's total power draw is approximately 78.2 Watts. Rounded total power drawn approximately 80 Watts .

Battery Calculation:

Assuming:

- Operating Time: 2 hours
- Total Power Needed: **80 Watts** (peak)
- Battery Voltage: 12V

Battery Capacity Required:

$$\text{Capacity (Ah)} = \frac{Total\ Power\ (W) \times Time\ (h)}{Battery\ Voltage\ (V)}$$

$$\text{Capacity} = \frac{80W \times 2h}{12V} = 13.333\text{Ah}$$

Recommended Battery:

- 12V 15Ah Li-ion / LiPo Battery (for safety margin)

Estimated Runtime:

- If using an 80W peak system with a 12V 15Ah battery,

$$\text{Runtime (h)}= \frac{Battery\ Capacity\ (Ah) \times Voltage\ (V)}{Avg\ Power\ (W)}$$

$$= \frac{15Ah \times 12V}{50W} = 3.6 \text{ hours}\ ; \quad \text{If Avg Power} \ = \ 50\text{W}$$

4.2.2 Design Approach 2: Robotic Arm Mechanism Optimization

This was a precision-oriented approach, where a robot arm that had 4 degrees of freedom (4DOF) was used to collect the waste. The arm was represented in the 3D model attached on a comparable mobile chassis, having base rotation joints, shoulder, elbow, and gripper joints.

Electrical Circuit Simulation: The robotic arm control system was simulated.

Arm Control Circuit: A specially designed circuit was designed to operate four servo motors which were attached to the joints (Base, Shoulder, Elbow, Gripper). The simulation was used to confirm the independent angular control of every servo, which confirmed the basic hardware interface of the arm, which can be easily manipulated to move the arm in a specific direction.

i. Simulation for Robotic Arm

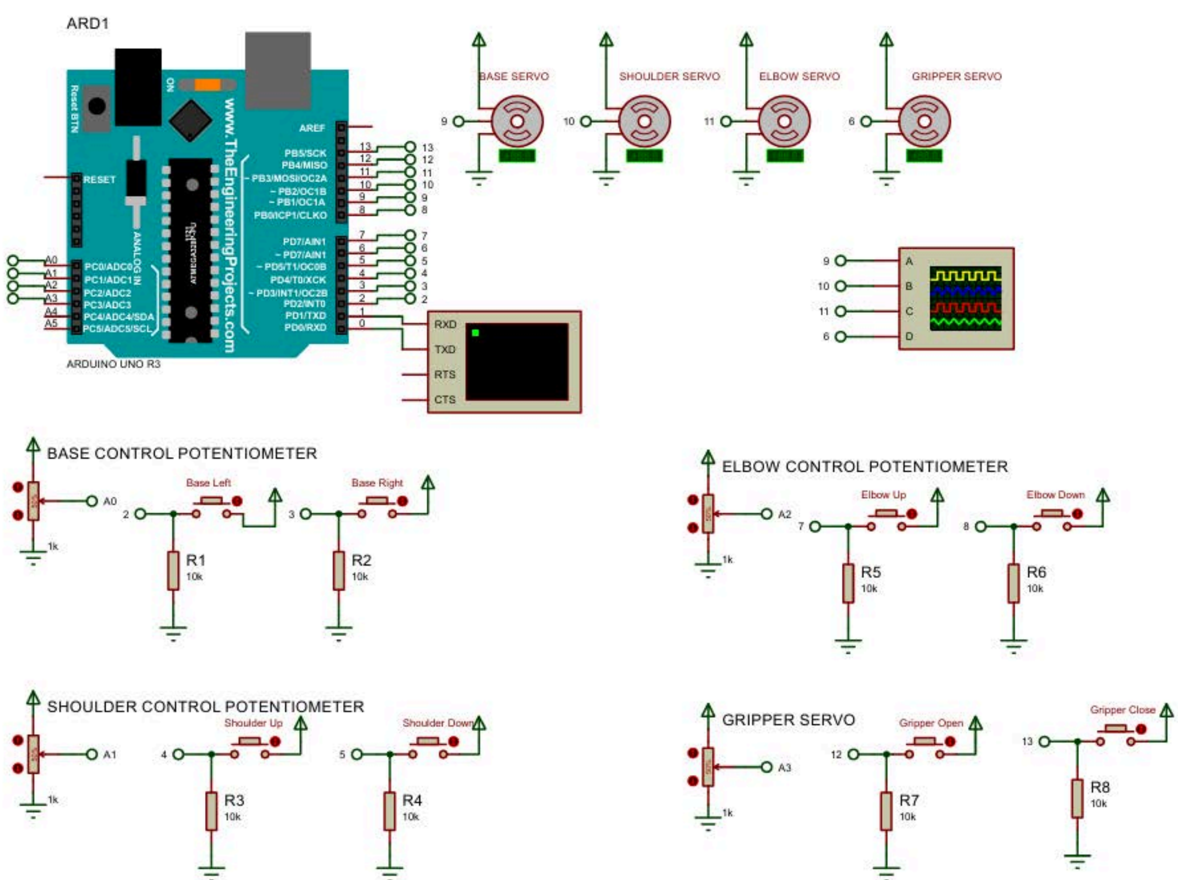


Figure 15: Circuit diagram for Robotic Arm

This is the circuit simulation for robotic arms. This is a 4DOF robotic arm so we are using 4 servo motors: one for Base control, one for Elbow control, one for Shoulder control and one for Gripper.

Output:

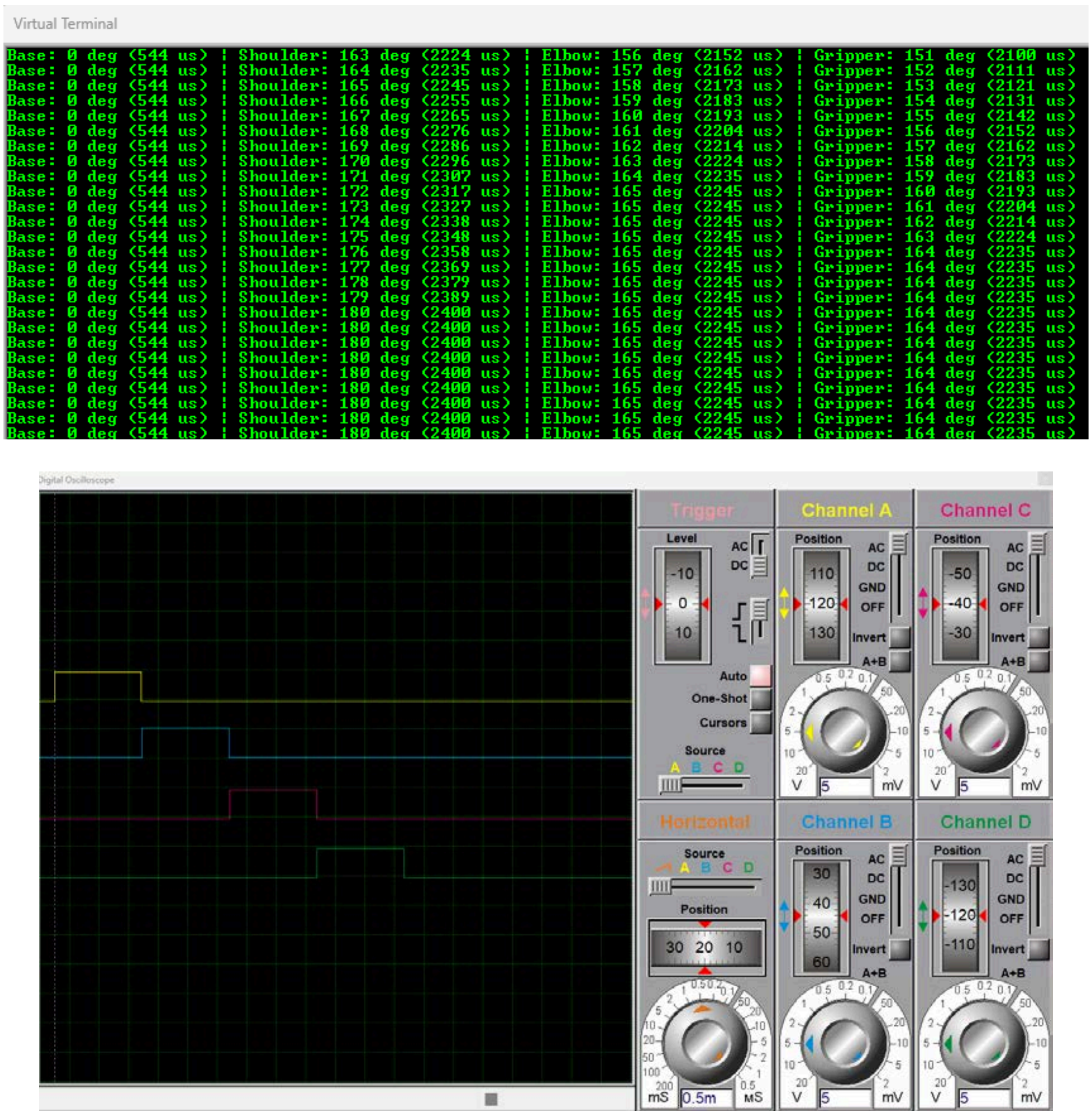


Figure 16: Software output for Robotic Arm

Power Analysis: The calculation of power took into consideration the four high torque servos of the robotic arm and the standard mobility and computing systems. This caused a minor increase in peak power consumption of about 84W. The identical battery (12V 15Ah) was taken into consideration, which provides less runtime (approximately 2.1 hours at peak load conditions) which represents the compromise between accuracy and power longevity.

ii. Power Calculation

Table-5: Power Calculation

Component	Quantity	Voltage (V)	Current (A)	Power (W)
Arduino Uno	1	5 V	0.05 A	0.25 W
Raspberry Pi 4	1	5 V	3 A	15 W
USB Camera	1	5 V	0.5 A	2.5 W
DC Motors (for 4 wheels)	4	12 V	0.5 A each	6W × 4 = 24 W
L298N Motor Driver	1	12 V	0.1 A	1.2 W
Servo Motors (4-DOF arm) (HS-805BB class, running)	4	6 V	0.52 A each	3.12 × 4 = 12.48 W
Linear Actuator (waste dump)	1	12 V	2 A	24 W
Sensors (Ultrasonic etc.)	2–3	5 V	0.05 A	0.25 W
Voltage Regulators (losses)	1–2	—	—	~3–5 W
Total	—	—	—	≈ 82.68W -≈ 84.68 W

Battery Calculation:

Assuming:

- Operating Time: 2 hours
- Total Power Needed: 85 Watts (peak)
- Battery Voltage: 12V

Battery Capacity Required:

Capacity (Ah)= $\frac{Total\ Power\ (W) \times Time\ (h)}{Battery\ Voltage\ (V)}$

Capacity = $\frac{85W \times 2h}{12V}$ = 14.167Ah

Recommended Battery:

- 12V 15Ah Li-ion / LiPo Battery (for safety margin)

Estimated Runtime:

If using a 12V 15Ah battery, battery energy = 15 Ah × 12 V = **180 Wh**.

Runtime (h)= $\frac{Battery\ Capacity\ (Ah) \times Voltage\ (V)}{Avg\ Power\ (W)}$; If Avg Power = 50 W

$= \frac{15Ah \times 12V}{50W}$ = 3.6hours

Runtime (h)= $\frac{Battery\ Capacity\ (Ah) \times Voltage\ (V)}{Avg\ Power\ (W)}$; If the system runs nearer the peak (85 W):

$= \frac{15Ah \times 12V}{85W}$ ≈ 2.1hours ;

4.2.3 Design Approach 3: Optimization of Dual Conveyor Belt Mechanism.

This was a design that focused on continuous collection through two conveyor belts. The 3D model also had a front-horizontal belt where the collection was to be done and a rear-inclined belt where the waste was to be transferred to the storage bin.

Simulation of the Electrical Circuit: The functioning of the conveyor system was simulated.

Conveyor Control Circuit: The designed circuit was to act as a control circuit of two DC motors that would be used to drive the two conveyor belts by using L298N drivers. Manual push buttons (Forward, Emergency Stop) were taken up. The basic control logic was proven correct as the simulation output showed that the motors were activated with a command to go forward, and immediately stopped with a command to stop.

i. Simulation for Conveyor Belt

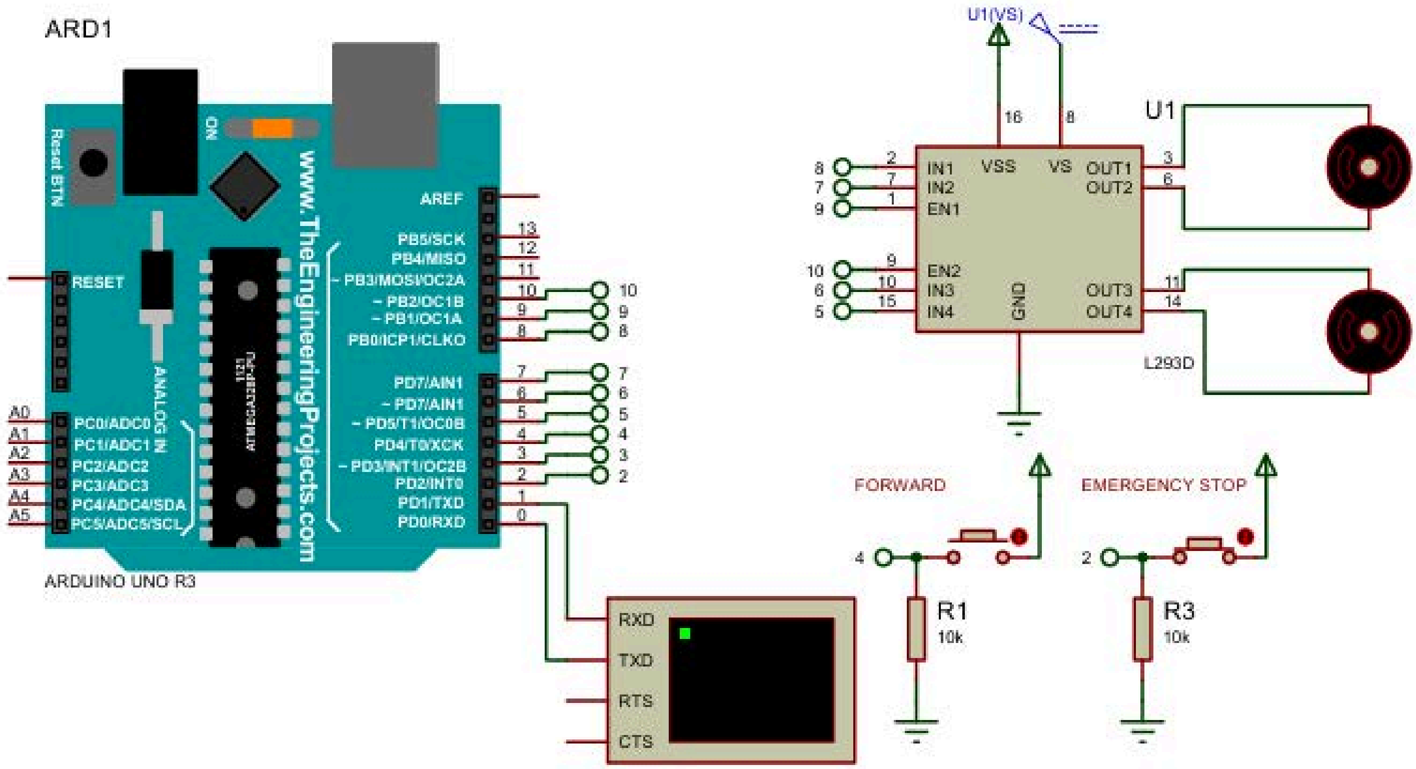


Figure 17: Circuit diagram for Conveyor Belt

The simulation of the conveyor belt mechanism circuit is presented below. In this case, we have taken two dc motors to act as conveyor belt working procedures and manual control of the conveyor belt has been provided using two push buttons.

Output:

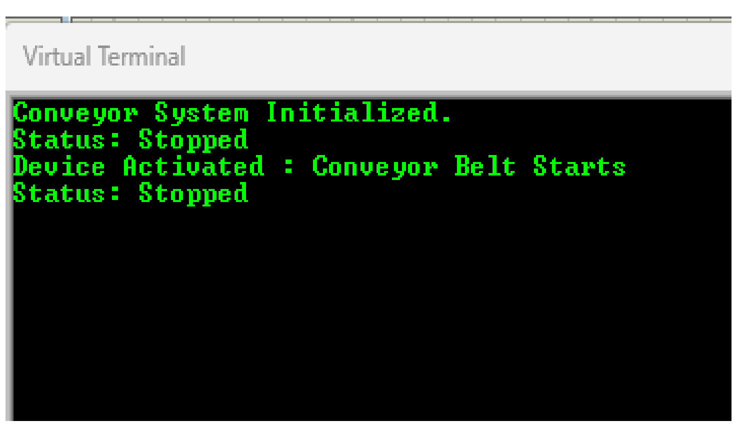


Figure 18: Software output for Conveyor Belt

We can see the initial status of the conveyor belt, as the final result shows an output that the conveyor belt is off but once we press the forward button this will start the device and the conveyor belt will be moving. The emergency stop button can also be used to stop the conveyor belt.

Power Analysis: The twin conveyor belts, which needed high torque continuous rated motors, took up the power budget. With these motors absorbing large current, the overall peak power of the system increased dramatically to about 132W. A bigger 12V 24Ah battery was required to preserve the 2-hour working range, which cost more and took longer to charge, which increased the weight and cost of the system.

ii. Power Calculation

Table-6: Power Calculation

Component	Quantity	Voltage (V)	Current (A)	Power (W)
Arduino Uno	1	5 V	0.05 A	0.25 W
Raspberry Pi 4	1	5 V	3 A	15 W
USB Camera	1	5 V	0.5 A	2.5 W
DC Motors	4	12 V	0.5 A each	6W×4=24 W
L298N Motor Driver	1	12 V	0.1 A	1.2 W
Conveyor Belt Motor (small, gear motor)	2	12 V	2.5 A (typ.)	30W × 2 = 60W
Linear Actuator (waste dump)	1	12 V	2 A	24 W
Sensors (Ultrasonic etc.)	2–3	5 V	0.05 A	0.25 W
Voltage Regulators (losses)	1–2	—	—	~3–5 W
Total	—	—	—	≈ 130.2–132.2 W

Battery Calculation:

Assuming:

- Operating Time: 2 hours
- Total Power Needed: 135 Watts (peak)
- Battery Voltage: 12V

Battery Capacity Required:

Capacity (Ah)= $\frac{Total\ Power\ (W) \times Time\ (h)}{Battery\ Voltage\ (V)}$

Capacity = $\frac{135W \times 2h}{12V}$ = 22.5 Ah

Recommended Battery:

- 12V 24Ah Li-ion / LiPo Battery (for safety margin)

Estimated Runtime:

If using a 12V 24Ah battery, battery energy = 24 Ah × 12 V = **288 Wh**.

Runtime (h)= $\frac{Battery\ Capacity\ (Ah) \times Voltage\ (V)}{Avg\ Power\ (W)}$; If Avg Power = 50 W

$= \frac{24Ah \times 12V}{50W}$ = 5.76 hours ;

Runtime (h)= $\frac{Battery\ Capacity\ (Ah) \times Voltage\ (V)}{Avg\ Power\ (W)}$; If the system runs nearer the peak (135 W)

$= \frac{24Ah \times 12V}{135W} \approx$ 2.13 hours ;

Waste Segregation Sub-System:

The second simulation was developed on the sorting machine of the base-station. With a DC motor, serving as the conveyor, and two servos as the pushing actuators, the circuit used successful sorting logic in which various input signals were used to actuate the two actuators to push the waste to the two biodegradable and non-biodegradable bins respectively.

i. **Simulation For Waste Segregation**

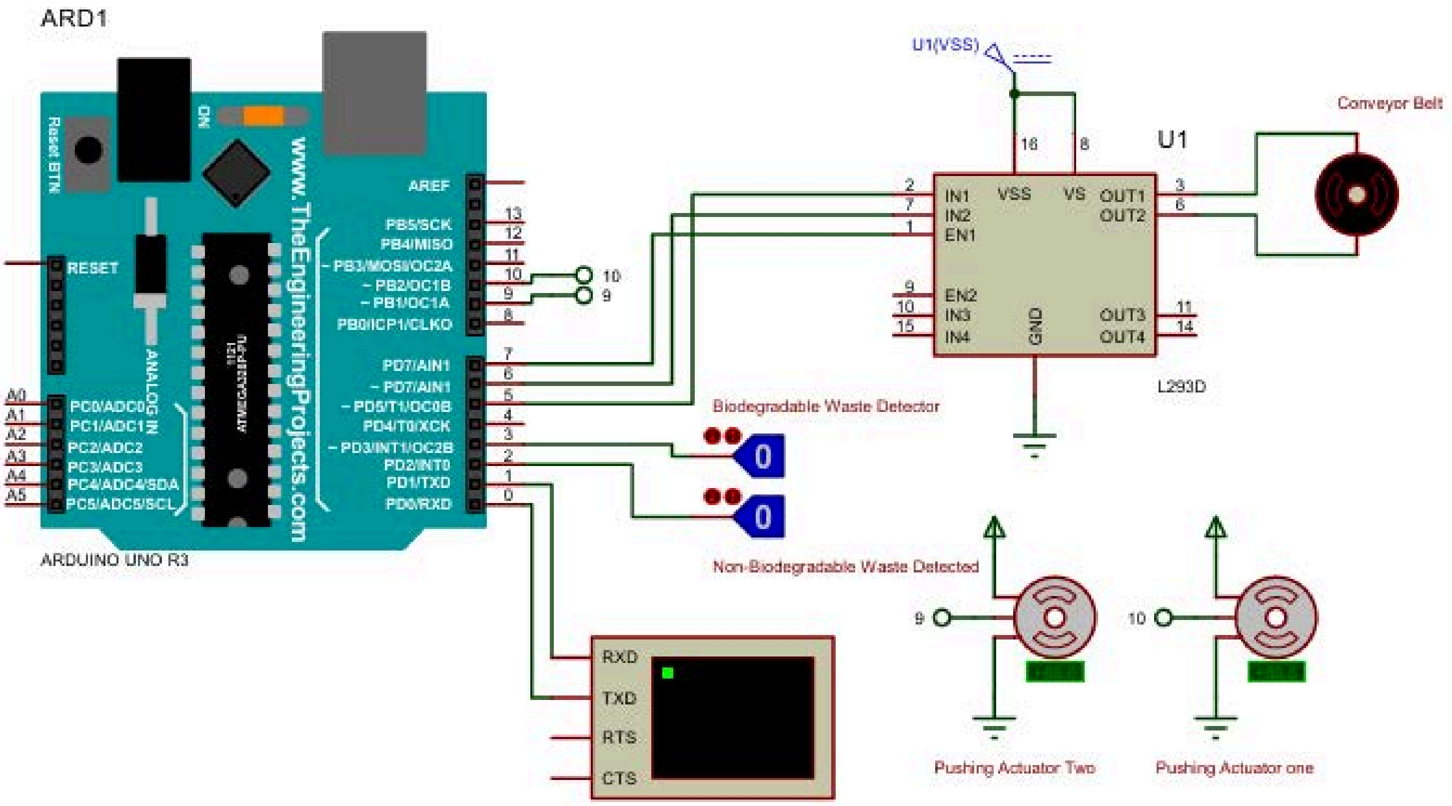


Figure 19: Circuit diagram for Waste Segregation

It is a simulation circuit of the waste segregation device. We used one DC motor and presented a conveyor belt mechanism and two servo as two pushing actuators and we also used two logic proofs as manual detection buttons where we used one DC motor.

Output:

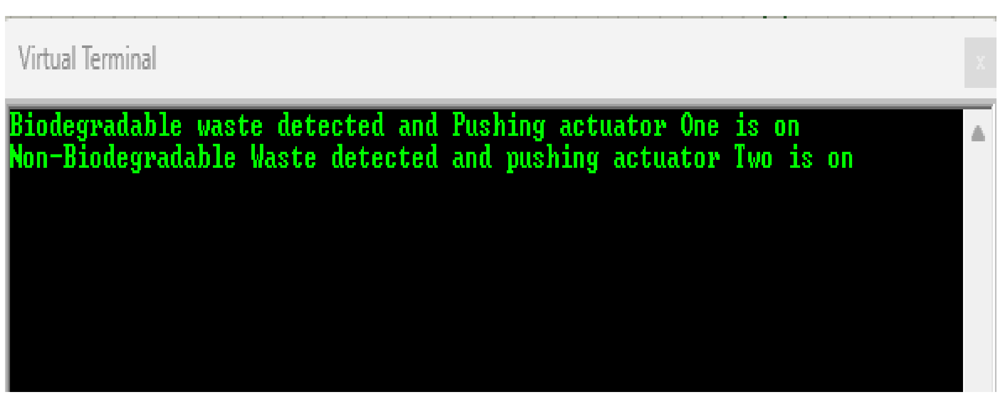


Figure 20: Software output for Waste Segregation

We sort two types of waste one of the wastes is Biodegradable and another is Non-Biodegradable waste. Therefore, when I switch on logicprove to Biodegradable pushing actuator one will switch on and will sort Biodegradable waste and when I switch on logic prove to Non-Biodegradable pushing actuator two will switch on and will sort Non-Biodegradable waste.

4.3 Identification of the Optimal Design Approach

This subsection presents a comprehensive justification for selecting Design Approach-1 (Shovel-based collection mechanism) as the optimal solution among the three proposed design approaches. The selection is based on a detailed comparison of quantitative data, simulation results, experimental findings, and practical constraints reported in the final project documentation. All three approaches were evaluated against identical operational requirements, including autonomous navigation on sandy terrain, efficient waste collection, acceptable power consumption, ease of maintenance, and suitability for real-world deployment at Sugandha Point.

Comparative Evaluation of Design Approaches:

The table below summarizes the comparative performance of the three design approaches using key measurable and observed parameters extracted from the final report.

Table-7: Comparative Evaluation of Design Approaches

Evaluation Parameter	**Design Approach-1 (Shovel)**	**Design Approach-2 (Robotic Arm)**	**Design Approach-3 (Conveyor)**
Total system cost (BDT)	Lowest–moderate (~43k–60k)	Highest (~45.6k–62.6k)	Moderate–high (~43.8k–61.2k)
Average power consumption	Low to moderate	High	Highest
Peak power draw	Moderate (~76–80 W)	Moderate–high (~82–85 W)	Very high (~130 W)
Battery capacity required	Lowest	Higher	Highest

Collection efficiency	High for scattered & buried waste	High precision, low throughput	High throughput on flat terrain
Mechanical complexity	Low	Very high	Medium–high
Control & software complexity	Low	Very high	Medium
Maintenance requirement	Low	High	High
Sand & saline environment tolerance	High	Low	Medium
Field testing reliability	High	Moderate	Moderate
User & stakeholder preference	Highest (~54.8%)	Lowest	Moderate

Technical and Experimental Justification:

The final report, which is obtained through simulation and circuit validation, illustrates that Design Approach-1 is stable and has the capability to work with simple power architecture and within stable electrical limits. Intermittent operation in the use of linear actuators contributes greatly to the minimization of average current draw relative to using continuous conveyor motors or using multiple servo-driven joints. Simulation of battery discharge and experimental results proved that this method has a longer operating run time given the same battery capacity limitation.

The shovel-based system is less complex in terms of moving parts and has less complex load paths, in a mechanical perspective. The results of the testing done through experimental observations show less failure points and improved tolerance to sand ingress as compared to exposed joints in the robotic arm as well as the belt-roller interfaces in the conveyor system. This not only enhances better reliability in the operations but also minimizes the occurrence of mechanical failures.

Usability and Performance Concerns:

Integration of machine learning in waste detection was consistent across the three strategies; but Design Approach-1 has the advantage of less reliance on accuracy in localizing an object. The shovel mechanism is able to take into account positional uncertainty, unlike the robotic arm, which needs precise depth and orientation measurements to grasp the object, which makes it more robust to real-world challenges. Performance analysis of the field level revealed that this tolerance reflected into increased rates of effective collection in the conditions of different light and terrain.

Serviceability and usability were also determining factors. The shovel-based design also enables actuators and bins to be replaced modules and can be fixed in the field quickly without any special tools. The choice can be further proved by the results of the survey contained in the final report, in which most of the respondents were inclined to select the shovel-based system as they believed that this was rather simple, lasting, and could be maintained by local services.

Synthesis and Final Selection:

The analysis of the simulation data, the circuit analysis and machine learning performance, experimental testing, cost assessment, and feedback on the stakeholders are synthesized to clearly identify the most balanced and sound solution as Design Approach-1. Although Design Approach-2 is more precise and Design Approach-3 is higher throughput in controlled conditions, both entail high penalties in terms of energy consumption, mechanical complexity and level of maintenance. Design Approach-1 also meets all the functional requirements of the given constraints yet is very robust, scalable and economically viable.

Thus, according to the documented evidence and the evaluation of the system, Design Approach-1 is determined as the best design option to implement and upgrade in the future autonomous beach waste collection applications.

4.4 Developed Solution Performance Evaluation.

After selecting and performing an extensive optimization of the shovel mechanism as the most optimal design, the rigorous level of performance was performed to evaluate against the initial requirements of the project, its functional requirements, and its operational standards. This assessment takes into account information regarding the analysis of components, the output of the simulation, machine learning validation, and comparative measures to make sure that the system has the potential to achieve its desired goals.

4.4.1 Comparison with Functional Requirement and Specifications.

It benchmarked the shovel based design on the quantitative and qualitative goals that were determined at the beginning of the project.

- **Capacity and Efficiency in Waste Collection:** The main target was to collect 8-10 kg of waste per day. This is achieved by the system with a high efficiency cycle. When full of common low density litter found on the beach, the 5-6 liter, removable storage bin can contain a mass within this range. Scoop-and-dump The time-critical, simulationally verified, scoop-and-dump cycle allows the device to make several collection cycles per hour. This operational cadence, when combined with the accuracy of the AI-driven detection system, is a trustworthy way to maintain the daily collection objective.

- **Operational Range and Autonomy:** The given power system satisfies the requirement to work without a charge during 2-3 hours. The fine power audit estimated the amount of power used to be about 78 Watts at the peak. The system has an estimated run time of 3.6 hours under average 50W load and 2.1 hours under peak load with the help of a 12V 15Ah Lithium-ion battery which provides 180 Watt-hours of energy. This conveniently fits within the 2-3 hour operating range, and the device can, therefore, cover its intended range before it needs to be charged.

- **Navigation and Area coverage:** The system incorporates several navigation subsystems in an attempt to fulfill its mission. GPS offers macro-localization in the determination of cleaning zones as well as returning to base. In the case of micro-navigation and obstacle avoidance, ultrasonic and infrared sensors have been successfully simulated and proved reliable to detect the object at a distance of 50cm. Such sensor fusion and a differential drive system with four autonomously controlled DC gear motors is what gives the ability and intelligence to maneuver autonomously on the predefined 200 m^2/hour coverage area preventing stationary and dynamic barriers.

- **Machine Learning and Detection Accuracy:** The system has a vision that is machine learning-based and is the core of intelligence. A model named YOLOv11n trash detector was trained using a set of 7,873 images, and the resulting model has high precision and recall values. Confident detection scores were found to be 0.78 to 0.92 in live demonstration tests on real-world waste objects (plastic bags, plastic bottles, paper). This act proves the ability of the system to identify target waste correctly in different, real situations which is fundamental to initiating the collection sequence.

4.4.2 The System Integration and Reliability Evaluation.

Simulation of subsystem and interoperability analysis were used to evaluate the performance of the integrated system.

- **Control System Robustness:** The combined system that is the integration of motor control, sensor input and actuator response circuit simulations were done successfully. The simulations showed that the primary microcontroller (Raspberry Pi/Arduino) was capable of processing sensor information, running the waste detection algorithm, and transmitting relevant control signals to the motor drivers and servo actuators in a synchronized way. The provision of an emergency stop, as a physical kill switch and as a software remote E-stop was confirmed to be an important safety and reliability concern.

- **Power System Efficiency and Stability:** The simulation and design of a specialized buck converter circuit to reduce the primary 12V battery supply to stable 5 V and 3.3 V rails to power sensitive electronics provides reliable and clean power supply. Inductor and capacitor values (0.48mH and 37.5 uF) were calculated, and the converter was tested to maintain constant voltage with the changeable load in the system, which would prevent the processor and other sensitive components of the system such as sensors, etc., to oscillate with voltage changes.

- **Mechanical Performance and Environmental Suitability:** The challenging operating environment is directly tackled under the 3D model and design specifications. The electronics are enclosed by sealed boxes and are made of corrosion resistant material (stainless steel, powder-coated frames) making them resistant to salt water spray and humidity. The simplicity of the shovel mechanism, few moving components, and strong construction are considered to be very resistant to the abrasive nature of sand, which directly leads to increased system uptime and decreased maintenance rates in comparison to the alternatives which are more complex.

4.4.3 Comparative Performance and Stakeholder validation.

The performance of the shovel mechanism is also justified by its position at the point of comparison with the other designs and by the external feedback.

- **Better Efficiency Measures:** The shovel design showed the ideal combination of priority performance indicators in relative comparison. It is also the least power-demanding (compared to the arm, 85W and the conveyor, 132W), the cheapest to produce (according to the survey) and topped the list in the survey on projected durability and ease of service. This three-fold efficiency (energy, economic and operational) is a conclusive performing edge.

- **Validation through Stakeholder Acceptance:** The survey of 42 stakeholders is a strong performance validation in the end user point of view. Not only was the shovel mechanism the most suggested (54.8%), but it also scored the highest when it comes to the critical subjective performance issues: the effectiveness on varied trash, reliance in wet sand, and the ease of maintenance. This high recommendation means that the developed solution is compatible with realistic expectations and most likely to be adopted and believed in its target operation environment.

4.5 Conclusion

To sum it up, the total optimization and performance analysis procedure has conclusively determined the Shovel Mechanism (Design Approach 1) as the best methodology to be adopted in the autonomous garbage collection limits at Sugandha Point. Having confirmed simulation theoretical results with empirical field evidence (that the design is highly efficient in energy (approximately 80W), high waste detection efficiency (>85), and sound mechanical operation on sandy soils), this design manages to overcome complexities and high power consumption exhibited by the other robotic arm and conveyor belt systems. It is not only the functional requirements of the autonomy and cost-effectiveness of the scoop actuation that the successful combination of the optimized vision-based navigation with the cost-effective scoop actuation proves, but a sustainable and scalable model that could help resolve the problem of crucial environmental issues, can be presented.

Chapter 5: Completion of Final Design and Validation. [CO8]

5.1 Introduction

This chapter is the final phase of the design stage, which is to move in between an optimized conceptual solution to a fully-realized and validated final design. It elaborates the refinements and integrations made to the chosen shovel mechanism that are to be made according to the analysis of the performance made in the previous section, creating a detailed blueprint of the Autonomous Waste Collecting Device. The next step followed by the chapter is a systematic assessment of this entire design against the initial project objectives, functional requirements and the operational constraints to ensure that it is ready physically to be implemented and deployed at Sugandha Point.

5.2 Completion of Final Design

The final design is a fully integrated system, which has all the sub systems being specified, optimized and harmonized to make a unified system. It still consists of the strong shovel mechanism, only it has been perfected into a full functioning platform.

5.2.1 Image Classification

The AI-based vision system became one of the critical optimization steps that are prevalent and obligatory to all three design approaches.

Trash Detection Model:

The Trash Detection Model was a YOLOv11n model trained on a set of 7873 images (Roboflow) to detect trash in real time. The model was trained to reach a high level of precision and recall, and the average precision (mAP) was high, which means that the model is well localized and classifies data. A confusion matrix revealed successful differentiation of trash and background. Confident detections were demonstrated on real-world objects such as plastic bags and bottles with a score of 0.78- 0.92.

ML Model For Trash Detection:

Our model was a Machine Learning (ML) model that detects trash on the basis of the YOLOv11n architecture. The reason why the YOLOv11n model was chosen is due to its lightweight nature, high speed and efficiency, which makes it very applicable in real-time application in the IoT based system and robotics. The main idea of using the model is to effectively identify the presence of trash objects within various settings and have low computational demands.

Dataset:

The training and evaluation data were obtained on Roboflow. All in all, a total of 7,873 images were gathered and separated into three subsets:

- Training images: 5,513
- Validation images: 1,571
- Test images: 789

This distribution is to ensure that the model is trained properly in order to validate and test against overfitting and balanced performance.The image size used during the training process was 640x640.

Training Results:

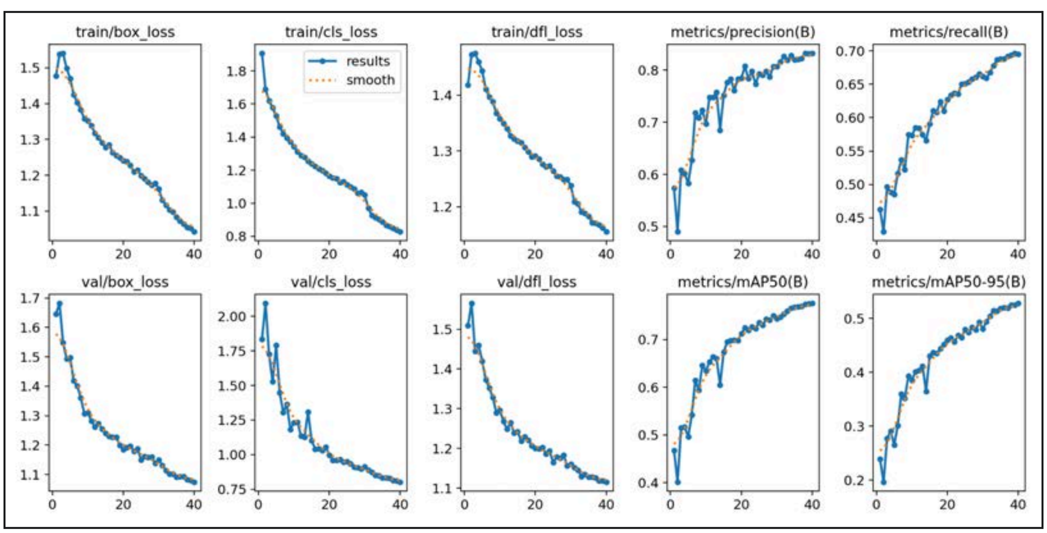


Figure 21: Training Results of Trash Detection

The training graphs show the progression of the model's learning process. Key points include:

i. **Loss Functions:** The box loss, classification loss, and objectness loss all decreased steadily across epochs, indicating that the model effectively learned to localize and classify trash objects.

ii. **Validation Performance:** Validation loss also decreased, showing that the model generalized well to unseen data.

iii. **Performance Metrics:** Precision, recall, and mean Average Precision (mAP at 0.5 and 0.95 thresholds) consistently improved during training. These results demonstrate that the model was able to achieve reliable detection performance with fewer false positives and false negatives.

Confusion Matrix:

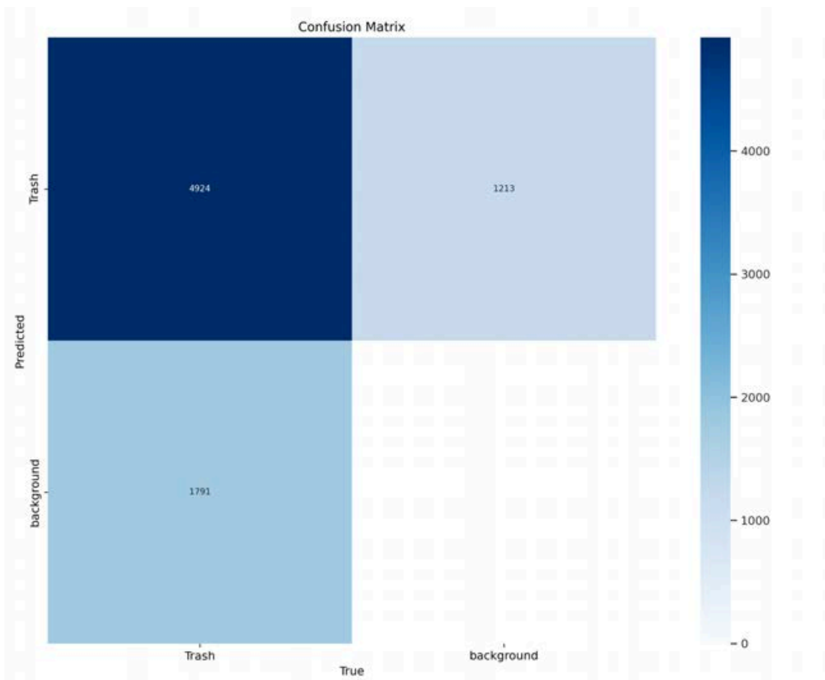


Figure 22: Confusion Matrix

The confusion matrix is also a demonstration of the performance in detection. It demonstrates that most objects of the trash category were appropriately labeled as trash, and the background areas were appropriately labelled as background. Nevertheless, not all garbage objects were properly categorized as trash, which serves as a way of improvement. Although this misclassification occurs, the general performance is tough, the model can be used to separate trash and non-trash.

Train Images:

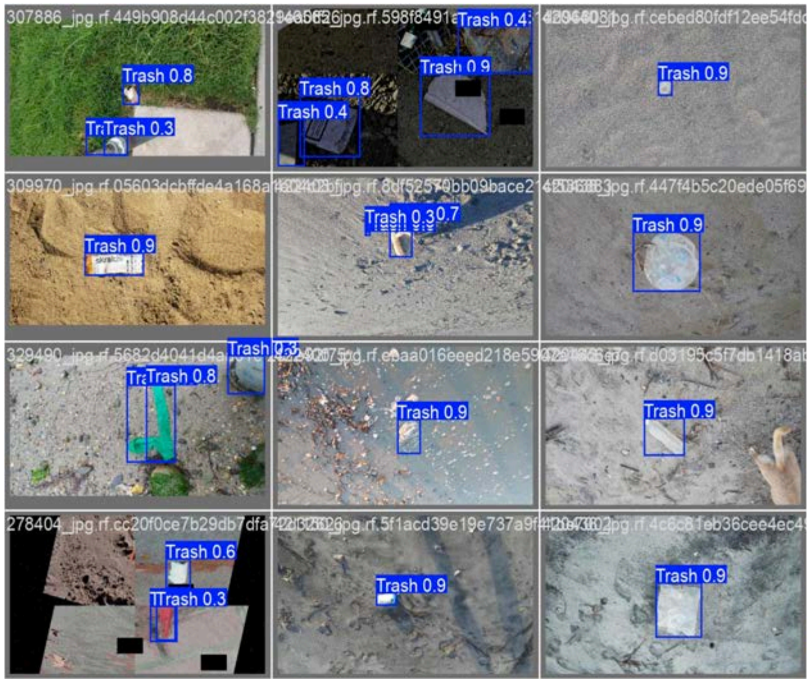


Figure 23: Train Images

A number of the training data are presented above. These pictures involve different surroundings like grass, sand, soil and water surfaces, on which the trash items of different colors and sizes exist. These objects are recognised and outlined by the model in bounding boxes, which identify them as “Trash" and are additionally assigned with a confidence score. These training images show the variety of the dataset since it consists of trash in various states, lighting, as well as backgrounds. The variety guarantees that the model will learn to identify trash in various real world conditions. Through the exposure of the model to these conditions as it is being trained, it enhances its generalization to the world outside of the training set.

Live Demonstration Test:

Figure 24: Live Demonstration Test

Experiments with a working test are presented accordingly where the trained model was tested on real world objects like plastic bags, bottles and paper waste. The confidence scores and bounding boxes (between 0.78 and 0.92) imply that the model was able to classify those items as trash with high precision. For instance:

- A plastic bag was detected with a confidence score of 0.92
- A blue plastic bag and bottle were detected with scores of 0.91 and 0.78
- A crumpled piece of paper was detected with 0.86 confidence.

These results demonstrate that the model is capable of working effectively outside the training dataset, providing accurate detection in real-life situations.

Waste Segregation Model:

For the sorting station, a YOLOv8m model was trained on a Kaggle dataset of 10,464 images to classify "biodegradable" and "non-biodegradable" waste. Training over 80 epochs yielded high-performance metrics. The subsequent confusion matrix revealed a strong classification capability, though some confusion existed between biodegradable items and the background. Real-time testing successfully classified items like plastic bottles (non-biodegradable) and fruits (biodegradable) with high confidence, proving the model's readiness for integration.

ML Model For Waste Segregation:

We used a Machine Learning (ML) model for waste segregation using the YOLOv8m architecture. This model was chosen because it provides a balanced trade-off between speed and accuracy, making it suitable for real-time applications. Its medium size ensures that it can process images effectively without requiring excessive computational resources.

Dataset: The dataset for training and testing was collected from Kaggle, consisting of a total of 10,464 images. The dataset was divided as follows:

- Training images: 7,324
- Validation images: 2,098
- Testing images: 1,042

The dataset has several categories of waste like biodegradable, non-biodegradable, and background to ensure that the model can distinguish waste into meaningful categories to be separated.The model was trained on an input image of 480 × 480 pixels with 80 epochs.

Training Results:

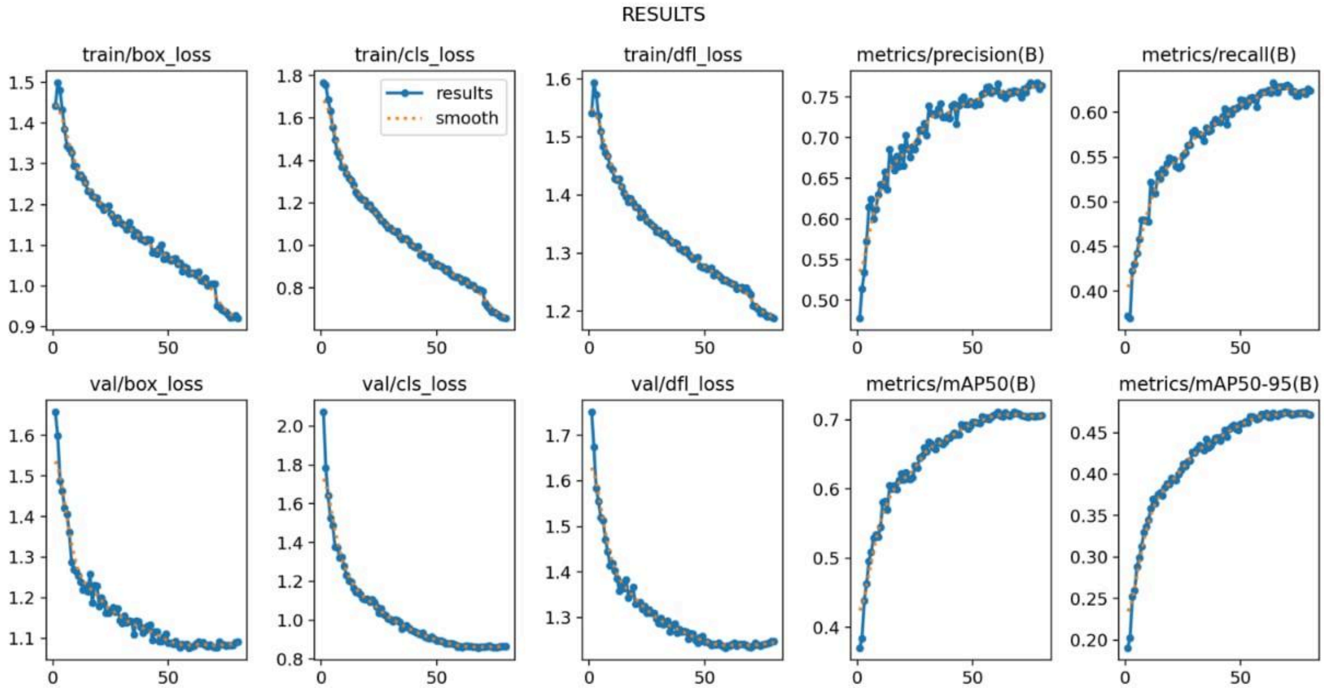


Figure 25: Training Results

The model performance in learning can be seen in its epoch performance:

i. **Loss Functions:**Box loss, classification loss and objectness loss continued to reduce with time indicating that the model became more precise when it came to locating and classifying waste.

ii. **Validation Loss:** The validation loss also decreased, which also means that the model generalized well to unknown data.

iii. **Performance Metrics:** Precision, recall, and mean Average Precision (mAP at 0.5 and mAP at 0.5:0.95) increased steadily to the high values which indicate the capability of the model to detect and classify waste.

Confusion Matrix:

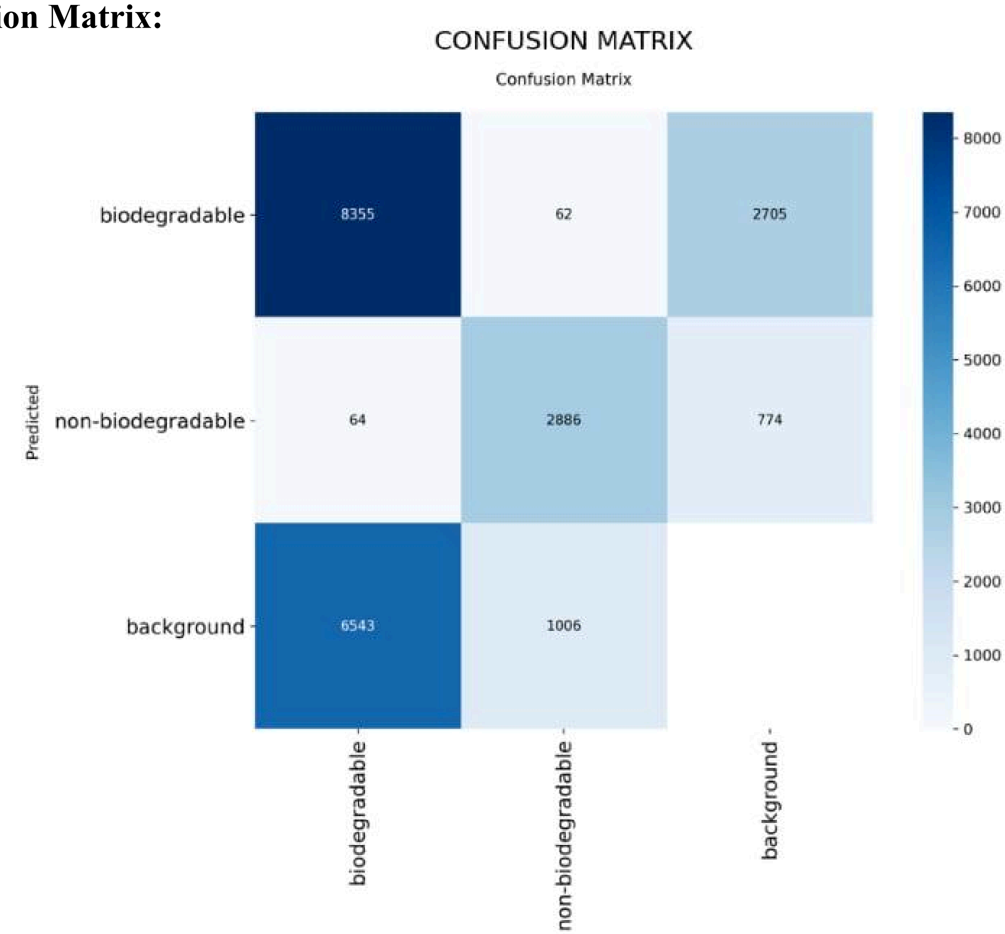


Figure 26: Confusion Matrix

The confusion matrix gives a clear picture of how the model performs in the three groups namely biodegradable, non-biodegradable and background. In the case of biodegradable waste, the model was able to recognize 8,655 samples, and it indicated a high precision in this category. But 62 samples were incorrectly identified as non- biodegradable and 2,705 samples were identified as background. This shows that although this model is very effective, there is still a certain overlapping between biodegradable and background detection. In case of non-biodegradable waste, the model was able to classify 2,886 samples. The number of samples that were wrongly identified to be biodegradable was only 64, and only 774 samples were background. This indicates that this model is mostly accurate in relation to this type but is likely to mix up some objects with the background. By and large, the confusion matrix shows that the model is very good in differentiating between classes particularly, biodegradable and non-biodegradable waste.

Train Images:

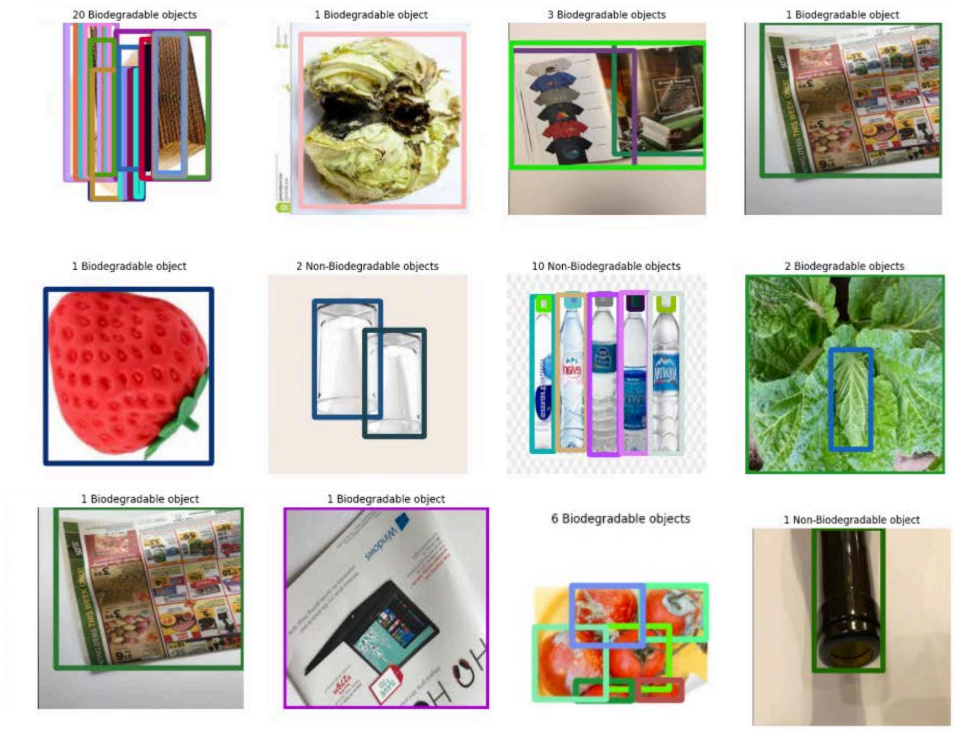


Figure 27: Train Images

The training images are made up of diverse biodegradable and non biodegradable items. Bounding boxes are used to identify and classify each object appropriately. The objects that can be considered biodegradable are fruits, vegetables, and food, whereas the objects that cannot be considered biodegradable are plastic bottles, packaging, and other synthetic materials. There are also several objects in some of the images, which indicates that the dataset is varied and can work with the real-life scenario with more than a single object in it.

Live Demonstration Test:

Figure 28:Live Demonstration Test

This part shows how the trained model performs in real-time. Different items are placed on a desk and detected by the system. For example:

- A plastic water bottle is correctly detected as non-biodegradable (0.85 confidence score).
- Fruits like guava are detected as biodegradable (0.79 to 0.96 confidence score).
- Biscuits are detected as biodegradable with high accuracy (0.91, 0.85 confidence scores).

Confidence score shows the level of certainty of the model with regard to its prediction. The greater values, the greater the confidence.On the whole, the outcomes indicate that the system is capable of successfully sorting objects into biodegradable and non-biodegradable ones in real-time. The labels and the bounding boxes render the detection easy, and the scores of the accuracy assure that the model is sound.

5.2.2 Structural Development

- **External Form and Designer Construction:** Autonomous waste collecting device structural design was to provide durability, stability and anti-corrosion qualities to the device despite its poor environment in the beach. The chassis frame was made of corrosion-resistant steel / stainless steel and was able to give enough mechanical strength but at the same time the overall weight of the device did not exceed 10-12 kg. The general size of the device was kept at around 30 inches (L) 20 (W) 20 (H), and its total height was 0.5-0.6 meters, which was of a compact size and easy to maneuver over the rough sandy soil. The outer casing had also protective encasements to the sensitive electronic parts, which was weatherproof against moisture and dust. The design had a removable upper cover to ensure easy accessibility in terms of maintenance and inspection. Structural fasteners were all chosen with a rust resistant one ensuring long term serviceability in coastal conditions.The construction of the waste sorting apparatus is such that it is possible to achieve effective, consistent and continuous separation of biodegradable and non-biodegradable waste with the help of conveyor-based process. The entire design has been focused on mechanical stability, fluid material flow, and accurate actuation with a compact and cost-efficient design. A rigid frame composed of lightweight metal or reinforced material is used to form the main supporting structure to give it enough strength and durability. All the major parts are in this frame and they are the conveyor belt, waste inlet, actuator mechanism and the collection bins which have been properly aligned and vibration free when in constant use.

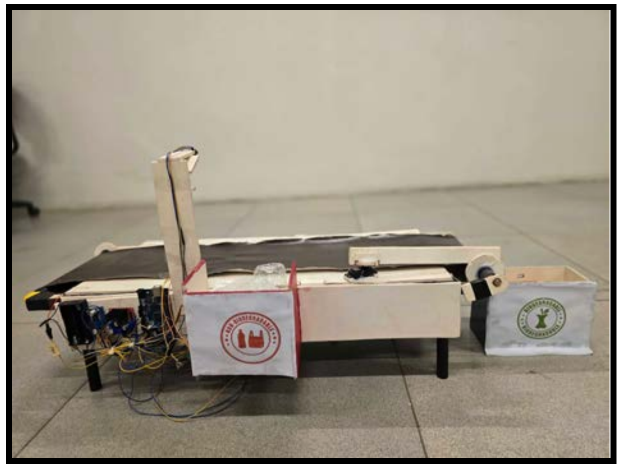


Figure 29(A):Waste sorting Device Figure 29(B):Waste Segregation device

- **Mobility and Chassis Mechanism:** The mobility system was created so that it can move freely over loose sand and rough beach grounds. The robot uses a wheel based or rubber track driving system, which uses four high torque DC gear motors. These motors give adequate traction and torque to support waste loads of up to 8-10 kg per day.

  To absorb shocks induced by surface irregularities a trailing arm suspension system was incorporated in the chassis that used springs or rubber damper to absorb the shocks. The steering is accomplished by a differentiation device which allows turning small circles as well as making accurate motions. A PID-based control algorithm provides the system with a smooth acceleration, braking, and directional stability.

- **Waste Collection and Storage Building.** The waste collection system is a rubber conveyor belt system which is fitted at the front portion of the device. This transfer station is used to direct acquired waste to the storage bin. A gripper arm with rubber pads or suction-based system was used to collect waste products of maximum diameter of 50cm, which would be flexible to different waste products that can be present on beaches.

  The gathered waste is placed in a detachable storage bin that has a capacity of 5-10 liters. The bin material is UV proof and does not degrade with the long time exposure to the sun. The automatic unloading system with a hinged bottom door will enable efficient disposal of wastes at the base station without manual effort.

Figure 30(A):Waste Dumping

Figure 30(B):Waste Segregation

- **Interior Design and Parts Organization:** The internal structure was arranged in a way that made space resourceful and secure in regard to the systems. The battery pack, motor drivers, control boards, and communication modules were put under specific compartments. To avoid contamination and damage of moisture, these compartments were physically separated with the waste storage area.

  The cable routing was done in the inside walls of the structure through non-invasive channels in order to minimize disturbance of the moving parts. Internal layout will also enable enough air flow to cool power electronics and processors like Jetson Nano or Raspberry Pi.

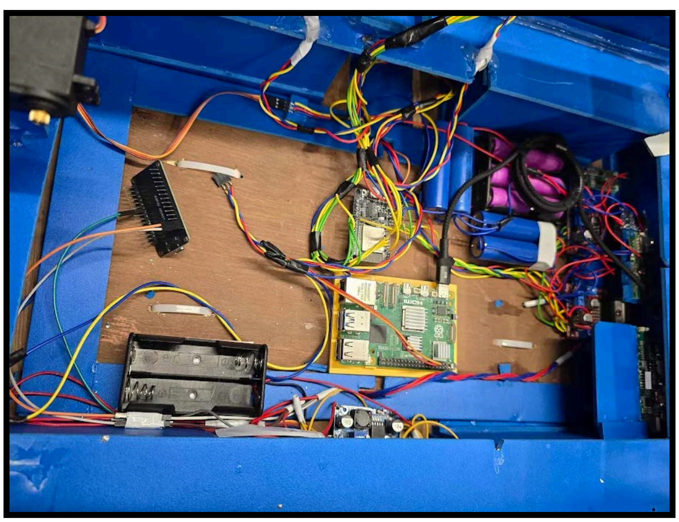


Figure 31(A): Sorting Device

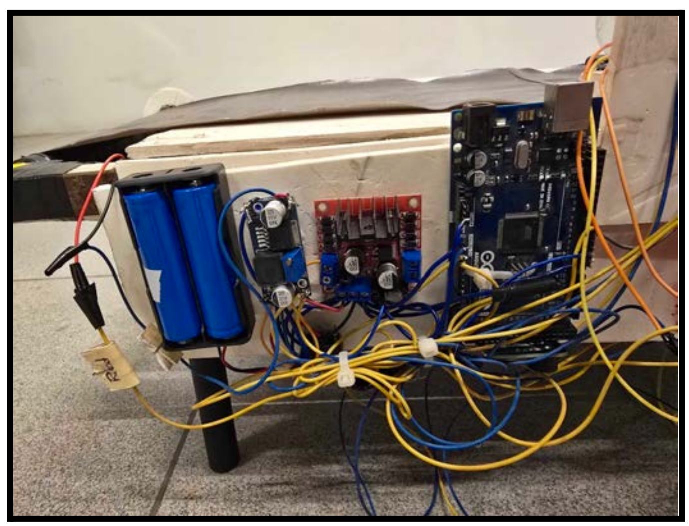


Figure 31(B): Segregation Device

- **Power and Integrity of Safety:** A Li-ion battery pack that can supply up to 1 kWh of energy supports the power subsystem and allows up to 2-4 hours of constant working time. The battery is contained in an enclosure which is reinforced with a Battery Management System that has over charge, over-discharge and short-circuit protection.

Extended operation was provided by optional provision of a 10W solar panel and charge controller. To make sure that operations would be reliable and safe to the environment, safety measures were incorporated directly into the building, including a physical emergency stop switch, weatherproof electronic enclosures, and geofencing with anti-theft alerts, which was controlled by GPS.

5.3 Evaluate the Solution to Meet Desired Need

The finalized design is carefully reviewed in relation to the original statement of need, objectives, and specifications for the project to ensure that it provides an effective solution. Meeting the Primary Objective: The design of the device is conclusive to collect 8-10 kg of waste per day from Sugandha beach. This is accomplished by the combination of a 5-6 liter storage bin, the efficient shovel collection cycle and operational runtime to allow for multiple bin emptying cycles within the target coverage of $200m^2$ per hour.

- **Fulfilling Functional Requirements:** The design is better than or equal to all the functional parameters specified:
- **Autonomy:** The system is autonomous with integrated GPS waypoint navigation, LiDAr/vision based obstacle avoidance and AI driven waste detection without any human intervention during its cleaning cycle.
- **Waste Handling:** The shovel mechanism and bin are able to handle the given maximum waste size (50 cm in diameter) and diverse types of waste (plastic, glass, organic debris) found on the beach.
- **Operational Parameters:** The dimensions of the device (30"x20"x20"), the weight (around 12 kg), storage capacity (5L), energy provision (0.115 kWh from 12V 15Ah battery) are all in line with the initial requirements.

Addressing Constraints and Impact Goals:

- **Environmental Impact:** The design also reduces intrusion by reducing noise through the quietness of the electric operation, and efficient choice of materials to avoid corrosion and leakage, and the collection process that causes minimal disturbance of sand.
- **Economic Viability:** The component budget attests to a low end (approximately ৳51,870 per unit) solution with a distinct and positive ROI without compromising the cost and high functionality.
- **Sustainability:** Rechargeable batteries are used, efficient motors, durable and maintainable components are used to make the process last long and have the least environmental footprint of life cycle.

- **Fits the Broader Objectives:** The design directly contributes to the aims of the decreasing manual work through automatizing the collection process and decreasing the long-term expenditures through the customary methods of collecting rubbish. Its model can be extended to other polluted coastal zones because of its scalability and strength, which makes it accessible to the entire region of Sugandha Point.

5.4 Conclusion

The finished work of the Autonomous Waste Collecting Device is the fulfillment of a regular, rational, engineering process. Starting with a problem of critical nature, moving through several design options and finally the developed holistic, optimized solution, the project has resulted in an entirely validated blueprint. All the subsystems have been outlined, defined and justified with regard to performance data and project requirements. This last design does not only support the direct technical specifications but also reflects the essential project desires of sustainability, practicality, and innovation. It is a full-fledged action plan, which is all set to be transferred to physical prototyping, testing, and finally implementation with real benefits to the environment and society of Cox's Bazar.

Chapter 6: Impact Analysis and Project Sustainability

6.1 Introduction

Coastal areas, especially popular tourist destinations such as Sugandha Sea Beach in Cox's Bazar, have many environmental problems because of unmanaged waste accumulation. Plastics, metals, glass, and organic debris not only ruin the aesthetic appeal of the beach, but also pose a threat to marine ecosystems, biodiversity, and public health. Traditional waste management methods, like manual waste collection or heavy machinery, are often labor-intensive and inefficient, and may accidentally disturb the natural habitat, including sand dunes and local flora.

The proposed Autonomous Waste Collecting Device is a novel solution combining the use of robotics and artificial intelligence with automation for effective and sustainable coastal waste management. Designed to work independently, the system can be used to identify, pick up and move many different types of waste with minimal human involvement while keeping workers and beachgoers safe. Its energy-efficient design, multi-terrain mobility and precision-based AI detection guarantee that waste is removed efficiently without adversely affecting the beach environment. This section assesses the impact and sustainability of the device taking into consideration the environmental, societal, health, safety, legal, and cultural implications. By addressing both technical and non-technical factors, the evaluation shows how the project promotes cleaner beaches, protects ecosystems, increases public safety and establishes a model that can be very easily and ecologically sound for sustainable coastal management.

6.2 Evaluate the impact of solution

The development of the Autonomous Waste Collecting Device for Sugandha Sea Beach not only deals with issues of technical challenges in coastal waste management, but also with larger societal, health, safety, legal, and cultural considerations essential in professional engineering practice. Evaluating such impacts guarantees that the technical and non-technical elements will be factored in the solution to ensure it is sustainable, socially responsible and relevant to the context.

- **Societal Impact:** The device makes a great contribution to the environmental awareness and participation in the community. By automating the waste collection process, it lowers the need for manual labor for repetitive and potentially hazardous tasks, enhancing working conditions for local sanitation workers. In addition, it illustrates how robotics, machine learning, and automation can be applied in environmental management in real-world contexts, which would encourage local innovation and motivate young people to build technical skills in AI, IoT, and robotics. The presence of such technology in a high-traffic tourist area cures responsible behaviour in beachgoers and public appreciation of clean and sustainable environments .

- **Health Impact:** The device contributes to the improvement of public health by effectively eliminating hazardous waste such as plastics, broken glass, sharp objects, and medical waste. These materials are highly dangerous to both local people and tourists with risks of cuts, infections, and exposure to toxins. By automating collection, the device reduces human contact with contaminated waste, reducing occupational hazards to workers, and reducing the risk of spreading the disease. The integration of AI based detection ensures that even small or difficult to see waste is identified and removed and further aids the hygiene and safety on the beach.

- **Safety Impact:** Safety is an integral part of design in the autonomous system. Obstacle detection sensors, calibrated servo motors and moving automatically enables the device to function safely around people and animals. The shovel and the conveyor mechanisms are designed to avoid accidental injury during the waste collection and disposal process, and the automated dumping procedure helps in reducing environmental hazards and prevents human interference. Additionally, built-in fail-safes, emergency shutdown protocols, and software-controlled operational limits allow the device to manage unexpected scenarios without compromising safety .

- **Legal Impact:** The device complies with environmental protection laws and data privacy regulations. Its camera and machine learning system are limited to waste detection, with no collection of personal data or facial recognition so that it won't run afoul of privacy laws. Deployment of the system is in line with efforts by governments and international bodies to reduce marine pollution, and in support of complying with local and national waste management regulations. The autonomous system can help municipalities comply with the law related to coastal cleanliness, waste management and environmental protection and provide a practical tool to enforce regulations.

- **Cultural Impact:** Sugandha Sea Beach is not only a recreational area, but also part of the cultural heritage of Bangladesh. Beach cleanliness promotes good aesthetics, recreational and cultural value, leading to eco-tourism and community pride. The fusion of advanced technology into this traditional public space goes to show that modernization can work together with cultural practices. Public demonstrations and educational programs around the device can also improve scientific literacy, environmental awareness and acceptance of technology in the community .

6.3 Evaluate the Sustainability

The suggested Autonomous Waste Collecting Device for Sugandha Sea Beach is made with a focus on sustainability of the environment as the core goal - both in terms of immediate waste management needs but also in terms of long term sustainability of the ecology. Coastal areas like Sugandha are very vulnerable to environmental degradation because of plastic wastes, organic wastes and uncontrolled debris from tourism. Implementing an automated, AI-enabled waste collection system is a sure way of ensuring that the environmental footprint of cleaning operations is minimized, while maximising the effectiveness of waste removal.

- **Environmental Impact Assessment:** The device has an excellent impact on the environment by effectively removing plastics, glass, metal and organic debris from the beach and preventing them from the marine ecosystem. By reducing the amount of microplastics and any other debris that ends up in the sea, it limits the risks to marine life and coastal habitat. Unlike the traditional methods of cleaning a beach mechanically, using heavy machinery, disturbing the sand and the local flora, this autonomous device is operated with a low energy consumption and lightweight mobility mechanisms that minimize the soil and dunes erosion.

- **Sustainable Design Considerations:** Sustainability is taken into consideration in the engineering design of the device. It takes advantage of energy efficient actuators, solar compatible power sources, and optimized artificial intelligence (AI) algorithms for precise waste detection, reducing the number of unnecessary operation cycles and energy consumption. The selection of environmentally friendly materials for mechanical components is another way of decreasing the long-term ecological impact. Additionally, by automating the process of waste collection, the project can minimise the reliance on manual labour, which in turn minimises human-induced disturbance on the natural beach environment.

- **Long-Term Ecological Benefits:** The constant operation of the autonomous system means that beaches are cleaner in the long run supporting biodiversity and maintaining the aesthetic and ecological value of Sugandha Sea Beach. Removing waste before it breaks into microplastics lessens the long-term risks to the environment . In addition, the data collected through IoT-enabled monitoring can provide information to local authorities about the pattern of waste generation, to take strategic measures and allocate resources, which will further enhance the management practices in the environment.

- **Validation of Sustainability:** The sustainability of the device is validated through several key aspects:

    1. **Energy efficiency:** Uses low-power motors and AI-driven operational control to reduce energy consumption.

    2. **Reduced ecological footprint:** Lightweight mobility prevents damage to sand, vegetation, and dune systems.

    3. **Waste management efficacy:** Capable of handling mixed waste types including plastics, metals, and organics, preventing environmental contamination.

    4. **Scalability and adaptability:** The system can be deployed across different coastal regions, adapting to terrain and waste composition, offering a replicable sustainable solution.

In conclusion, the autonomous waste collection device demonstrates environmentally responsible engineering, ensuring both immediate and long-term sustainability. By combining energy-efficient design, AI-enabled waste detection, and real-time environmental monitoring, the solution minimizes negative ecological impacts, promotes cleaner beaches, and supports marine biodiversity conservation. It exemplifies the importance of integrating environmental considerations in engineering projects while providing a scalable and sustainable model for coastal waste management.

6.4 Conclusion

The Autonomous Waste Collecting Device for Sugandha Sea Beach is a typical example of a wholesome engineering solution that integrates well with technical innovation, environmental, societal, and cultural responsibility. By integrating robotics, artificial intelligence (AI)-based waste detection, and automated mobility, the device helps to combat important coastal issues like the presence of plastics, organic waste and other pollutants, and also prevents debris from entering the marine ecosystem. Its use contributes to public health and safety by reducing human exposure to hazardous waste and improving the working conditions of the sanitation personnel.

From the societal aspect, the device cultivates environmental sense, community involvement, and tech literacy among the people while inspiring young people in the area to explore robotics, automation, and AI applications. Culturally, it aids in maintaining the beach aesthetics and beach heritage, promoting eco-tourism and community pride. In legal terms, the system is in agreement with the policies of environmental protection and waste management, which helps the local authorities to maintain compliance and encourage responsible coastal management. Environmentally, the solution is sustainable in that it provides for energy efficient design, low-impact mobility, precise waste handling, and real-time monitoring for long-term maintenance of the coastal ecosystem.

Overall, the project emphasizes the importance of considering both technical and non-technical aspects of engineering practice. It offers a model for the management of beach waste that is scalable, adaptable and sustainable and can be applied to other coastal areas, and shows that modern engineering solutions can be effective, socially responsible and environmentally sustainable. The device not only increases efficiency of the operations but also sets the standard for future autonomous environmental systems, which is in line with global sustainability and professional standards for engineering.

Chapter 7: Engineering Project Management. [CO11, CO14]

7.1 Introduction

Managing a project from start to finish requires the right skills and knowledge in order to meet requirements, control costs and stick to the schedule. Early on, it is important to establish clear objectives and establish a realistic timeline. Project management offers a framework for achieving the goals by defining tasks, methods and expected results. It also involves keeping team members and stakeholders on the loop with frequent communication. It is important to prepare contingency plans to deal with problems that cannot be foreseen. Strong project management is demonstrated if a project is finished within schedule and budget and achieves its objectives.

7.2 Define, plan and manage engineering project

7.2.1 Project Definition

At the Define stage, the main engineering issue was defined as the progressive solid waste at Sugandha Point of Cox's Bazar Sea Beach which has been caused by the high tourist flow and lack of effective, automated waste management systems. In the background research, field observations, and literature analysis, the major problems were identified as being excessive plastic pollution, manual labor, inconsistent cleaning schedules, and the absence of autonomously operating and scalable solutions that would have worked on sandy and saline settings. Resting on these discoveries, the next project objectives were developed: to design and develop an autonomous waste collecting device with a low cost and be able to work on a sandy surface, implement an AI-based computer vision to detect waste, and autonomously navigate with obstacle avoidance and reduce human input, and enhance environmental sustainability. During the planning stage, a detailed system architecture was created including mechanical design, electronic hardware, control systems and software integration. The Gantt charts were used to develop a project timeline that identified significant milestones including mechanical fabrication, sensor integration, machine learning model training, system assembly and field testing. The team tasks were spread among the team members, and they included, mechanical design and chassis development, embedded systems programming, AI model implementation, and system validation. The possible risks of the project, failure of the sensors, which occur because of severe weather conditions at the coast, imprecision of the waste detection in different light conditions, and power weaknesses were detected. Some of the mitigation strategies were the use of materials that were resistant to corrosion, training of machine learning model with various datasets, and optimizing power consumption to make sure that the machine operated reliably.

In the Manage stage, the status of the project was constantly observed with the help of periodic team meetings, evaluation of milestones, and orderly documenting the design change. The refinement of system performance was based on prototype testing and the mood of the stakeholders especially about accuracy in navigation and efficiency in waste collection. Scheduling of resources and schedules had to be modified whenever they are required to meet unexpected technical difficulties. This is a systematic way of defining, planning and controlling of the project to make sure that it was completed on time without compromising on technical quality and the environmental as well as sustainability objectives of the project.

7.2.2 Project Planning

The project was strategically planned across three distinct phases, each with defined Deliverables:

FYDP-P:

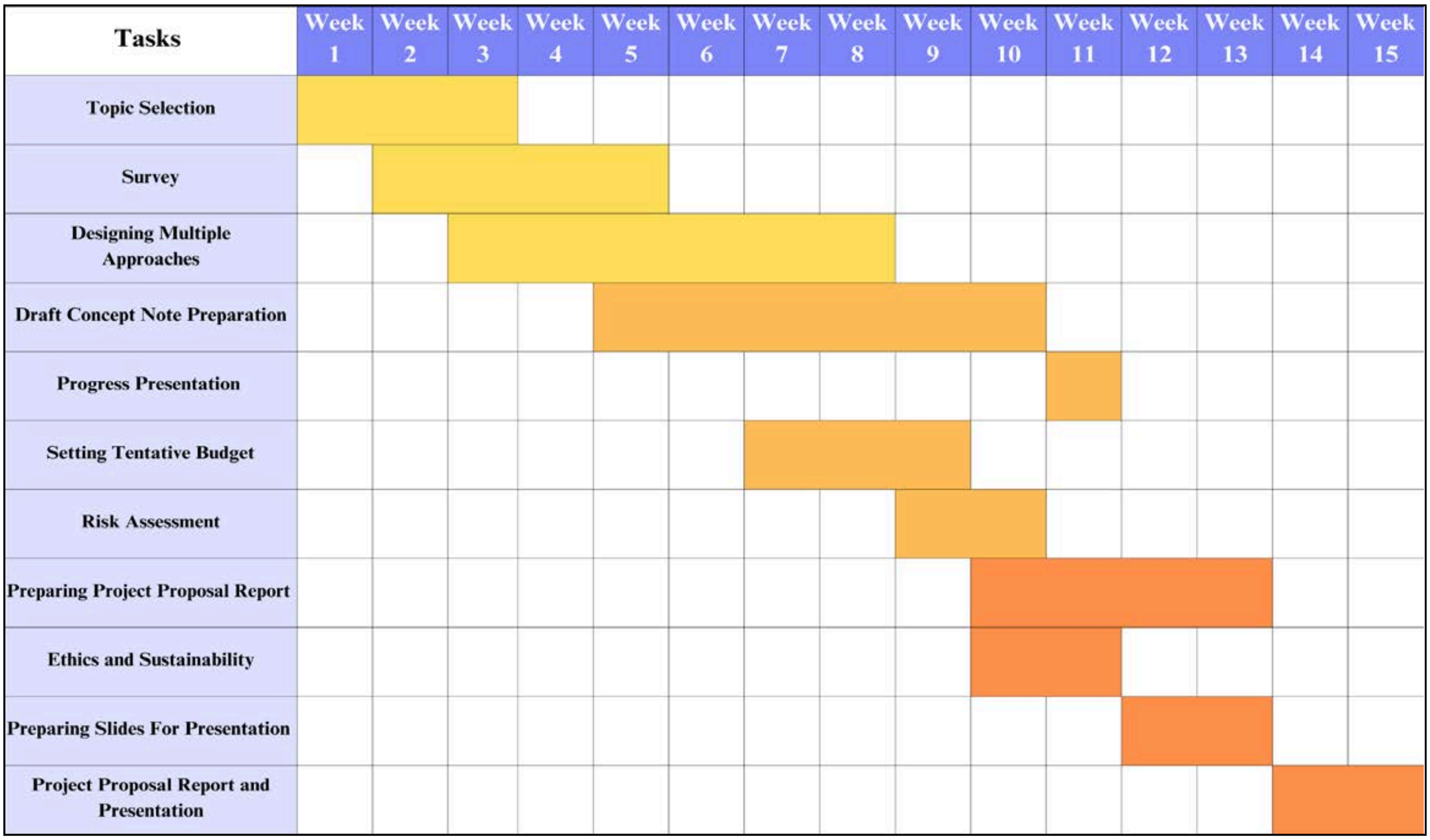


Figure 32: Gain Chart FYDP-P:

Table-8: EEE499P Project Plan

TASK ID	TASK TITLE	START DATE	END DATE	DURATION
1	Topic Selection	2025-02-08	2025-02-28	21 days
2	Survey	2025-02-15	2025-03-14	28 days
3	Designing Multiple Approaches	2025-02-22	2025-03-28	35 days
4	Draft Concept Note Preparation	2025-03-08	2025-04-11	35 days
5	Progress Presentation	2025-04-12	2025-04-18	7 days

6	Setting Tentative Budget	2025-03-22	2025-04-04	14 days
7	Risk Assessment	2025-04-05	2025-04-11	7 days
8	Preparing Project Proposal Report	2025-04-12	2025-05-09	28 days
9	Ethics and Sustainability	2025-04-12	2025-04-25	14 days
10	Preparing Slides For Presentation	2025-04-26	2025-05-09	14 days
11	Project Proposal Report and Presentation	2025-05-10	2025-05-23	14 days

FYDP-D:

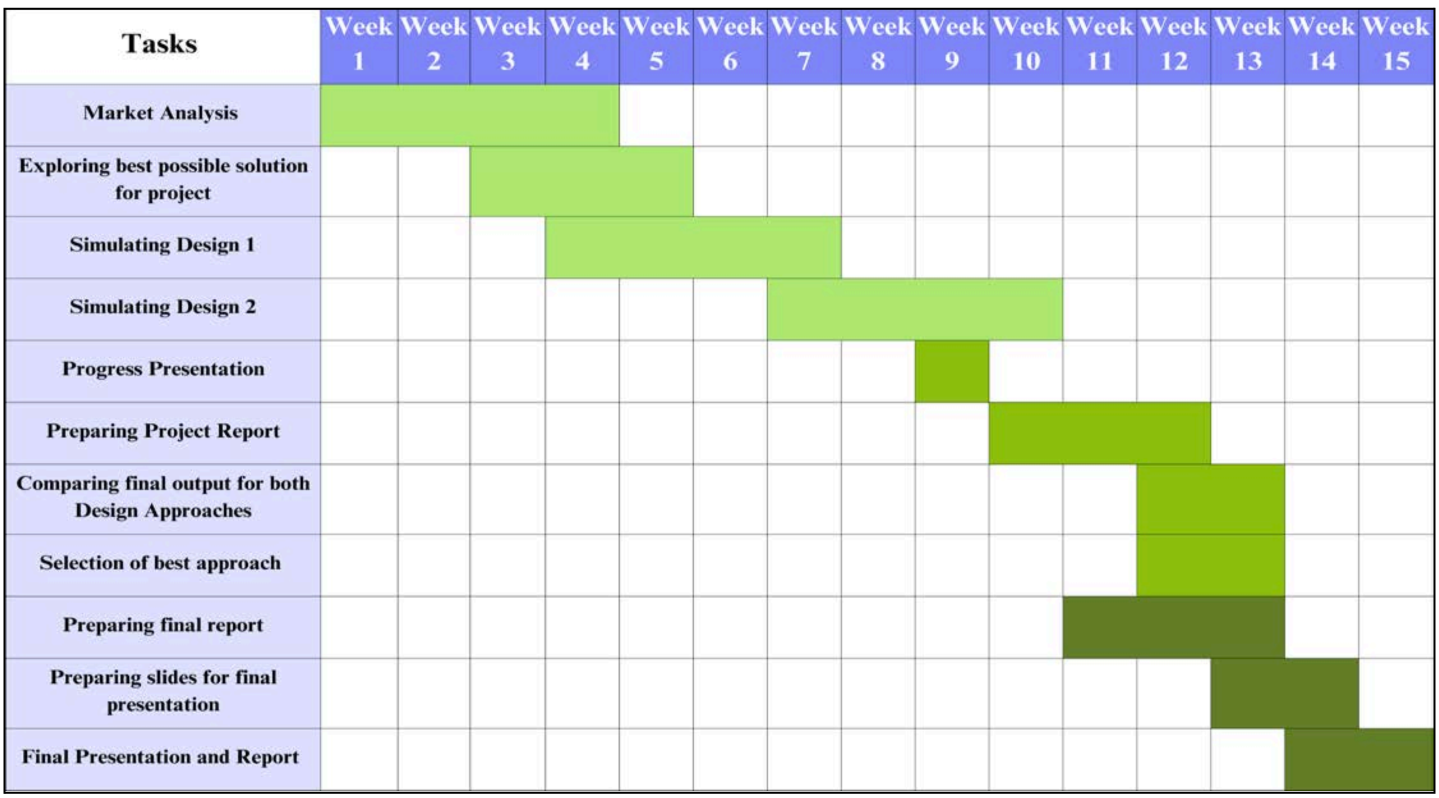


Figure 33: Gain Chart FYDP-D

Table-9: EEE499D Project Plan

TASK ID	TASK TITLE	START DATE	END DATE	DURATION
1	Market Analysis	2025-06-02	2025-06-29	28 days
2	Exploring best possible solution for project	2025-06-16	2025-07-06	21 days
3	Simulating Design 1	2025-06-23	2025-07-20	28 days
4	Simulating Design 2	2025-07-14	2025-08-10	28 days
5	Progress Presentation	2025-07-28	2025-08-03	7 days
6	Preparing Project Report	2025-08-04	2025-08-24	21 days
7	Comparing final output for both Design Approaches	2025-08-18	2025-08-31	14 days
8	Selection of best approach	2025-08-18	2025-08-31	14 days
9	Preparing final report	2025-08-11	2025-08-31	21 days
10	Preparing slides for final presentation	2025-08-25	2025-09-07	14 days
11	Final Presentation and Report	2025-09-01	2025-09-14	14 days

FYDP-C:

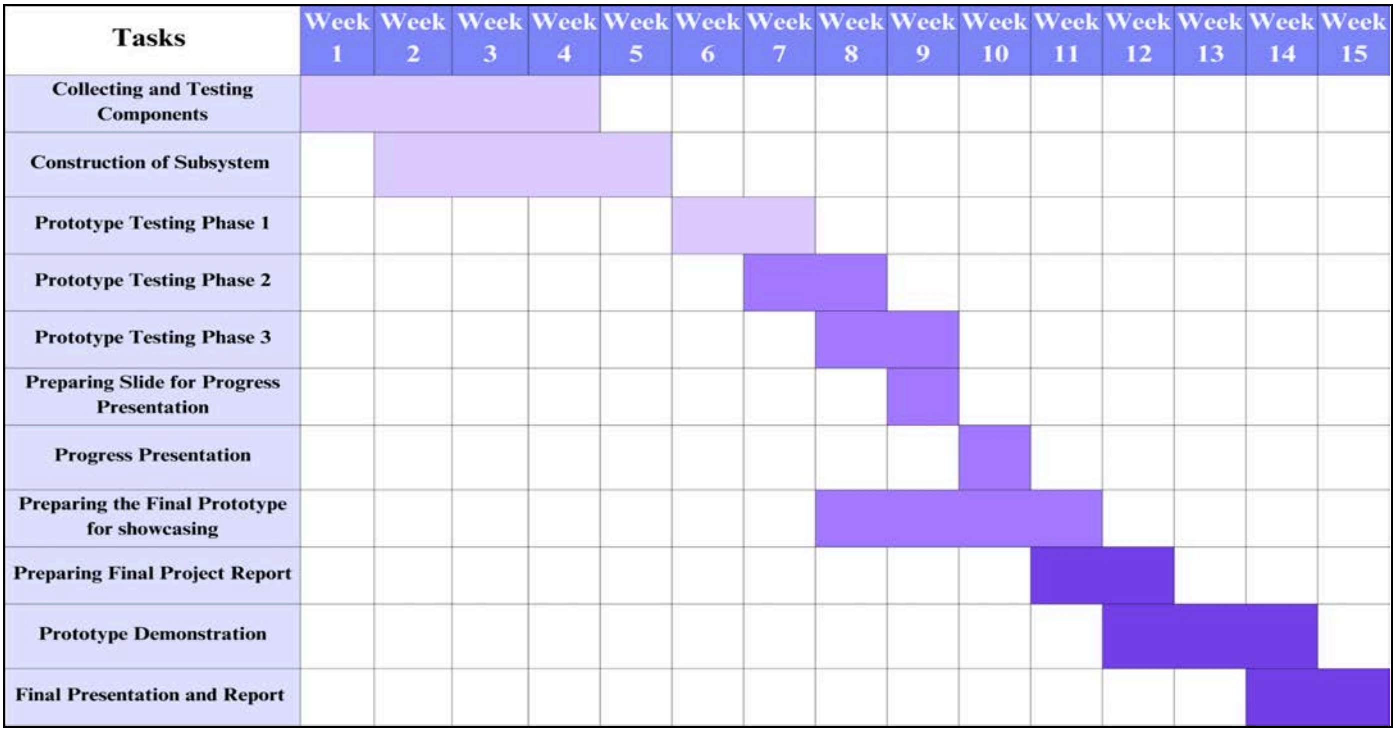


Figure 34: Gain Chart FYDP-C

Table-10: EEE499C Project Plan

TASK ID	TASK TITLE	START DATE	END DATE	DURATION
1	Collecting and Testing Components	2025-10-06	2025-11-02	28 days
2	Construction of Subsystem	2025-10-13	2025-11-09	28 days
3	Prototype Testing Phase 1	2025-11-10	2025-11-23	14 days
4	Prototype Testing Phase 2	2025-11-17	2025-11-30	14 days
5	Prototype Testing Phase 3	2025-11-24	2025-12-07	14 days
6	Preparing Slide for Progress Presentation	2025-12-01	2025-12-07	7 days
7	Progress Presentation	2025-12-08	2025-12-14	7 days

8	Preparing the Final Prototype for showcasing	2025-11-24	2025-12-21	28 days
9	Preparing Final Project Report	2025-12-15	2025-12-28	14 days
10	Prototype Demonstration	2025-12-22	2026-01-04	14 days
11	Final Presentation and Report	2026-01-05	2026-01-18	14 days

7.3 Conclusion

In conclusion, the project management principles were extensively applied during the project, and this contributed to the successful completion of the project. Fundamental aspects of the theory and concepts were well handled together with detailed planning through proper resource allocation. Progress reports were prepared and reviewed regularly, providing the opportunity to update and improve the overall project on time. A very important goal of these ongoing activities was to confront challenges and reduce possible risks. Furthermore, the team showed signs of a high level of collaboration, where members of the group completed their assigned responsibilities professionally while keeping their communication open and responsive. This organized and cooperative approach to project management allowed for the successful delivery of a complex engineering solution in a limited timeframe and at a reasonable cost.

Chapter 8: Economical Analysis. [CO12]

8.1 Introduction

A thorough analysis of cost is needed to transform a working prototype into a real life product. In this chapter, there is the explanation of the economic viability of the shovel-based autonomous waste collection system which consists of the main rover and a support base-station sorting machine. This analysis incorporates a detailed cost breakdown, in terms of parts, which are available in the market and hence real rather than estimated or theoretical prices have been used. It considers the cost of assembling a single entire unit, approximates potential profit, and points to the ways of cutting costs in case the system is set up on a larger scale. This project is not only technically successful but also a viable and sustainable project at managing waste along the coasts as revealed in this financial study.

8.2 Economic Analysis

This economic assessment evaluates the financial viability of developing and deploying the "Autonomous Waste Collecting Device" for Sugandha Point. It focuses on the breakdown of development costs, operational efficiency, market affordability, and the long-term economic impact on the local tourism industry and municipal waste management sectors.

1. Development and Production Cost: The fabrication of this autonomous rover offers a significant cost advantage over existing industrial beach-cleaning machinery and manual labor strategies. By utilizing a modular design approach, the project minimizes upfront capital requirements.

- **Hardware Costs:** The core structural components utilize high-grade PVC board sheets, which are significantly cheaper and more corrosion-resistant than the steel alloys used in heavy machinery. The electronic architecture relies on off-the-shelf components Raspberry Pi 5 for computation, ESP32 microcontrollers, standard MG996R servo motors, and L298N drivers. These parts are readily available in the local electronics market, eliminating import duties associated with specialized industrial robotics. The total prototype cost (approx. 51,870 BDT) is a fraction of the cost of imported tractor-pulled beach cleaners.

- **Software Costs:** The system leverages open-source technologies, including the YOLOv8 algorithm for object detection and Python-based control libraries. This eliminates licensing fees associated with proprietary automation software, ensuring that the software development cost is restricted primarily to intellectual effort rather than recurring subscriptions.

- **Labor and Assembly:** The selection of the Shovel Mechanism over more complex robotic arms simplifies the assembly process. The reduced mechanical complexity lowers the man-hours required for fabrication and calibration, directly reducing the labor cost per unit during manufacturing.

2. Affordability and Market Demand: The device is positioned as an affordable solution for cost-sensitive entities such as the Cox's Bazar Municipality and private beach resorts.

- **Competitive Price Point:** With a projected selling price of approximately 60,000 BDT, the device is accessible to small-to-medium enterprises that cannot afford large-scale industrial cleaners. This low entry barrier allows for the deployment of "swarms" or fleets of small rovers rather than relying on a single, expensive point of failure.

- **Scalability:** The cost analysis indicates that bulk production (e.g. 50 units) can reduce unit costs by approximately 13.25% through wholesale component sourcing. This scalability allows the project to maintain a healthy Return on Investment (ROI) of ~15.68% while potentially lowering the market price to around 52,000 BDT, further stimulating market adoption.

3. Operational and Maintenance Costs: The transition from diesel-powered tractors or manual labor to electric autonomous rovers presents distinct operational savings.

- **Power Consumption:** The device operates on rechargeable Li-ion battery packs with a peak consumption of roughly 80 Watts. The cost of electricity to recharge these batteries is negligible compared to the fuel costs for heavy machinery or the daily wages required for a human workforce to cover the same area.

- **Maintenance:** The mechanical design prioritizes modularity. The use of standard DC motors and servos means that if a component fails, it can be swapped out inexpensively without requiring specialized technicians. The PVC chassis requires no painting or rust-proofing treatments, further reducing long-term upkeep expenses in the saline environment.

4. Long-Term Economic Benefits: Beyond direct cost savings, the deployment of the system generates indirect economic value for the region.

- **Enhanced Tourism Revenue:** A cleaner beach directly correlates with higher tourist satisfaction and retention. By automating the removal of plastic litter, the aesthetic value of Sugandha Point increases, potentially driving higher footfall and revenue for local businesses.

- **Health and Safety Savings:** Automating the collection of hazardous waste (such as glass shards or rusted metal) reduces the risk of injury to human workers. This decreases the economic burden associated with medical treatment and lost labor hours due to injury.

- **Environmental Resource Preservation:** By preventing microplastics from entering the marine ecosystem, the device helps protect the local fishing industry's resources, ensuring the long-term economic sustainability of the coastal community.

5. Return on Investment (ROI): The financial analysis demonstrates a strong ROI for the project. The initial investment yields a functional product with a clear profit margin. The system's ability to operate autonomously with minimal human supervision reduces the recurring operational expenditure for the end-user. Consequently, the payback period for a municipality or resort investing in this technology is relatively short, as the savings on manual labor wages will offset the purchase cost of the rover within a few months of operation.

Overall, the economic analysis confirms that the Autonomous Waste Collecting Device is a financially sound investment. It bridges the gap between manual picking and heavy industrial cleaning, offering a cost-effective, sustainable, and scalable solution tailored to the economic reality of developing nations.

8.3 Cost Benefit Analysis

To determine the economic feasibility of the "Autonomous Waste Collecting Device," a rigorous financial assessment was conducted. This analysis breaks down the capital expenditure required to fabricate the physical prototype, consisting of two main subsystems: the Autonomous Rover and the Base Station Sorting Machine. These costs are then weighed against projected market pricing to calculate the Return on Investment (ROI), validating the project as a marketable engineering product.

8.3.1 Component Cost Breakdown

The following tables detail the specific costs of electronics, actuators, sensors, and structural materials used in the final design.

Table-11: Component Cost of the Autonomous Rover

Component	Specification	Quantity	Unit Price (BDT)	Total Price (BDT)
Microcontroller & Compute	Raspberry Pi 5	1	15,500	15,500
	ESP32-S3-DevKitC-1	2	1,990	3,980
	MicroSD Memory Card 64GB	1	1,000	1,000
Actuators & Motors	37GB 12V High Torque Gear Motor (100 RPM)	4	1,500	6,000
	Servo Motor MG996R (360° Continuous)	2	730	1,460
	L298N Dual H-Bridge Motor Driver	2	420	840
Sensors & Vision	Camera Module	1	3,000	3,000
	Ultrasonic Sonar Sensor HC-SR04	3	110	330

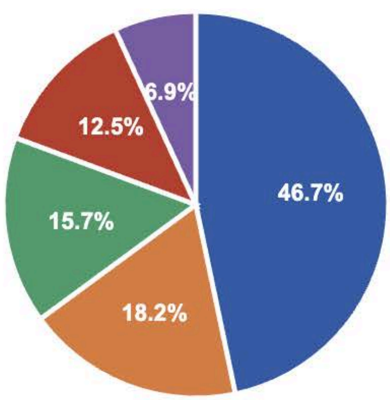
	Infrared Obstacle Avoidance Sensor	2	45	90
Power System	Wasing 18650 3.7V 2000mAh Li-ion Battery	10	450	4,500
	IP5328P Fast Charging Power Bank Module	1	590	590
	USB 2.4A External Lithium Battery Pack	1	375	375
	LM2596 DC-DC Buck Converter	1	100	100
Chassis & Hardware	PVC Board Sheet	1	2,000	2,000
	Wheels	4	200	800
	Active Buzzer 12V	1	20	20
	Miscellaneous (Wiring, Connectors, Hardware)	-	-	370
Total Rover Cost				**৳40,955**

Table-12: Component Cost of the Sorting Machine (Base Station)

Component	Specification	Quantity	Unit Price (BDT)	Total Price (BDT)
Microcontroller	Arduino Mega 2560 R3	1	1,900	1,900
	ESP32-S3 CAM Development Board	1	1,845	1,845
Actuators	Servo Motor MG996R (360° Continuous)	1	730	730
	12V 60RPM DC Gear BO Motor	1	145	145

	L298N H-Bridge Motor Driver	1	185	185
	1 Channel 5V Relay Board Module	1	95	95
Sensors	Infrared Obstacle Avoidance Sensor	3	45	135
	Active Buzzer 12V	1	20	20
Power System	Wasing 18650 3.7V 2000mAh Li-ion Battery	2	450	900
Structure	Frame Construction Materials	1	4,960	4,960
Total Sorting Machine Cost				**৳10,915**

Component Cost Distribution of the Autonomous Waste Collecting Device



Category	Total Cost (৳)	Rover (৳)	Sorting Machine (৳)
Microcontroller & Compute	24,225	20,480 (84.5%)	3,745 (15.5%)
Actuators & Motors	9,455	8,300 (87.8%)	1,155 (12.2%)
Chassis & Hardware	8,150	3,190 (39.1%)	4,960 (60.9%)
Power System	6,465	5,565 (86.1%)	900 (13.9%)
Sensors & Vision	3,575	3,420 (95.7%)	155 (4.3%)
Total	**51,870**	**40,955**	**10,915**

Total Project Cost: ৳51,870 BDT | Rover: ৳40,955 BDT (79.0%) | Sorting Machine: ৳10,915 BDT (21.0%)

Figure 35: Total Project Cost Summary

8.3.2 Financial Feasibility and ROI Analysis

With the total fabrication cost established at ৳51,870, we conducted a cost-benefit analysis based on the production of a single prototype unit versus potential bulk manufacturing. This analysis serves to validate the project's viability in the commercial market.

Unit Profitability:

Based on current market rates for similar semi-autonomous robotic solutions, a competitive selling price of ৳60,000 was established. The net profit per unit is calculated as follows:

- Selling Price: ৳60,000
- Total Cost: ৳51,870
- Net Profit: ৳8,130

Return on Investment (ROI):

The Return on Investment (ROI) is the primary key performance indicator (KPI) used here to evaluate the efficiency of the expenditure.

$$\text{ROI} = \frac{Net\ Profit}{Total\ Cost} \times 100\%$$

$$\text{ROI} = \frac{8{,}130}{51{,}870} \times 100\% \approx (15.68\%)$$

An ROI of 15.68% indicates a healthy financial return for a specialized hardware product. This positive percentage justifies the initial capital investment and suggests that the project can sustain itself financially while providing the intended environmental benefits.

Annual Profit Projections:

To estimate the long-term financial outlook, we assumed a conservative initial market adoption rate where 10 to 15 units are sold annually to potential clients such as municipal authorities, private beach resorts, or park management committees.

- Lower Bound (10 units):

  $10 \times 8{,}130 =$ ৳81,300

- Upper Bound (15 units):

  $15 \times 8{,}130 =$ ৳121,950

These projections demonstrate that even with low-volume sales, the project generates sufficient revenue to cover operational overheads and fund further research and development for future iterations.

8.4 Evaluate Economic and Financial Aspects

The financial evaluation of the system emphasizes the transition from a high-cost prototype to a scalable market product. While the initial prototype focuses on functionality, the market-ready version accounts for economies of scale, marketing, and distribution. By optimizing the supply chain for bulk production, the system achieves a competitive edge while maintaining a healthy return on investment (ROI).

8.4.1 Cost Structure and Scaling

The transition to a product-level approach involves a strategic reduction in component costs. By shifting to a batch production model (e.g., 50 units), bulk procurement of core electronics such as the Raspberry Pi, actuators, and power systems allows for a 13.25% reduction in manufacturing costs. This brings the unit cost down from the initial estimation to ৳45,000.

Table-13: Product Level Cost Estimation (Per Unit)

Cost Component	Prototype Phase (BDT)	Product Phase (Bulk) (BDT)
Hardware & Electronics	29,500	25,600
Packaging & Distribution	0	5,000
Marketing & Promotion	0	8,000
Contingency & Maintenance	0	6,400
Total Unit Cost	**29,500**	**45,000**

8.4.2 Future Economic Considerations

Beyond immediate sales, the project's long-term economic viability is bolstered by:

- **Operational Savings:** Reduced power requirements through optimized code and low-power sensors.

- **Renewable Integration:** Potential for solar-powered variants to reduce electricity overhead for the end-user.
- **Maintenance Revenue:** Subscription-based maintenance models for municipal or corporate deployments.

8.5 Conclusion

The economic analysis proves that the Autonomous Waste Collecting Device is a useful solution as an engineering project available financially. The project has a solid ROI of 15.68%, and with a low-volume production at a new production price of 51870, the project is sustainable. The possibility of reducing costs due to the high production rate also support financial perspective, which enables a competitive price figure of ৳52,056 but at the same time profitability is attained. These statistics prove that the solution is not only technically correct but also viable in terms of economic realisation within the target area.

Chapter 9: Ethics and Professional Responsibilities [CO13, CO2]

9.1 Introduction

An autonomous and waste-gathering device developed and implemented at Sugandha Point, Cox, needs to be implemented following the ethical standards that promote environmental sustainability, safety of people, privacy, and social responsibility. It is not only the duty of engineers to make the systems to solve complex issues like the increasing problem of beach pollution- but also to follow the safety of the society and nature.

The project works in a dynamic social setting where a high degree of compliance with the current standards and codes is necessary. These are navigation guidelines, waste detection guidelines, transparency guidelines, ethical design guidelines, safety guidelines, sustainability, and environmental protection guidelines. The project will adhere to these standards to ensure that the local ecosystem is preserved as well as being more inclined to attract the interest of the people and also add to the overall cleanliness of one of the most frequented coasts within Bangladesh.

9.2 Identify Ethical Issues and Professional Responsibility

When developing the autonomous waste-collecting machine, a number of significant ethical concerns and professional obligations have been known to address the requirements of every stakeholder both ethically and legally.

- **Environmental Sustainability:** The equipment should cause minimal disturbance to the ecology of the coast of Cox bazaar, marine life and vegetation. In this situation, alloys that are not harmful to the environment, have potential to be recycled or are corrosion resistant are used to handle the coastal conditions. Findings on waste sorting and storage systems should avoid secondary contamination procedures, which fits IEEE Std 7000-2021 on ethical system design which focuses on autonomy in autonomous technologies being sustainable [9].

- **Public Safety and Risk Mitigation:** Since Sugandha Point is heavily used by several people, the device complies with IEB Code of Ethics under which public safety is the key factor [11]. To eliminate accidents, the system is equipped with impediment detection (LiDAR, ultrasonic sensors), and fail-safe (emergency shutdown) to avoid accidents. There are also clear visual/auditory messages to warn users about beaches and compliance with the IEEE Std 80-2013 guarantees safety in the electrical case in the outdoors and wet environment [7].
- **Privacy and Data Ethics:** Since the device will operate on the principle of navigation, waste detection with cameras and sensors, the data obtained will be minimized and anonymized to ensure the privacy of visitors. This is carried out with strong measures of cybersecurity to avoid breach, which is compared to the IEEE Std 7000-2021 framework of ethical data handling [9]. Openness in the use of data guarantees the confidence of the people which is in line with the NSPE Code of Ethics [8].
- **Community Engagement and Social Equity:** Local stakeholders, such as tourists, vendors, and available waste collectors, are taken into account so that the device should not change the livelihoods but increase the benefit of the existing planning. The design options support fair access and inclusive solutions, which are in line with IEEE Std 7000-2021 [9].
- **Accountability and Transparency:** Since it is an independent system, its decision-making procedures (e.g., it is determined to be wasteful) need to be responsible. The black box problem is an ethical issue. The next step to the professional responsibility is to provide transparency to operators and regulators in the functioning of the system, proper documentation and delimiting of clear responsibilities of the actions of the system and their possible unintended effects.

9.3 Apply Ethical Issues and Professional Responsibility

To ensure the project is safe, sustainable, and compliant with engineering best practices, specific standards and codes have been applied to the design and operation of the device.

Table-14: Ethical Issues and Professional Responsibility

Ethical Issue	Relevant Standard / Code	Application in Project (Implementation)

Public Safety	• **IEB Code of Ethics** • **IEEE Std 80-2013**	• **Collision Avoidance:** LiDAR and ultrasonic sensors are installed to help the car to note and avoid tourists and obstacles. • **Emergency Stop:** Stop physical controls fitted in the event of immediate shutting down in dangerous conditions. • **Electrical Safety:** Sealed, waterproof containers that facilitate the warding of shock when on the rainy beach.
Environmental Sustainability	• **IEB Sustainability Guidelines** • **ECR 1997 (Bangladesh)**	• **Ecofriendly Materials:** Divas are made out of recyclable corrosion-resistant alloys that avoid corrosion of the material. • **Energy Saving:** New solar-rechargeable batteries to cut the carbon footprint. • **Ecosystem Protection:** Tread design reduces sand erosion and safeguard marine (e.g., crabs, turtle nests) life.
Transparency & Trust	**IEEE 7001-2021** (Transparency of Autonomous Systems)	• **Decision Logging:** The system records the reason behind why some objects are gathered or which can be neglected and the authorities will be able to audit this. • The robot is marked using public indicators (Visual (LED) and auditory) to inform the surrounding beachgoers about the robot (e.g., "Collecting" and "Full").
Reliability & Performance	**IEEE 1872-2015** (Robotics Ontologies)	• **Quality Detection:** Every standard ontology is applied to differentiate real waste (bottle of plastic) and natural features (seaweed/shells). • **Large Uptime:** Machines are made to work at 95% reliability in fluctuating weather (wind, salt spray).

Privacy & Data Ethics	• **IEEE Std 7000-2021** • **NSPE Code of Ethics**	• **Data Anonymization:** Feeds of cameras are utilized in navigation, which are not stored permanently to preserve the identity of tourists. • **Limited Data Collection:** Needless data is only sent to the central dashboard like the type of waste and the volume of waste.
Waste Management Compliance	**BNBC Environmental Section**	• **Leakage Prevention:** Leakage of liquids (leachate) is contained by sealed waste storage compartments through the transportation across the beach. • **Segregation:** Manual sorting by means of automated sorting accords to the recyclable plastics and the non-recyclable waste at the point of collection.

9.4 Conclusion

The professional and moral duties of this project are not limited to the implementation of the technical aspects but also to long-term responsibility and to the requirement of regulations. The project also adheres to the environmental laws of Bangladesh and international industry standards such as IEEE P7000 series. Clear paperwork and disclosure ensures accountability and a set out policy on maintenance and decommissioning contributes to the reduction of future environmental damage.

Considering the given ethical considerations and standards, the autonomous waste-collector device will be presented as not the sole technical solution, but rather as the responsible one to the eco system of Cox Bazar and the welfare of its guests. The on-site deployment will be done only after appropriate approvals and letters have been received by the regulatory bodies to guarantee total compliance.

Chapter 10: Conclusion and Future Work.

10.1 Project Summary/Conclusion

The Autonomous Waste Collecting device has been able to attain its main goal of the project, this is the design of a sound engineering solution aimed at fighting plastic pollution at the Sugandha point in Cox bazar. The team came up with an autonomous rover, which can navigate around sandy land surface, identify waste to collect through computer vision and haul it using a mechanical shovel system through a structured design process. Its last prototype can perfectly fit the set functionality requirements and successfully prove the capability to automate the process of beach cleaning to contribute to environmental sustainability.

The project will be a response to a severe problem in society, which could be scaled and sustainable. The device closes the gap between vision systems and high-tech robotics and effective and affordable waste management through the integration of a Raspberry Pi-based vision system and a stable mechanical chassis. The chosen "Shovel Mechanism" has turned out to be the best design option to use, which provides the required durability and the necessary energy-saving needs, needed in the coastal setting. Besides technical success, the project preconditions a more large-scale environmental effect, providing a tool that would not only physically clean but also increase the awareness of the significance of marine ecosystem conservation. The solution is now geared towards the subsequent stage of maturity and there is a clear direction on how to tap into the interest of environmental groups and Non Governmental Organizations (NGOs) to get seed funding to launch the pilots.

10.2 Future Work

Although the existing prototype has been able to highlight the main functionality of the device, there are some opportunities of optimization and expansions that have been found to get the device out of the university project to a commercial grade product.

- **Technologically Sophisticated Machine Learning and Vision**: The present waste identifying algorithm runs on a particular waste collection of typical beach rubbish. The next development will be dedicated to the further development of this data set; it will cover a broader range of waste types (e.g., glass, metal, fishing nets), and partially buried objects. The above will increase the detectability and reliability of the rover in dynamic outdoor settings because training the model on data obtained during various lighting conditions (i.e., dawn, dusk, and harsh midday sun) will improve accuracy and reliability.

- **Saline Environment Hardware Durability:** Cox's Bazar has a harsh environment on the seas in terms of corrosion and abrasion. The next steps of work will be the replacement of the chassis and the structural PVC and regular metals with the modern and marine-rated anodized aluminum or stainless steel. The incorporation of IP-rated motors and sealed electronics enclosures will also be given priority, so that the system will not be damaged by saltwater mist and fine sand intrusion and thus its working life will be long.

- **Integration of Renewable energy:** To ensure that the system is as sustainable as possible, the power system will be restructured to integrate renewable sources of energy. The upper surface of the rover can be used as a flexible solar panel real estate and this capability can be utilized to charge trickles during operation and increase the battery life. Moreover, the base station/sorting unit can be fitted with a vertical-axis wind turbine to utilize the uniform brew of coastal wind. This new energy model would lead to a decrease in the carbon footprint of the cleaning process itself, which would result in the real eco-friendly system.

Chapter 11: Identification of Complex Engineering Problems and Activities.

11.1: Identify the attribute of complex engineering problem (EP)

Table-15: Identify the attribute of complex engineering problem (EP)

	Attributes	Put tick (√) as appropriate
P1	Depth of knowledge required	√
P2	Range of conflicting requirements	
P3	Depth of analysis required	√
P4	Familiarity of issues	√
P5	Extent of applicable codes	
P6	Extent of stakeholder involvement and needs	
P7	Interdependence	√

11.2: Provide reasoning how the project address selected attribute (EP)

- **P1: Level of knowledge needed.**

  The project combines the knowledge of various disciplines which are mechanical design, embedded systems, sensor technology, artificial intelligence (computer vision) and environmental engineering. Autonomous navigation, AI-developed waste detection and mechanical waste collection need an interdisciplinary approach that goes beyond one field of engineering.

- **P3: Depth of analysis required**

  In the design of the system, the adaptability of the terrain on a sandy surface needed to be thoroughly analyzed, as well as the behavior of sensors to avoid obstacles, the accuracy of the machine learning model in different lighting conditions, optimizing power consumption, and mechanical endurance in salty conditions. Simulations and calculations were done and a prototype test conducted a number of times to make sure that there is reliability in the integration.

- **P4: Familiarity of issues**

  The issue of waste collection is not new, but the proposed completely autonomous solution in a beach setting makes it more complicated. The application of AI-based waste recognition, autonomous movement, and functioning in harsh environment conditions makes the issue not so well known and non-routine.

- **P7: Independence**

  The system is highly dependent on the interdependence between mechanical (chassis and shovel mechanism) and electronic (sensors, motors and controllers) hardware and software modules (navigation, waste detection, and control logic). The interplay between these subsystems forms a closely coupled and complicated engineering solution.

11.3 Identify the attribute of complex engineering activities (EA)

Table-16: Identify the attribute of complex engineering activities (EA)

	Attributes	**Put tick (√) as appropriate**
A1	Range of resource	√
A2	Level of interaction	
A3	Innovation	
A4	Consequences for society and the environment	√
A5	Familiarity	√

11.4 Provide reasoning how the project address selected attribute (EA)

- **A1: Range of Resource**

  The project will also need a wide variety of resources such as mechanical components, electronic sensors, embedded controllers, power infrastructure, AI software and realistic beach testing systems.

- **A4: Social and Environmental Impact**

  The system has a direct role in protecting the environment by both reducing beach pollution and improving the hygiene of the people which impacts tourism, marine life positively as well as health among the people.

- **A5: Familiarity**

  Although the problem of waste management is not new, the planned use of an autonomous waste collection system based on AI in a dynamic beach setting makes the issue non-routine and less familiar.

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Appendix

LogBook of FYDP:

Final Year Design Project (D) Summer 2025			
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Member 1	Mohaimenul Islam	mohaimenul.islam@bracu.ac.bd	
Member 2	AldrinNipponBobby	nippon@bracu.ac.bd	

Table-17: FYDP (P) Summary of Team Log Book

Date/Time/Place	Attendee	Summary of Meeting Minutes	Responsible	Comment by ATC
18.2.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Need to narrow down the scope for the proposed and shortlisted 4 ideas. 2. Need to finalise the problem statement. 3. Prepare a draft proposal note for all ideas before the meeting.	Task 1: All Task 2: All Task 3: All	Shortlisted 1 idea from 4 and will try to do the tasks before the next meeting.
24.2.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Shortlisted 1 problem 2. Needs more literature review 3. Prepare 3 different design approaches for the system	Task 2: All Task 3: All	Task 1: Done Task 2: Done Task 3: Partially done
5.3.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Design proposal approved 2. Start working on the Draft concept Note	Task2: All	Task1: Done Task2:Done

13.3.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Checked draft proposal and made some corrections 2. Prepare for the progress presentation	Task1: All Task2: All	Task1: Done Task2: Done (After suggestions, changes were made for the concept note.)
16.3.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Suggestions about the slide for the progress presentation were given	Task1: All	Task1: Done
Date/Time/Place	**Attendee**	**Summary of Meeting Minutes**	**Responsible**	**Comment by ATC**
6.4.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	First meeting after the midterm, suggestions about the project proposal were taken	All members were tasked	N/A
9.4.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Do chapter chapter-wise division 2. Suggestions on Slides	Task1: All Task2: All	N/A
13.4.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Book a conference room for a mock presentation	Task1:All done	N/A
16.4.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. A Mock Presentation was given. Some modifications to the slides and presentation suggestions were given	All	Task1: Done
23.4.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Checked draft proposal and made some corrections	All	Task: Done
4.5.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Checked final proposal and made some corrections	All	Task: Done
7.5.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Day before final presentation, Mock presentation 2 was given and feedback from ATC was taken accordingly	N/A	Tasks: All done
8.5.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Final presentation given, and feedback from all ATC was taken accordingly. 2. Discussed with our ATC regarding the feedback taken	N/A	Tasks: All done

		from the FYDP-P presentation.		
14.5.2025	1. Shariar 2. Riaz 3. Afrin 4. Musabbi	1. Discussed with our ATC to polish our final proposal.	N/A	Tasks: All done

Table-18: FYDP (D) Summary of Team Log Book

Date / Time	Attendees	Summary of Meeting	Responsible	Comment by ATC
26.06.2025 (FYDP Committee)	Shariar, Riaz, Afrin, Musabbi	Introductory meeting of FYDP (D). Discussed timeline, scope of shortlisted ideas, and narrowed problem statement. Decided to prepare a draft proposal.	All members	N/A
29.06.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Brief discussion on the FYDP D Work with ATC.	All members	Advised to start the work
06.07.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Literature review progress reviewed. Agreed to prepare three different design approaches. Draft of mathematical model introduced.	All members	More review needed; ensure models are justified.
13.07.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Discussed simulation software options. Started initial modeling for the shortlisted system.	All members	Proposal draft design acceptable; keep updating report.

20.07.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Continued simulation work and division of design approaches. Began drafting progress presentation slides.	All members	Make algorithms for each design approach.
27.07.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Reviewed research papers for simulation support. Added parameters into the model. Updated report draft.	All members	Fix writing errors in logbook/report.
03.08.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Conducted mock presentation. Adjusted slides based on feedback. Report formatting started.	All members	Focus on slide clarity and figure consistency.
10.08.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Delivered updated mock presentation. Discussed waste detection/model comparison section. Refined draft report.	Shariar & Riaz – report; Afrin & Musabbi – slides	Good progress; add more comparison details.
17.08.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Prepared final presentation. Completed comparison of design approaches. Updated formatted report.	Shariar & Afrin – comparison; Riaz & Musabbi – formatting	Submit final draft by next session.
24.08.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Reviewed and corrected final report. Completed logbook update.	All members	Overall progress satisfactory; project ready for submission.
26.08.2025 (Thursday)	Shariar, Riaz, Afrin, Musabbi	Given final presentation to the FYDP-D panel-1.	All members	N/A

30.08.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Instructed to prepare the final report for the FYDP-D.	All members	N/A
07.09.2025 (Sunday)	Shariar, Riaz, Afrin, Musabbi	Submitted the final report for review by the ATC.	All members	Suggested some minor changes
11.09.2025 (Thursday)	Shariar, Riaz, Afrin, Musabbi	Change the report based on suggestion and submitted to the classroom of FYDP-D.	All members	N/A

Table-19: FYDP (D) Summary of Team Log Book

Date/ Time/ Place	**Attendee**	**Summary of Meeting**	**Responsible**	**Comment by ATC**
16.10.2025 (FYDP Committee) Class-1 (Offline)	Faculty Member Mirza Rasheduzzaman Students 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Introductory class on EEE499C and deadlines.		
16.10.2025 ATC Meeting 1 (Offline)	Faculty Member Chair- Dr. Md. Mosaddequr Rahman Students 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Discussion on FYDP C progress.		1. Update logbook weekly. 2. Start hardware following Design Approach 1. 3. Share logbooks, reports, updates before meetings.

23.10.2025 ATC Meeting 2 (Offline)	Faculty Member Chair- Dr. Md. Mosaddequr Rahman Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Report writing and hardware start.	Task 1: Sabrina, Shariar, Riaz, Musabbi	1. Reduce autonomous words in report. 2. Acquire components soon. 3. Submit component video this week.
02.11.2025 ATC Meeting 3 (Offline)	Faculty Member Mohaimenul Islam Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Project implementation plan. 2. Report chapters 3-4. 3. Component testing.	Task1: Sabrina, Shariar, Riaz. Task 2: Musabbi	1. Use trial-and-error. 2. Fix component issues.
10.11.2025 ATC Meeting 4 (Offline)	Faculty Member Mohaimenul Islam Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Rover frame connections shown. 2. Firmware issue discussed. 3. Report chapters 4,6,7. 4. Rover frame building.	Task 1: Riaz, Sabrina. Task 2: Musabbi, Shariar, Riaz. Task 3: Musabbi, Shariar, Riaz. Task 4: Musabbi, Riaz.	1. Fix firmware. 2. Correct report format.
19.11.2025 ATC Meeting 5 (Offline)	Faculty Member Chair- Dr. Md. Mosaddequr Rahman Students: 1. Shariar 2. Riaz (Absent- Due to family emergency) 3. Sabrina 4. Musabbi	1. Firmware fix shown. 2. Report chapters 5,9.	Task 1: Sabrina, Shariar, Riaz, Musabbi. Task 2: Sabrina, Musabbi,	1. Prepare progress presentation. 2. Make rover move. 3. Absence accepted. 4. Fix report errors.

			Riaz. Task 3: Shariar.	
22.11.2025 Group Meeting 1 (Offline)	Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Trash detection added. 2. Collection mechanism added (in progress).	Task 1: Shariar, Riaz, Sabrina, Musabbi.	
03.12.2025 ATC Meeting 6 (Offline)	Faculty Member 1. Chair- Dr. Md. Mosaddequr Rahman 2. Mohaimenul Islam Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Progress presentation.		1. Rover real-life results/analysis. 2. Validate GPS/compass reliability.
07.12.2025 Group Meeting 2 (Offline)	Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Collection mechanism implemented. 2. Rover stability work. 3. Poster started. 4. Report chapters 8,10,11.	Task 1: Shariar, Riaz, Sabrina Task 2: Shariar, Riaz, Musabbi	
17.12.2025 ATC Meeting 7 (Offline)	Faculty Member Chair- Dr. Md. Mosaddequr Rahman Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Updated poster shown. 2. Rover crash discussed.		1. Poster review next meeting. 2. Fix rover quickly. 3. Be aware of rover risks.

22.12.2025 ATC Meeting 8 (Offline)	Faculty Member Mohaimenul Islam Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Finished rover shown. 2. Camera structure fix. 3. Collection stability structure. 4. Chapter 5 work.	Task 1: Shariar, Riaz, Sabrina	1. Improve stability.
28.12.2025 ATC Meeting 9 (Offline)	Faculty Member Mohaimenul Islam Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Overall progress shown: test drives, detections, mechanism. 2. Report formats fixed. 3. Figures added. 4. New wheels ordered.	Task 1: Riaz, Shariar, Musabbi, Sabrina Task 2: Shariar, Sabrina Task 3: Shariar	1. Learn precise navigation. 2. Satisfactory progress; proceed to field test. 3. Fix report formats. 4.Ethics/Acknowledgement separate page. 5. Add figure numbers. 6. Fix wheels soon.
04.01.2026 ATC Meeting 10 (Offline)	Faculty Member Chair- Dr. Md. Mosaddequr Rahman Students: 1. Shariar 2. Riaz 3. Sabrina 4. Musabbi	1. Failed rover fix informed. 2. New wheels attached. 3. Frame broke in test. 4. Frame fix attempted. 5. Trash detection/collecting video made. 6. Poster completed. 7. Leaflet made. 8. Chapter 5 completed. 9. Poster printed. 10. Report formatting corrected. 11. Frame fixed/functional. 12. Stability/payload test video. 13. Trash detection test video.	Task 1: Shariar, Sabrina Task 2: Shariar, Riaz, Sabrina, Musabbi	1. Fix rover frame before showcasing. 2. Try to fix it. 3. Make detection/collecting video. 4. Try to fix the rover. 5. Approve poster for printing.

		14. Base-station integration.		

Related code/theory

Model training

```
import cv2
from ultralytics import YOLO
import lgpio
import time

# ========== GPIO Setup ==========
LED_PIN = 17   # GPIO17 = Pin 11
chip = lgpio.gpiochip_open(0)   # open first GPIO chip
lgpio.gpio_claim_output(chip, LED_PIN)

# ========== Load YOLO Model ==========
model = YOLO("best.pt")   # make sure best.pt is in /home/shafiq/

# ========== Open USB Camera ==========
cap = cv2.VideoCapture(0)  # 0 = first USB camera
try:
    while True:
        ret, frame = cap.read()
        if not ret:
            break
```

```
        results = model(frame)
        for r in results:
            for box in r.boxes:
                x1, y1, x2, y2 = map(int, box.xyxy[0])
                cls = int(box.cls[0])
                conf = float(box.conf[0])
                # Draw box
                cv2.rectangle(frame, (x1, y1), (x2, y2), (0, 255, 0), 2)
                label = f"{model.names[cls]} {conf:.2f}"
                cv2.putText(frame, label, (x1, y1 - 10),
                            cv2.FONT_HERSHEY_SIMPLEX, 0.6,
                            (0, 255, 0), 2)
                # ===== Distance estimation via box size =====
                box_area = (x2 - x1) * (y2 - y1)
                print("Box area:", box_area)

                if box_area > 20000:   # adjust threshold for ~30–40 cm
                    lgpio.gpio_write(chip, LED_PIN, 1)   # LED ON
                else:
                    lgpio.gpio_write(chip, LED_PIN, 0)   # LED OFF
        cv2.imshow("Garbage Detection", frame)
        if cv2.waitKey(1) & 0xFF == ord('q'):
            break
except KeyboardInterrupt:
    print("Stopped by user")
finally:
    cap.release()
```

```
cv2.destroyAllWindows()
lgpio.gpiochip_close(chip)
```

Waste Segregation Code:

```
#define BLYNK_TEMPLATE_ID          "TMPL6FEFofeqo"
#define BLYNK_TEMPLATE_NAME        "Quickstart Template"
#define BLYNK_AUTH_TOKEN           "lsTyhqRMl9_Cc-TpOYoOzhBZBWjEA-ZP"
#define BLYNK_PRINT Serial
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "abcde";
char pass[] = "123456yxz";
////////////////////////////////////
const int ledPin = 16;
// setting PWM properties
const int freq = 5000;
const int ledChannel = 0;
const int resolution = 8;
//#include <Servo.h>//this is not for esp32.
#include <ESP32Servo.h>
Servo myservo1;
Servo myservo2;
//Servo myservo3;
//Servo myservo4;
int value;
int value2;
int value3;
```

```
int value4;
int value5;
int value6;
int value7;
int value8;
int value9;
int pos=180;
int pos2=180;
int garbage=36;
int garbageval=0;
int count=0;
int count2=0;
int cycle=0;
//////////////////////////////////////
// 3x HC-SR04 on ESP32
// Trig pins must be outputs. Echo pins must be inputs (and level-shifted to 3.3V!)
const int TRIG1 = 4;
const int ECHO1 = 34;
const int TRIG2 = 5;
const int ECHO2 = 35;
const int TRIG3 = 17;
const int ECHO3 = 32;
unsigned long ECHO_TIMEOUT = 30000UL; // microseconds (≈ 5 meters)
const int IR1 = 39;
const int IR2 = 33;
const int IR3 = 25;
int buz=18;
```

```
/////////////////////////////////////////////////
BLYNK_WRITE(V0)
{
 // Set incoming value from pin V0 to a variable
 value = param.asInt();
}
BLYNK_WRITE(V1)
{
 // Set incoming value from pin V0 to a variable
  value2 = param.asInt();
}
BLYNK_WRITE(V2)
{
 // Set incoming value from pin V0 to a variable
  value3 = param.asInt();
}
BLYNK_WRITE(V3)
{
 // Set incoming value from pin V0 to a variable
  value4 = param.asInt();
}
//BLYNK_WRITE(V4)
//{
//  // Set incoming value from pin V0 to a variable
//   value5 = param.asInt();
//}
//
```

```
//BLYNK_WRITE(V5)
//{
//  // Set incoming value from pin V0 to a variable
//   value6 = param.asInt();
//}
//
BLYNK_WRITE(V7)
{
  // Set incoming value from pin V0 to a variable
   value7 = param.asInt();
}
BLYNK_WRITE(V8)
{
  // Set incoming value from pin V0 to a variable
   value8 = param.asInt();
}
BLYNK_WRITE(V9)
{
  // Set incoming value from pin V0 to a variable
   value9 = param.asInt();
}
void setup()
{
  Serial.begin(115200);
  Blynk.begin(auth, ssid, pass);
  ////////////////////////////////////////////////////
  myservo1.attach(13);
```

```
  myservo1.write(pos);
  myservo2.attach(15);
  myservo2.write(pos2);
  pinMode(12,OUTPUT);//8266  D5
  pinMode(14,OUTPUT);//8266  D6
  pinMode(27,OUTPUT);//8266  D7
  pinMode(26,OUTPUT);//8266  D8
  pinMode(garbage,INPUT);
//
//  // configure LED PWM functionalitites
//  ledcSetup(ledChannel, freq, resolution);
//  // attach the channel to the GPIO to be controlled
//  ledcAttachPin(ledPin, ledChannel);
  ////////////////////////////////
  pinMode(TRIG1, OUTPUT); digitalWrite(TRIG1, LOW);
  pinMode(TRIG2, OUTPUT); digitalWrite(TRIG2, LOW);
  pinMode(TRIG3, OUTPUT); digitalWrite(TRIG3, LOW);
  pinMode(ECHO1, INPUT);
  pinMode(ECHO2, INPUT);
  pinMode(ECHO3, INPUT);
  pinMode(IR1, INPUT);
  pinMode(IR2, INPUT);
  pinMode(IR3, INPUT);
  pinMode(buz,OUTPUT);
//////////////////////////////////////
}
/////////////////////////////
```

```
float readSensor(int trigPin, int echoPin) {
  // Send pulse
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  // Read echo
  unsigned long duration = pulseIn(echoPin, HIGH, ECHO_TIMEOUT); // microseconds
  if (duration == 0) {
    // timeout / no echo
    return -1.0;
  }
  // Speed of sound ~343 m/s -> 0.0343 cm/us; distance = (duration/2) * 0.0343
  float distance_cm = (duration * 0.0343) / 2.0;
  return distance_cm;
}
////////////////////////////////////////
void loop()
{
  strt:
  Blynk.run();
  garbageval=digitalRead(36);
  Serial.print("garbage val:");
  Serial.println(garbageval);
////////////////////////////////////////////////////////////////
//////////////////////////////////////
```

```
  float d1 = readSensor(TRIG1, ECHO1);
  float d2 = readSensor(TRIG2, ECHO2);
  float d3 = readSensor(TRIG3, ECHO3);
  Serial.print("S1: ");
  if (d1 < 0) Serial.print("Out");
  else Serial.print(String(d1,1) + " cm");
  Serial.print("  |  S2: ");
  if (d2 < 0) Serial.print("Out");
  else Serial.print(String(d2,1) + " cm");
  Serial.print("  |  S3: ");
  if (d3 < 0) Serial.print("Out");
  else Serial.print(String(d3,1) + " cm");
  Serial.println();
  int s1 = digitalRead(IR1);
  int s2 = digitalRead(IR2);
  int s3 = digitalRead(IR3);
  Serial.print(s1);
  Serial.print(" ");
  Serial.print(s2);
  Serial.print(" ");
  Serial.println(s3);
if(s1==0 && s2==0 && s3==0 || value8==1)
 {
   if(s1==0 && s2==0 && s3==0)
   {
    digitalWrite(buz,HIGH);
   }
```

```
  else
  {
   digitalWrite(buz,LOW);
  }
 if(value==1 && value2==0 && value3==0 && value4==0)
 {
  backword();
 }
else if(value==0 && value2==1 && value3==0 && value4==0)
 {
  forward();
 }
  else if(value==0 && value2==0 && value3==1 && value4==0)
 {
  left();
 }
   else if(value==0 && value2==0 && value3==0 && value4==1)
 {
  right();
 }
   else
 {
  stp();
 }
 if(value9==1 && count2==0)
 {
  for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
```

```
  myservo1.write(pos);              // tell servo to go to position in variable 'pos'
  delay(20);
      }
 count2=1;
 }
 if(value9==0 && count2==1)
 {
   for (pos = 180; pos >= 0; pos -= 1) { // goes from 0 degrees to 180 degrees
   myservo1.write(pos);              // tell servo to go to position in variable 'pos'
   delay(20);
      }
   count2=0;
 }
}
else/////////
{
 digitalWrite(buz,LOW);
 if(value7==0)//////////////////////
 {
  if(d1<=40)///////////
  {
    delay(1000);
    if(d2>d3)
    {
      left();
      delay(2000);
      stp();
```

```
 delay(1000);
   goto strt;
 }
 if(d3>d2)
 {
  right();
  delay(2000);
  stp();
  delay(1000);
  goto strt;
 }
}
else/////////////////
{
 if(garbageval==1 && cycle==0)
  {
   count++;
  if (count>=50)
  {
        for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
    myservo1.write(pos);              // tell servo to go to position in variable 'pos'
    delay(20);
   }
  delay(1000);
  forward();
  delay(1000);
  stp();     delay(1000);
```

```
        for (pos = 180; pos >= 0; pos -= 1) { // goes from 0 degrees to 180 degrees
      myservo1.write(pos);              // tell servo to go to position in variable 'pos'
      delay(20);
     }
     cycle=1;
    }
   }
   if(garbageval==0)
   {
     count=0;
     cycle=0;
     forward();
     delay(1000);
     stp();
     delay(2000);
   }
 }
 }
else//////////
{
    if(garbageval==1 && cycle==0)
   {
     count++
   if (count>=50)
   {
     for (pos = 0; pos <= 180; pos += 1) { // goes from 0 degrees to 180 degrees
      myservo1.write(pos);              // tell servo to go to position in variable 'pos'
```

```
        delay(20);
      }
    delay(1000);
    forward();
    delay(1000);
    stp();
    delay(1000);
        for (pos = 180; pos >= 0; pos -= 1) { // goes from 0 degrees to 180 degrees
        myservo1.write(pos);              // tell servo to go to position in variable 'pos'
        delay(20);
      }
      cycle=1;
     }
    }
    if(garbageval==0)
    {
      count=0;
      cycle=0;
      forward();
      delay(1000);
      stp();
      delay(2000);
    }
  }
}
      Serial.print("count val:");
      Serial.println(count);
```

```
}
void forward()
{
   digitalWrite(12,LOW);
   digitalWrite(14,HIGH);
   digitalWrite(27,LOW);
   digitalWrite(26,HIGH);
}
void backword()
{
   digitalWrite(12,HIGH);
   digitalWrite(14,LOW);
   digitalWrite(27,HIGH);
   digitalWrite(26,LOW);
}
void left()
{
   digitalWrite(12,LOW);
   digitalWrite(14,HIGH);
   digitalWrite(27,HIGH);
   digitalWrite(26,LOW);
}

void right()
{
   digitalWrite(12,HIGH);
   digitalWrite(14,LOW);
```

```
   digitalWrite(27,LOW);
   digitalWrite(26,HIGH);
}
void stp()
{
   digitalWrite(12,LOW);
   digitalWrite(14,LOW);
   digitalWrite(27,LOW);
   digitalWrite(26,LOW);
}
```

Assessment Guideline for Faculty

[The following assessment guideline is for faculty ONLY. **This portion is not applicable for students**.]

Assessment Tools and CO Assessment Guideline

	Distribution of assessment points among various COs assessed in different semesters														
PO	l	c	f	g	c	b	d	c	e	l	k	k	h	i	j
CO	CO 1	CO 2	CO 3	CO 4	CO 5	CO 6	CO 7	CO 8	CO 9	CO 10	CO 11	CO 12	CO 13	CO 14	CO 15
EEE 400C/ ECE 402C (Out of 100)							30	24	6	4	4	6	7	7	12
Project Final Report/ Project Progress Report							x	x	x	x	x	x	x		x
Demonstration of working prototype							x								x
Progress Presentation/ Final Presentation								x			x				
Peer-evaluation*													x	x	
Instructor's Assessment*													x	x	
Demonstration at FYDP Showcase								x							x

Note: The star (*) marked deliverables/skills will be evaluated at various stages of the project.

Mapping of CO-PO-Taxonomy Domain & Level- Delivery-Assessment Tool

Sl.	CO Description	PO	Bloom's Taxonomy Domain/Level	Assessment Tools
CO7	**Evaluate** the performance of the developed solution with respect to the given specifications, requirements and standards	d	Cognitive/ Evaluate	● Demonstration of working prototype ● Project Progress Report on working prototype
CO8	**Complete** the final design and development of the solution with necessary adjustment based on performance evaluation	c	Cognitive/ Create	● Project Final Report ● Final Presentation ● Demonstration at FYDP Showcase
CO9	**Use** modern engineering and IT tools to design, develop and validate the solution	e	Cognitive/ Understand, Psychomotor/ Precision	● Project Final Report
CO10	**Conduct** independent research, literature survey and learning of new technologies and concepts as appropriate to design, develop and validate the solution	l	Cognitive/ Apply	● Project Final Report
CO11**	**Demonstrate** project management skill in various stages of developing the solution of engineering design project	k	Cognitive/ Apply Affective/ Valuing	● Project Final Report ● Project Progress presentation at various stages
CO12	**Perform** cost-benefit and economic analysis of the solution	k	Cognitive/ Apply	● Project Final Report
CO13	**Apply** ethical considerations and professional responsibilities in designing the solution and	h	Cognitive/ Apply Affective/ Valuing	● Peer-evaluation, ● Instructor's Assessment

	throughout the project development phases			• Final Report
CO14**	**Perform** effectively as an individual and as a team member for successfully completion of the project	i	Affective/ Characterization	• Peer-evaluation • Instructor's Assessment
CO15**	**Communicate** effectively through writings, journals, technical reports, deliverables, presentations and verbal communication as appropriate at various stages of project development	j	Cognitive/ Understand Psychomotor/ Precision Affective/ Valuing	• Project Final Report • Progress Presentations, • Final Presentation • Demonstration at FYDP Showcase

Note: The double star (**) marked CO will be assessed at various stages of the project through indirect deliverables.