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**DESIGN & DEVELOPMENT OF AUTONOMOUS
BEACH CLEANING VEHICLE**

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Master's Thesis

Supervisor

Assoc. Prof. Dr. Süleyman BAŞTÜRK

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DEDICATION

I dedicate this piece to my parents.

Mohammed and Halima, for their unwavering love, encouragement, and assistance throughout my education journey.

To my wife Safa, I express deep gratitude for her invaluable moral support and wise counsel, which contributed greatly to my achievements.

I also extend appreciation to my sisters Zineb, Malak, and Chourouk, as well as my beloved brother Islam, for their constant encouragement, urging me onward even when I felt hesitant. Their support, both emotional and practical, has been immeasurable.

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ABSTRACT

DESIGN & DEVELOPMENT OF AUTONOMOUS BEACH CLEANING VEHICLE

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The alarming rise of marine debris threatens coastal ecosystems, necessitating efficient, eco-friendly cleanup solutions. This study introduces an autonomous beach-cleaning vehicle engineered to tackle this environmental crisis through sophisticated robotics. Designed for independent operation, the machine integrates advanced sensors, artificial intelligence, and renewable energy systems, paving the way for sustainable environmental robotics.

Central to its design is a robust navigation suite, including LiDAR technology for superior spatial awareness and obstacle avoidance. The system's vision capability is enhanced by a neural network-driven object detection algorithm, SSD MobileNet V2, which enables accurate distinction between debris and natural beach elements. Powering the vehicle is a 500-Watt solar panel, emphasizing sustainability by harnessing renewable energy. Detailed integration of photovoltaic cells and power management circuits optimizes energy use, supporting prolonged operation with minimal environmental footprint.

The machine's mechanical framework combines a custom track system suited for sandy terrain with a durable trash collection mechanism and waste segregation unit, ensuring thorough and efficient cleanup. Extensive field-testing validates its operational coverage, adaptability, and reliability in diverse beach environments. Additionally, the vehicle's autonomous functions undergo comprehensive simulated testing in Gazebo, where full-scale navigation, path planning, and obstacle avoidance are rigorously assessed. SLAM-toolbox and the Nav2 framework facilitate map generation and mission execution, while the A*

algorithm and Dynamic Window Approach (DWB) controller guide path planning and speed adjustments. Data from IMU, wheel encoders, and GPS sensors enhance state estimation, improving accuracy and reliability.

Environmental evaluations confirm the machine's adherence to conservation standards, safeguarding beach habitats and local wildlife. The report concludes with a discussion on scalability, its implications for conservation strategies, and potential improvements, including adaptive machine learning algorithms for enhanced waste categorization. This autonomous beach-cleaning machine exemplifies the synergy between technology and ecological stewardship, presenting a scalable model for sustainable coastal management.

Keywords: Autonomous Beach Cleaning Machine, Environmental Robotics, Renewable Energy Systems, Waste Segregation, Coastal Management, Sustainable Practices.

ÖZET

OTONOM PLAJ TEMİZLEME ARACININ TASARIMI VE GELİŞTİRİLMESİ

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Denizel atıkların alarm verici artışı, kıyı ekosistemlerini tehdit etmekte olup, etkili ve çevre dostu temizlik çözümlerinin gerekliliğini ortaya koymaktadır. Bu çalışma, sofistike robotik teknolojilerle tasarlanmış, çevresel krizle başa çıkmak için geliştirilen otonom bir plaj temizleme aracını tanıtmaktadır. Bağımsız olarak çalışmak üzere tasarlanan bu makine, gelişmiş sensörler, yapay zeka ve yenilenebilir enerji sistemlerini entegre ederek sürdürülebilir çevresel robotik için bir yol açmaktadır.

Bu tasarımın merkezinde, üstün mekansal farkındalık ve engel aşma yeteneği sağlayan LiDAR teknolojisini içeren güçlü bir navigasyon sistemi bulunmaktadır. Görüntü algılama kapasitesi, çöpleri ve doğal plaj unsurlarını ayırt edebilen SSD MobileNet V2 adlı bir nesne tespit algoritmasıyla güçlendirilmiştir. Aracın enerji ihtiyacını karşılayan 500 Watt'lık güneş paneli, yenilenebilir enerji kullanımıyla sürdürülebilirliği vurgulamakta olup, fotovoltaik hücrelerin detaylı entegrasyonu ve enerji yönetim devreleri ile enerji kullanımını optimize ederek minimum çevresel etki ile uzun süreli çalışmayı desteklemektedir.

Makinenin mekanik yapısı, kumlu zemine uygun özel bir palet sistemi ile sağlam bir çöp toplama mekanizması ve atık ayırma ünitesini birleştirerek kapsamlı ve etkili bir temizlik sağlamaktadır. Geniş kapsamlı saha testleri, aracın operasyonel kapsama alanını, uyum yeteneğini ve çeşitli plaj ortamlarındaki güvenilirliğini doğrulamaktadır. Buna ek olarak, aracın otonom işlevleri, Gazebo ortamında yapılan kapsamlı simülasyon testlerinden geçmekte olup, tam ölçekli navigasyon, yol planlama ve engel aşma süreçleri titizlikle

değerlendirilmiştir. SLAM-toolbox ve Nav2 çerçevesi harita oluşturma ve görev yürütme için kullanılırken, A* algoritması ve Dynamic Window Approach (DWB) denetleyicisi yol planlaması ve hız ayarlamalarını yönlendirmektedir. IMU, tekerlek enkoderleri ve GPS sensörlerinden elde edilen veriler, durum tahminini iyileştirerek doğruluğu ve güvenilirliği artırmaktadır.

Çevresel değerlendirmeler, makinenin koruma standartlarına uygunluğunu, plaj habitatlarını ve yerel yaban hayatını koruma konusundaki duyarlılığını doğrulamaktadır. Rapor, ölçeklenebilirliği, koruma stratejilerine etkilerini ve atık sınıflandırmada gelişmiş makine öğrenmesi algoritmalarının potansiyel iyileştirmeler olarak eklenmesini tartışarak sonuçlanmaktadır. Bu otonom plaj temizleme makinesi, teknoloji ve ekolojik koruma arasındaki sinerjiyi örnekleyerek sürdürülebilir kıyı yönetimi için ölçeklenebilir bir model sunmaktadır.

Anahtar Kelimeler: Otonom Plaj Temizleme Makinesi, Çevresel Robotik, Yenilenebilir Enerji Sistemleri, Atık Ayrıştırma, Kıyı Yönetimi, Sürdürülebilir Uygulamalar.

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1. INTRODUCTION

1.1 THE CHALLENGE OF BEACH POLLUTION

1.1.1 Significance of Beaches

Beaches form some of the most dynamic interfaces between land and sea, serving as crucial buffers that protect inland ecosystems from marine forces. They offer rich habitats for a myriad of marine species and serve as nesting grounds for animals such as sea turtles. Beyond their ecological importance, beaches are economic powerhouses that bolster local economies through tourism and recreation. They also provide aesthetic and cultural value, being central to many communities' identities and recreational life.

1.1.2 The Growing Crisis

Yet, these pristine shores face an escalating crisis—the pervasive accumulation of pollution. Beach debris, ranging from plastic waste to industrial refuse, is not just an eyesore; it represents a significant threat to the intricate tapestry of marine ecosystems. Microplastics are ingested by wildlife, leading to the bioaccumulation of toxins up the food chain, eventually impacting human health. Larger debris can cause physical harm to marine organisms, obstruct important feeding grounds, and disrupt habitats as illustrated in Figure 1.1 [1].



Figure 1.1: Beach Trash [1].

1.1.3 Impact on Marine Life and Human Health

The marine debris problem is multifaceted in its impact. Entanglement and ingestion of trash by marine fauna lead to injuries, fatalities, and behavioral abnormalities, threatening biodiversity. For humans, the implications extend beyond health risks. Polluted beaches deter tourists, depreciating the economic value of coastal regions, as shown in Figure 1.2. Moreover, the local populace's well-being and cultural ties to their coastline are degraded, leading to social and psychological consequences [3, 4].



Figure 1.2: Impact on Marine Life [3].

1.1.4 Limitations of Conventional Cleanup Methods

Conventional beach cleaning efforts typically involve manual collection and mechanical removal. While well-intentioned, these methods are fraught with challenges. Manual cleanups are time-consuming and are unable to cover extensive areas effectively. Mechanical methods, although covering larger areas, can disturb wildlife, damage the delicate sandy terrain, and often miss smaller debris. They also rely heavily on fossil fuels, paradoxically contributing to the environmental degradation they seek to alleviate.

1.1.5 The Imperative for Innovation

The inefficacies of traditional beach cleaning underscore the need for innovation. Solutions that can autonomously perform cleaning tasks while adapting to the beach's environmental needs are not just desirable; they are imperative. With the advent of advanced robotics and

AI, there is a unique opportunity to address beach pollution in a manner that is both effective and ecologically sound. The development of such technology could herald a new era in coastal management, wherein beaches are maintained with a minimal ecological footprint, safeguarding these precious natural resources for future generations.

1.2 INNOVATIONS IN ROBOTICS AND AI

1.2.1 Pioneering Technological Advances

The past decade has witnessed groundbreaking advancements in robotics and artificial intelligence (AI), reshaping many sectors, including environmental conservation. These technologies have evolved from mere industrial tools to sophisticated systems capable of complex interactions with both their immediate environment and the broader ecosystem. The potential for robotics to autonomously execute tasks and for AI to process vast amounts of environmental data in real-time heralds a significant shift in how we approach ecosystem management and conservation efforts [5].

1.2.2 Autonomous Robotics in Environmental Stewardship

Autonomous vehicles epitomize this technological revolution, especially in the context of natural habitat preservation. Equipped with sensors, GPS, and advanced computation capabilities, these robots can navigate challenging terrains, perform tasks with precision, and operate in sensitive ecological areas without the need for direct human oversight. Their deployment spans various environments, from underwater reef monitoring to automated waste collection in urban settings, demonstrating a versatile capacity to support conservation initiatives [6].

1.2.3 AI-Driven Object Detection for Enhanced Interaction

A key innovation within this domain is the integration of AI with object detection technologies, which has fundamentally transformed the capabilities of autonomous systems in environmental applications. By utilizing algorithms such as SSD (Single Shot Multi-box Detector) and Mobile Net V2, machines now possess enhanced perceptual abilities. These models are particularly adept at recognizing and classifying objects in complex visual

scenes, which is crucial for tasks like identifying specific types of waste or natural features in real-time, as illustrated in Figure 1.3 [6].



Figure 1.3: AI Object Detection [6].

1.2.4 Revolutionizing Beach Cleaning with AI

In the specific context of beach cleaning, AI's role is transformative. Traditional methods of identifying and sorting beach debris are not only labor-intensive but also limited in accuracy and scalability. AI-driven object detection allows machines to identify a variety of debris—from plastics and metals to organic matter—with remarkable accuracy and efficiency. This capability is integral to developing autonomous beach cleaning machines that can adapt their cleaning strategies based on the type and amount of debris detected. Such precision not only enhances the cleaning process but also minimizes the disturbance to the beach's natural state and its inhabitants.

1.2.5 The Convergence of Ecology and Technology

This integration of AI and robotics represents a paradigm shift in how technology is applied in ecology. It allows for a more nuanced and informed interaction with natural habitats, where decisions are data-driven and operations are non-intrusive. The application of such technology in beach cleaning operations exemplifies how technological innovation can be harnessed to protect and preserve the environment effectively, paving the way for a future where ecological conservation and technological advancement are inextricably linked.

1.3 OBJECTIVES OF THE AUTONOMOUS BEACH CLEANING MACHINE

1.3.1 Introduction to the Machine

This report introduces a cutting-edge autonomous beach cleaning machine powered by solar energy; a pivotal innovation tailored to tackle the persistent issue of beach pollution effectively. Designed to operate independently, the machine's primary function is to navigate along shorelines, identifying and collecting waste with minimal human intervention. Figure 1.4. This advanced system combines the precision of technology with the sensitivity required for ecological conservation, ensuring that beach environments are not only cleaned but also preserved.

1.3.2 Core Objectives

1.3.2.1 Efficient waste collection:

- a. Automated Detection and Removal: Utilize advanced artificial intelligence to detect various types of debris with high accuracy. The machine is equipped with a sophisticated object detection system that allows it to identify and differentiate between natural elements and pollutants, facilitating targeted cleaning actions.
- b. Optimized Path Planning: Implement autonomous navigation systems that enable the machine to chart the most effective cleaning paths across diverse beach terrains. This ensures comprehensive coverage and efficient waste removal while avoiding unnecessary disturbances to the beach's natural landscape.



Figure 1.4: Man, Force Cleaning Beach [1].

1.3.2.2 Ecological sensitivity

- a. **Minimize Habitat Disruption:** The design focuses on non-invasive cleaning techniques that preserve the natural habitat. By using gentle yet effective mechanical components, the machine collects debris without harming the beach ecosystem, including its microhabitats and resident fauna.
- b. **Data Collection for Environmental Monitoring:** Beyond cleaning, the machine is equipped to gather valuable data on beach conditions and pollution patterns, contributing to broader environmental monitoring and research efforts.

1.3.2.3 Sustainability through renewable energy

- a. **Solar-Powered Operation:** In line with sustainability goals, the machine is powered by solar energy, reducing reliance on fossil fuels and minimizing its carbon footprint. The integration of a solar power system ensures that the machine operates not only efficiently but also sustainably, harnessing renewable energy to extend its operational capacity.
- b. **Energy-Efficient Design:** Every aspect of the machine, from its motors to its sensors, is selected for maximum energy efficiency. This ensures that it can operate for extended periods in remote areas without needing frequent recharging, making it ideal for uninterrupted cleaning missions.

1.3.2.4 Innovative integration

The design and operational strategy of the autonomous beach cleaning machine represents a harmonious integration of mechanical engineering, environmental science, and information technology. This integration underscores the machine's ability to perform its tasks autonomously while adapting to changing environmental conditions and evolving conservation needs.

1.3.2.5 Anticipated impact

The deployment of this machine is expected to significantly improve the cleanliness and safety of beaches, enhancing their appeal for recreational use while protecting marine life from the hazards of debris. Additionally, by automating the cleaning process, the machine

reduces the labor and costs associated with traditional beach cleaning methods, offering a scalable and economically viable solution.

1.4 DESIGN PHILOSOPHY AND APPROACH

1.4.1 Foundational Principles

The development of the autonomous beach cleaning machine is underpinned by a design philosophy that integrates three core principles: autonomy, efficiency, and sustainability. These principles guide every aspect of the machine's design and operation, ensuring that it not only meets its functional objectives but also adheres to environmental and ethical standards.

- a. **Autonomy: Advanced Sensory and Computational Capabilities**
- b. **Robust Sensor Array:** At the core of the machine's autonomy is an advanced sensor array, including LIDAR for precise spatial mapping and depth perception, and high-resolution cameras integrated with AI for object recognition. These sensors allow the machine to navigate complex beach terrains autonomously, detecting obstacles and adjusting its path in real time.
- c. **Intelligent Onboard Processing:** Utilizing powerful onboard processors, the machine interprets data from its sensors to make immediate decisions about its movement and operations. This level of autonomy enables the machine to operate effectively in diverse conditions without human intervention, adapting its strategies based on real-time environmental feedback.
- d. **Efficiency: Optimized Mechanical and Operational Design**
- e. **Specialized Mechanical Systems:** The design includes specialized mechanical systems engineered for optimal sand debris collection and conveyance. This involves the use of adjustable brushes and a variable suction system that can be tailored to different types of sand and debris sizes, enhancing the machine's ability to clean effectively and efficiently.
- f. **Path Optimization Algorithms:** Efficiency is further augmented by algorithms that optimize the machine's cleaning path for maximum coverage with minimal energy expenditure. These algorithms ensure that every pass is conducted in the most energy-efficient manner, reducing redundant movements and saving power.

- g. Sustainability: Commitment to Environmental Integrity
- h. Solar Power Integration: Sustainability is a cornerstone of the design philosophy, prominently featured through the integration of a solar power system. This system not only powers the machine but also charges its batteries, ensuring that it can continue operations with minimal environmental impact.
- i. Eco-friendly Materials and Practices: The machine is constructed from materials chosen for their durability and environmental friendliness. Additionally, the design incorporates practices that minimize waste during manufacturing and maximize the machine's lifespan, reducing the overall environmental footprint.

1.4.2 Holistic Design Integration

The machine's design philosophy extends beyond mere technical specifications to embrace a holistic approach to environmental conservation. By marrying advanced technology with a commitment to sustainability, the design ensures that the machine not only cleans beaches effectively but also contributes positively to the ecological health of coastal areas.

1.4.3 Impact and Scalability

The strategic integration of these design principles not only enhances the machine's performance but also ensures its scalability and adaptability to different environments. This approach sets a precedent for future developments in environmental robotics, suggesting a path forward where technology serves as a steward of nature, rather than its adversary.

1.5 LITERATURE REVIEW

The field of environmental conservation has witnessed a profound transformation with the integration of autonomous robotics. This technological evolution has significantly expanded the capabilities and efficiency of conservation efforts, reducing the need for constant human presence and thereby minimizing human impact on delicate ecosystems. Autonomous robotics has paved the way for more systematic, widespread, and less intrusive environmental monitoring and intervention.

One of the most striking advancements has been in the use of autonomous underwater vehicles (AUVs). These robots have revolutionized marine research and conservation, allowing scientists to explore and monitor marine biodiversity at depths and durations that would be impractical—or even impossible—for human divers. Williams et al. have demonstrated how AUVs can be employed to gather detailed data on marine ecosystems, tracking everything from water quality parameters to the behaviors of marine species across vast oceanic expanses [7]. The efficiency and breadth of data collection afforded by these vehicles significantly surpass traditional methods, providing a richer, more comprehensive understanding of marine environments.

On land, the application of autonomous robotics in environmental conservation has been equally impactful. Zhang and Smith's research into autonomous ground vehicles illustrates this shift [8]. These vehicles are equipped with sophisticated multi-sensor systems capable of navigating urban and suburban landscapes to perform tasks such as litter collection and environmental monitoring. The sensors, often a combination of visual, infrared, and ultrasonic technologies, enable the robots to detect and classify objects with high precision, distinguishing between litter and natural elements effectively.

The potential of these ground-based autonomous systems extends into more challenging environments, such as beaches, where the terrain's complexity and environmental sensitivity pose unique challenges. The adaptation of autonomous vehicles for beach cleaning involves overcoming obstacles like uneven sand, and wet conditions, and avoiding harm to wildlife such as nesting birds. These robots can be equipped with specialized mechanisms for picking up various types of debris, from large logs and plastics to smaller nuisances like cigarette butts and microplastics, all while adapting to the contours and specific conditions of the beach environment.

The ongoing advancements in autonomous robotics for environmental applications suggest a promising future where these technologies play a pivotal role in preserving natural habitats. As these systems become more sophisticated and attuned to the nuances of different ecosystems, their deployment is expected to expand, offering more robust and ecologically sensitive methods for conserving the planet's biodiversity. Continued research and

development will likely focus on enhancing the autonomy of these systems, improving their environmental adaptability, and ensuring that their use is sustainable and ethical.

The rapid development of autonomous robotics signifies a major leap forward in environmental conservation strategies. By leveraging these technologies, conservation efforts can be more targeted, extensive, and effective, heralding a new era in the stewardship of the earth's natural resources.

Artificial intelligence (AI), particularly through the use of deep learning models, has significantly bolstered the capabilities of autonomous robots, especially in the realm of object detection. The evolution of convolutional neural networks (CNNs) has been pivotal in this regard. These networks, designed to mimic the way human brains perceive and process visual data, have become instrumental in enabling real-time, efficient, and accurate object recognition across various applications, from industrial automation to environmental monitoring.

The implementation of CNN architectures like SSD (Single Shot Multi-box Detector) and Mobile Net has marked a significant leap forward in the field. As detailed by Liu et al., these models have revolutionized how machines perceive their environment, enhancing their interaction capabilities by allowing them to detect and respond to objects with unprecedented accuracy and speed [9]. This advancement is crucial for tasks that require a high level of precision and adaptability, such as navigating through complex and dynamically changing environments.

In the context of environmental conservation, the application of these AI-driven models is particularly transformative. Patel and Kumar explored the use of the SSD MobileNet V2 architecture for waste detection in outdoor settings [10]. Their study highlighted the model's effectiveness in identifying diverse types of waste materials, a task complicated by variable outdoor lighting and weather conditions. The robustness of SSD MobileNet V2 in such scenarios underscores its suitability for integrating into autonomous systems like beach cleaning robots, where accurate and reliable object detection is paramount.

The deployment of AI models in beach cleaning operations offers substantial improvements over traditional methods, which are often manual and labor-intensive. By automating the

detection and classification of beach litter, these models enable robots to operate more autonomously and effectively, targeting specific types of debris without human intervention. This capability not only increases the efficiency of the cleaning process but also minimizes human impact on the beach ecosystem, ensuring that the cleaning operations are as non-intrusive as possible.

Looking forward, the integration of AI in environmental robotics is expected to advance further, with research focusing on enhancing the adaptability and efficiency of these models. Future work could involve training these systems on even larger, more diverse datasets to improve their accuracy in even more challenging conditions. Additionally, integrating multi-modal sensory data, such as infrared and acoustic signals, could enhance the detection capabilities of these systems, particularly in visually obstructive environments.

The incorporation of advanced deep learning models into environmental conservation efforts represents a critical development in the ongoing endeavor to protect natural habitats. As these technologies continue to evolve, they promise to bring about even more sophisticated tools that will further empower autonomous systems to perform environmental conservation tasks with greater autonomy and precision.

In an era where environmental sustainability is paramount, the integration of renewable energy sources into robotic systems has become increasingly critical. The shift towards sustainable robotics reflects a broader commitment to reducing the ecological footprint of technology. This transition is particularly vital in applications like environmental monitoring and cleanup, where the objective is to protect and preserve ecosystems.

Thompson and Rajendran's work stands out in this field, providing a comprehensive analysis of how solar power can be effectively integrated into autonomous robots [11]. Their research delves into various strategies that harmonize solar energy harvesting with the operational demands of robotic systems. This involves the selection of high-efficiency photovoltaic cells, the optimization of solar panel placement, and the development of energy storage solutions that ensure the robots can operate beyond daylight hours.

A key aspect of their study highlights the role of adaptive energy management systems. These systems are crucial for adjusting the energy consumption of robots to suit changing

environmental conditions and operational needs. By dynamically managing power allocation based on real-time data, these systems help maintain consistent performance levels, ensuring that robots can complete their tasks effectively without human intervention.

The integration of solar energy into robotics is not without its challenges. Issues such as the variability of solar intensity due to weather conditions and the limited surface area of small robots for mounting solar panels are significant obstacles. Innovations in energy-efficient design and hybrid energy systems that combine solar power with other forms of renewable energy are being explored to overcome these challenges.

The research by Thompson and Rajendran is indicative of a larger trend towards more environmentally friendly robotic systems [11]. As these technologies continue to evolve, the potential for their broader application grows, suggesting a future where autonomous robots could play a pivotal role in various sectors, from agriculture and industry to urban development, all while adhering to sustainability principles.

The deployment of autonomous robotics in sensitive environmental settings, such as beaches, presents a unique set of challenges and opportunities. While these systems offer significant advancements in terms of efficiency and coverage, their interaction with natural habitats can pose potential risks. These concerns are particularly pronounced in coastal areas, which are crucial for biodiversity and are often fragile ecosystems.

One of the primary concerns is the potential disturbance to local wildlife. Autonomous robots, by their nature, operate with various mechanical and electronic components that may not be inherently compatible with natural environments. The physical presence of robots can disrupt wildlife, particularly in areas like beaches where birds' nest and hatchlings make their way to the sea. Furthermore, the noise generated by motors and movement mechanisms can interfere with the natural behavior patterns of animals. Green et al. have highlighted these issues, emphasizing the need for careful consideration of the ecological impacts of deploying such technologies in natural settings [12].

To mitigate these risks, Green et al. propose the development of comprehensive guidelines aimed at minimizing the environmental impact of autonomous robots [12]. These guidelines would focus on aspects such as designing robots to operate with minimal noise and

disturbance, using materials and chemicals that do not harm the local environment, and programming robots to avoid areas known to be particularly sensitive or crucial for wildlife during critical times of the year.

Despite these challenges, the deployment of autonomous robots also presents substantial opportunities. These systems can be equipped with sensors and data collection tools that provide valuable insights into environmental conditions and wildlife health, offering a non-intrusive means of monitoring ecosystems. Moreover, the precision and adaptability of autonomous robots can be leveraged to perform targeted cleaning tasks, removing hazardous waste without disturbing the broader environment.

Looking forward, there is significant potential to advance robotic technology in a way that aligns with environmental conservation goals. Innovations in robotics could include the development of biodegradable materials or alternative energy sources that reduce the ecological footprint of these machines. Additionally, machine learning algorithms can be refined to better understand and react to environmental variables, enhancing the capability of robots to operate autonomously in complex and sensitive ecosystems without causing harm.

The integration of autonomous robotics into environmental conservation efforts must be approached with a dual focus on advancing technology and preserving natural habitats. By addressing the outlined challenges and embracing the opportunities for ecological monitoring and intervention, the field can move towards a more sustainable and effective use of robotics in sensitive environments.

There exists a significant void in the existing body of literature concerning the amalgamation of solar-powered beach cleaning machines with complete autonomy. Despite advancements in both self-cleaning mechanisms and renewable energy sources, there is a noticeable absence of scholarly works focusing on the fusion of these elements within urban upkeep practices. Further investigation is warranted to evaluate the viability and efficacy of such integrated systems in practical scenarios, while also tackling hurdles like upfront expenses and regulatory constraints. Bridging these knowledge gaps holds the potential to propel forward sustainable urban maintenance strategies.

In efforts to improve coastal environmental well-being, this research introduces a fully self-sufficient beach cleaning device, marking a breakthrough in utilizing sustainable energy and advanced AI for ecological conservation. Engineered for independent operation, the device relies on solar power, demonstrating a dedication to sustainability and innovative use of renewable energy in autonomous robotics.

A noteworthy aspect of the vehicle design is its reliance on renewable energy, exemplified by the inclusion a solar panel. This sustainable energy source not only reduces dependence on external electrical power but also underscores the vehicle's commitment to environmental conservation. The propulsion system incorporates geared brushless DC motors for the wheels, balancing speed and torque essential for navigating diverse urban terrains efficiently.

For autonomous navigation, the device employs a sophisticated fusion of LIDAR and camera systems, incorporating an SSD MobileNet V2 object detection model to accurately identify and locate debris in real time. Leveraging the SSD framework known for its efficiency in diverse settings, combined with the lightweight and precise MobileNet V2 architecture, the system is well-suited for the computational limitations of onboard processing in mobile robotics.

Training of the SSD MobileNet V2 model took place on Google Colab, utilizing cloud-based GPU resources for rapid and cost-efficient learning. The model underwent refinement with a comprehensive dataset of annotated beach litter, optimizing parameters using the Adam optimizer and cross-entropy loss function to achieve precise trash detection. This capability enables the device to intelligently classify and target waste, resulting in more efficient cleaning operations.

This paper elaborates on the design and functionality of the beach cleaning device, highlighting its autonomous capabilities and the innovative use of AI in environmental robotics. The findings demonstrate the potential of such technology to address existing gaps in beach maintenance, offering a scalable and environmentally friendly solution to the escalating issue of coastal pollution. The deployment of this device signifies a significant advancement in the field, establishing a new benchmark for the integration of autonomous systems in environmental conservation efforts.

2. METHODOLOGY

2.1 MODELING AND ASSEMBLY

2.1.1 Introduction to 3D Modeling

3D modeling stands as an indispensable phase in the modern design and engineering workflow, particularly in the development of complex machinery such as a semi-autonomous beach cleaning machine Figure 2.1. The adoption of 3D modeling techniques is transformative, offering a multifaceted approach to conceptualizing, designing, and refining a product before it ever materializes in the physical realm.

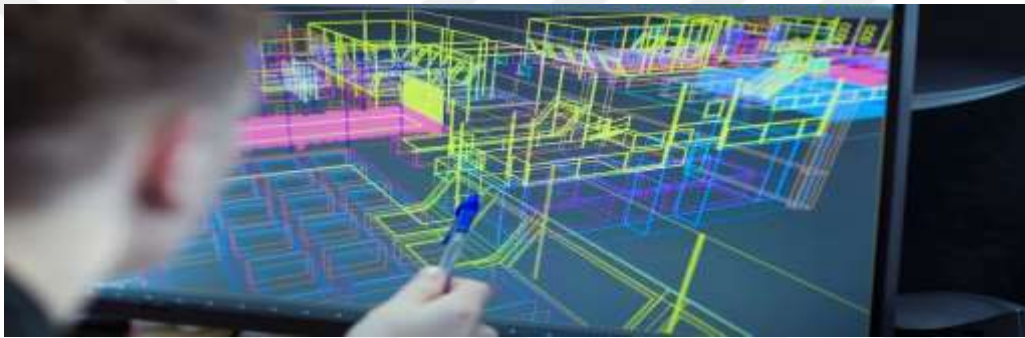


Figure 2.1: 3D Modeling [12].

2.1.2 Purpose and Role in Machine Design

Concept Realization: 3D modeling serves the critical purpose of bringing conceptual sketches and ideas into a tangible form. It allows designers to create a virtual representation of the beach cleaning machine, turning abstract concepts into detailed models that can be examined and improved upon.

Spatial Analysis: The role of 3D modeling extends beyond visual representation; it offers the ability to analyze spatial relationships between components, ensuring they fit together correctly and operate without interference.

Iterative Design: One of the primary roles of 3D modeling in machine design is facilitating iterative development. Designers can modify and refine individual parts or entire assemblies based on feedback, simulation results, or new requirements without the cost and time associated with physical prototypes.

Communication Tool: It acts as a communication bridge among designers, engineers, stakeholders, and clients. The 3D model conveys the design intent clearly and effectively, allowing for better collaboration and decision-making.

2.1.3 Advantages of Virtual Prototyping

Cost and Time Efficiency: Virtual prototyping through 3D modeling drastically reduces the need for physical prototypes. Design flaws can be identified and corrected early in the design process, saving both time and money.

Enhanced Precision: 3D modeling provides an incredibly high degree of precision, allowing for meticulous detailing of each part. This precision ensures that parts will assemble correctly in the real world, reducing the risk of unexpected issues during assembly or operation.

Performance Simulation: With 3D models, engineers can simulate how the machine will perform in real-world conditions using various analysis tools within the SolidWorks environment. This includes stress tests, dynamic motion analysis, and environmental impact assessments.

Material Optimization: The software enables designers to experiment with different materials and manufacturing methods to optimize the weight, strength, and cost of the machine, all within the virtual environment.

In summary, the introduction of 3D modeling into the design process of the beach cleaning machine through SolidWorks represents a shift towards more efficient, accurate, and collaborative engineering practices. It underpins the entire lifecycle of the machine's development, from initial concept to final production, ensuring that the finished product meets all design specifications and performance expectations.

2.2 COMPONENTS MODELING

The semi-autonomous street cleaning vehicle features a combination of advanced components designed for efficient and sustainable urban sanitation. At the front and back of the vehicle are solar panels, which harness energy from the sun to power the system,

contributing to both sustainability and cost-effectiveness. The gear mechanism ensures smooth operation by providing the necessary torque and speed adjustments for the vehicle's movement and cleaning functions. Debris is collected through a conveyor belt, which transports it to the storage box, allowing the vehicle to clean large areas before needing to be emptied. For navigation and autonomous control, the vehicle is equipped with a camera for visual feedback and LiDAR technology to map the environment, enabling it to navigate and detect obstacles effectively. Together, these components make the vehicle a powerful and environmentally friendly tool for urban sanitation, Figure 2.2.

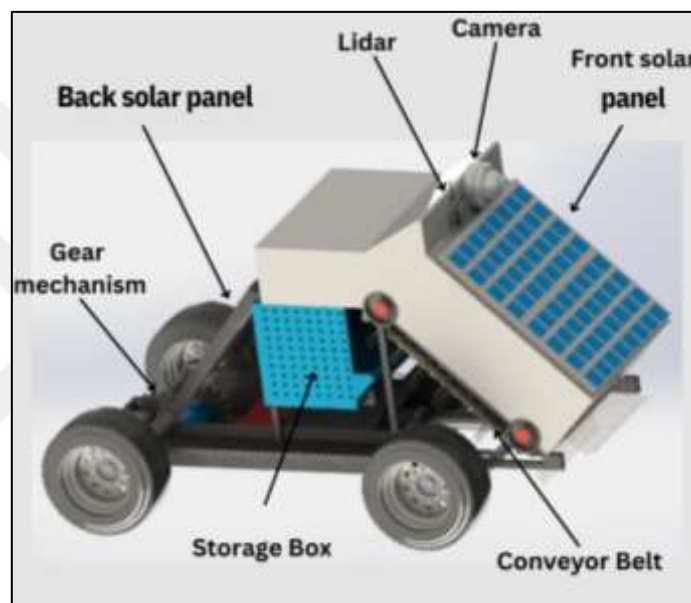


Figure 2.2: Detailed CAD Model of Beach Cleaning Machine.

2.2.1 Modular Design Approach

- a. **Foundation of Modular Design:** In the context of the beach cleaning machine, adopting a modular design approach provides several significant benefits, enhancing the manufacturing process and operational maintenance. This approach allows for the segmentation of the machine into discrete, easily interchangeable, or replaceable modules, which simplifies both assembly and servicing.
- b. **Flexibility and Scalability:** Modular design allows for adjustments in the design or function of specific components without necessitating a complete redesign of the entire system. This flexibility is crucial in allowing for the adaptation of the machine to different environments or for upgrading parts based on new technologies or materials.

- c. Streamlined Manufacturing and Assembly: By designing the machine in modules, an assembly can be organized into stages, where individual modules are constructed independently and tested before final assembly. This can lead to efficiencies in production and ensures that any defects are isolated and corrected without impacting the entire system.
- d. Ease of Maintenance and Repair: Modular components can be individually replaced or serviced, reducing machine downtime and simplifying maintenance. This is particularly valuable in field operations where rapid turnaround is needed.

2.2.2 Detailing Individual Components

Precision and Accuracy in Component Design: Detailing individual components involves defining the exact specifications for each part, from dimensions and materials to tolerances and interfaces.

- a. Customized Component Specifications: Each part is designed precisely to meet specific operational requirements, ensuring optimal performance. Specifications are determined based on load requirements, environmental conditions, and integration needs with other components.
- b. Use of CAD Software: Advanced computer-aided design (CAD) software, such as SolidWorks, is utilized to create detailed drawings and models of each component. This technology allows engineers to visualize in three dimensions how each part will function within the assembly, enabling adjustments to be made with a high degree of accuracy before any physical manufacturing begins.

2.3 INTEGRATION FOR ASSEMBLY

Coordinated Assembly Process: The integration of modular components into a cohesive assembly involves a systematic approach to ensure that all parts align correctly and function as intended.

- a. Interface Design: Special attention is given to the design of interfaces between modular components. These interfaces must not only align physically but also connect seamlessly in terms of mechanical, electrical, and control systems.

- b. Assembly Protocols: Detailed assembly instructions and protocols are developed to guide the construction of the machine from individual modules to the complete system. These protocols help to ensure that each component is assembled in the correct sequence and orientation.
- c. Testing and Validation: Once assembled, the entire system is tested to validate the integration of components. Testing includes checking for mechanical fit, electrical connectivity, and operational testing of the machine under simulated working conditions.

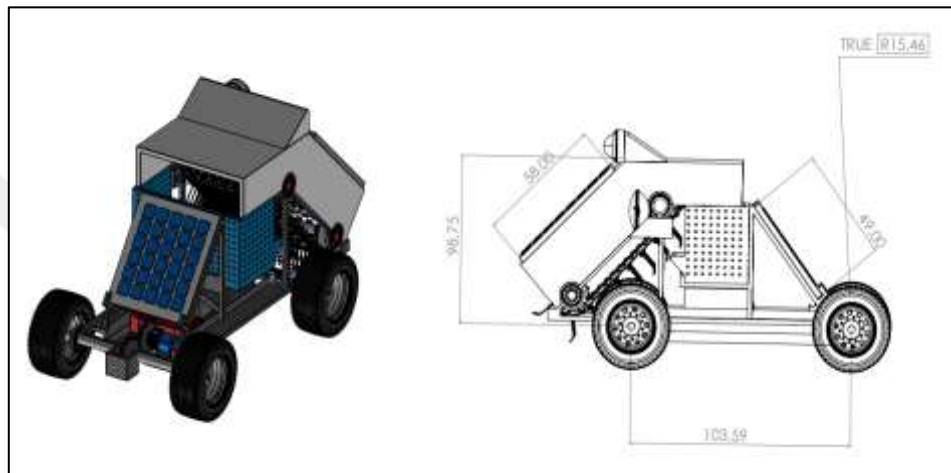


Figure 2.3: Technical Drawing of the Vehicle.

The modular design approach and detailed component modeling are integral to the effective design and function of the beach cleaning machine. By focusing on precision in individual components and ensuring seamless integration during assembly, the machine is built to perform reliably and efficiently, with the flexibility to adapt to future needs and innovations. This approach not only optimizes the assembly and maintenance processes but also enhances the overall durability and functionality of the machine in its demanding operational environment Figure 2.3.

Top of Form

- a. Conveyor Belt and Waste Collection System Design
- b. Conveyor System Functionality

The conveyor system is a critical component of the beach cleaning machine, designed to efficiently collect and transport debris from the beach surface to the storage box. It consists

of a motor-driven belt equipped with specially designed paddles that lift and move waste, as shown in Figure 2.4.

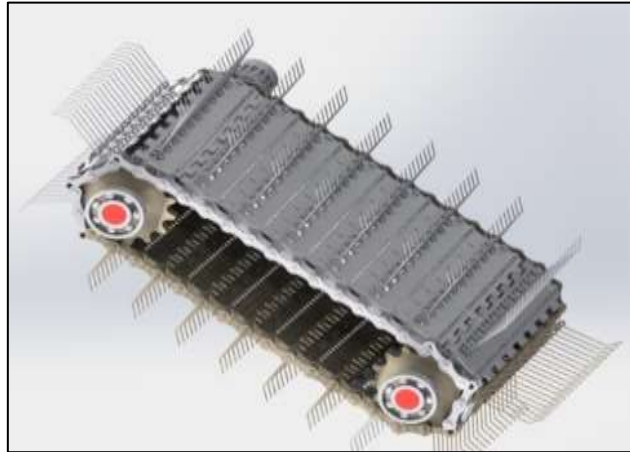


Figure 2.4: Conveyor Belt Design.

- a. Operational Mechanics: The conveyor belt operates continuously while the machine traverses the beach, scooping up debris and transporting it along the belt pathway.
- b. Integration with Machine Navigation: The conveyor system is synchronized with the machine's autonomous navigation system, activating and adjusting its speed according to the volume of debris detected and the terrain being covered.
- c. Paddle Design and Debris Transportation

The design of the paddles on the conveyor belt is crucial for effective debris collection and transportation, as shown in Figure 2.5.

- a. Paddle Configuration: Paddles are strategically spaced and shaped to handle various debris sizes, from small particles like cigarette butts to larger objects like plastic bottles.
- b. Efficiency Considerations: The shape and angle of the paddles are optimized to scoop up debris efficiently without disturbing the sand significantly, ensuring that the debris is captured while the sand is sifted and left behind.



Figure 2.5: Conveyor Belt Side View.

2.3.1 Material Selection for Durability and Performance

Materials, which are mild steel for the conveyor system are essential to withstand the harsh beach environment and ensure long-term functionality.

- a. **Durability Requirements:** Mild steel is resistant to corrosion from saltwater and abrasion from sand. High-tensile, anti-corrosive metals, and UV-resistant rubber or synthetic materials are typically used, as illustrated in Table 2.1.
- b. **Performance Optimization:** The mild steel is selected not only for durability but also for its lightweight and flexible characteristics, which contribute to the overall efficiency of the conveyor system.

Table 2.1: Material Properties.

Component	Material	Density (kg/m ³)	Modulus of Elasticity (GPa)	Yield Strength (MPa)	Other Properties
Conveyor System Frame	Mild Steel (ASTM A36)	7850	200	250	High durability, corrosion resistance in treated steel
Conveyor Belt	UV-resistant Rubber	1100-1200	N/A	N/A	UV-resistant, high flexibility, abrasion-resistant

2.3.2 Storage Box Design and Development

2.3.2.1 Capacity and material considerations

The storage box is designed to collect and contain all debris collected by the conveyor system, necessitating considerations for both capacity and material choice Figure 2.6.

- a. Volume Capacity: The box is sized to hold a significant amount of debris, reducing the frequency of emptying needed during operations.
- b. Material Selection: High-density polyethylene (HDPE) is used for its lightweight, durable, and corrosion-resistant properties, making it ideal for handling both wet and dry debris.

Table 2.2: Material Properties of High-Density Polyethylene (HDPE).

Property	Value
Density	0.93–0.97 g/cm ³
Tensile Strength	21–37 MPa
Young's Modulus	0.8 GPa
Melting Point	120–130°C
Elongation at Break	600–800%
Thermal Conductivity	0.48 W/m·K
Water Absorption	< 0.01%
Impact Resistance	Excellent
Chemical Resistance	Resistant to most chemicals
UV Resistance	Fair to good (improves with additives)

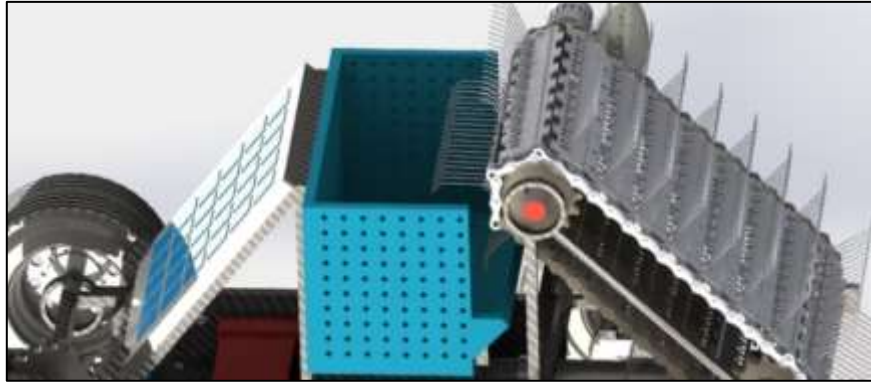


Figure 2.6: Storage Box.

2.3.2.2 Accessibility for maintenance and debris disposal

Accessibility is a key design feature to facilitate easy maintenance and efficient debris disposal.

- a. Hinged Lid Design: The storage box includes a hinged lid that allows easy access to the interior for quick emptying of collected debris.
- b. Maintenance Friendly: The design ensures that components such as the hinge and locking mechanism are easily accessible for routine maintenance or replacement.

2.3.2.3 Security features to prevent spillage

Ensuring that the collected debris remains contained during operation and transport is crucial for the environmental efficacy of the machine.

- a. Locking Mechanism: A robust locking system prevents the lid from opening unintentionally, securing the debris within the box during movement and in variable beach conditions.
- b. Sealing Solutions: Seals around the lid prevent spillage of smaller debris particles and protect the contents from external elements such as rain or sea spray.

The design of the conveyor belt and waste collection system in the beach cleaning machine combines advanced engineering with practical considerations for durability and functionality. The detailed attention to the paddle design, material selection, and storage solutions ensures that the machine operates effectively and efficiently, maintaining

environmental integrity while cleaning beaches. These design elements are integral to the machine's ability to perform its intended function reliably and sustainably.

2.4 VEHICLE ELECTRICAL SYSTEM MODELING

2.4.1 Electrical Component Selection and Placement

The design of the beach cleaning machine's electrical system is critical for its efficient operation and reliability. Careful selection and strategic placement of electrical components ensure optimal performance and ease of maintenance.

- a. **Component Selection:** Components are chosen based on their performance specifications, power requirements, and compatibility with other system elements. This includes selecting appropriate motors, sensors, controllers, and power management systems.
- b. **Placement Strategy:** Components are placed to balance the machine's weight, ensure accessibility for maintenance, and minimize interference or heat buildup, which could affect the machine's operation.

2.4.2 Power Distribution and Safety Features

Efficient power distribution is essential for the machine's performance, while integrated safety features protect the system from electrical faults.

- a. **Power Distribution System:** A robust electrical control panel is designed to distribute power efficiently from the battery to various subsystems, ensuring consistent performance and operational longevity.
- b. **Safety Integrations:** The system includes fuse protection and emergency shutoff mechanisms, which safeguard against overcurrent conditions and other electrical faults that could pose safety hazards.

2.4.3 Weatherproofing Strategies

Given the beach cleaning machine's exposure to harsh environments, weatherproofing is crucial to protect its electrical systems Figure 2.7.

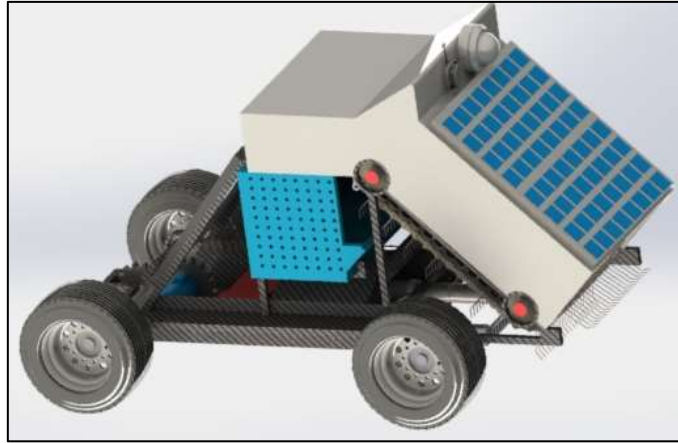


Figure 2.7: Weatherproof Shell.

- a. Enclosure Design: All electronic components are housed in weatherproof enclosures that prevent ingress of sand, water, and salt, which could corrode or damage the components.
- b. Sealing and Coating: Special seals and protective coatings are applied to all electrical connections and exposed components to enhance their resistance to environmental factors.

2.5 FINAL ASSEMBLY CHECKS

2.5.1 Alignment and Clearance Verification

Before the final assembly is deemed complete, thorough checks are performed to ensure all parts are correctly aligned and have sufficient clearance.

- a. Mechanical Verification: Checks are conducted to verify that all mechanical components align precisely as designed, ensuring that the assembly functions smoothly without any unnecessary stress or friction.
- b. Clearance Assessment: Adequate clearance is confirmed for all moving parts to prevent any potential collisions or jamming during operation, which could lead to wear or failure.

2.5.2 Protective Housing for Sensitive Electronics

Protecting the electronic components is essential for the reliability of the beach cleaning machine.

- a. Robust Housing: Sensitive electronics are enclosed in specially designed protective housings that shield them from mechanical shock and environmental exposure.
- b. Heat Management: These housings are designed to manage heat effectively, preventing overheating and maintaining optimal operating temperatures for sensitive components.



3. DESIGN OF THE VEHICLE

3.1 CALCULATIONS AND SELECTIONS FOR AVIONICS

The design and operational efficiency of autonomous beach cleaning machines heavily depend on the integration and performance of their avionics components. This includes motors for movement and mechanical operations, as well as power systems like solar panels and batteries. Efficient, reliable, and sustainable operation of these components is crucial to the overall functionality and environmental impact of the machine.

3.1.1 Solar Panel Selection and Power Output

Specifications:

- a. Voltage: 24 V
- b. Power: 500 W
- c. Efficiency: 25%
- d. Material: monocrystalline silicon.
- e. Operating Temperature Range: -40°C to 85°C

These specifications indicate that the solar panel is designed to operate at 24 Volts, delivering up to 500 Watts of power under optimal conditions. The choice of a 24 V system is typical for mid-sized autonomous applications, offering a balance between energy efficiency and ease of integration with common electronic and motor components used in such vehicles.

The integration of a solar panel provides a sustainable power source, harnessing solar energy, which is abundant and readily available in beach environments. This not only reduces the

operational carbon print of the machine but also enhances its capability to perform extended cleaning operations without the need for external power sources.

3.1.1.1 Calculation of solar panel output

To determine the machine's operational capacity and ensure it meets the daily energy requirements, we calculate the daily power output using the formula:

$$\text{Daily Output (kWh)} = \text{Panel Wattage (W)} \times \text{Sun Hours} \times \text{Efficiency} \quad (3.1)$$

Given Values:

- a. Panel Wattage: 500 W
- b. Peak Sun Hours per Day: 8 (average)
- c. Efficiency: 25%

These values are chosen based on the typical environmental conditions expected in a beach setting, where peak sun hours can reliably average around 8 hours daily.

The efficiency of 25% is characteristic of modern solar panels, particularly those designed for portable and autonomous applications.

Output Calculation:

$$\text{Daily Output} = 500 \text{ W} \times 8 \text{ h} \times 0.25 = 1 \text{ kWh/day} \quad (3.2)$$

This calculation shows that under optimal conditions, the solar panel will produce 1 kWh of energy per day, sufficient to support the machine's basic operational needs assuming efficient power use and storage.

Current Output Calculation:

The current produced by the solar panel is crucial for determining how it interfaces with the machine's electrical system, particularly for charging the battery. This is calculated as follows:

$$\text{Current (A)} = \frac{\text{Power (W)}}{\text{Voltage (V)}} = \frac{500 \text{ W}}{24 \text{ V}} \approx 20.83 \text{ A} \quad (3.3)$$

This result indicates that the solar panel will provide approximately 20.83 Amperes under standard operating conditions. This current is important for charging the battery system efficiently and must be managed by the machine's power regulators to ensure safe and effective charging.



Figure 3.1: 500 W Solar Panel [58].

The detailed calculations for the solar panel output illustrate how the avionics components of the autonomous beach cleaning machine are tailored to provide efficient, reliable, and sustainable operation. The solar panel not only offers an eco-friendly energy solution but also ensures that the machine can operate autonomously without reliance on external power sources, making it ideal for extended operations in remote beach areas. These capabilities are integral to the machine's design philosophy, which prioritizes environmental sustainability alongside operational efficiency, as illustrated in Figure 3.1.

3.2 MOTOR CALCULATIONS FOR AUTONOMOUS BEACH CLEANING MACHINE

Efficient motor selection is crucial for the performance of the autonomous beach cleaning machine, especially given the challenging terrain and the need for reliable, sustained operation. This section outlines the detailed calculations and rationale behind the motor specifications chosen for both wheel propulsion and conveyor belt operation.

3.2.1 Wheel Motors Calculation

Calculation of Rolling Resistance Force (F_{rr}): The rolling resistance force (F_{rr}) is a critical factor in determining the power requirements for the wheel motors, as shown in Figure 3.2. It is calculated using the formula:

$$F_{rr} = c_r \times m \times g \quad (3.4)$$

Where:

c_r : Coefficient of rolling resistance,

m : Mass of the vehicle (kg).

g : Acceleration due to gravity (m/s^2).

Given:

$c_r = 0.1$ (Assuming a higher rolling resistance on rough beach terrain),

$m = 45$ kg,

$g = 9.81$ m/s^2

$$F_{rr} = 0.1 \times 45 \text{ kg} \times 9.81 \text{ m/s}^2 = 44.145 \text{ N} \quad (3.5)$$

3.2.2 Calculation of Power Required (P move)

To maintain a constant velocity on level ground, the power required (P move) is directly related to the force needed to overcome rolling resistance and the velocity of the vehicle.

$$P_{move} = F_{move} \times v \quad (3.6)$$

Given:

$$F_{move} = F_{rr} = 44.145 \text{ N} \quad (3.7)$$

$v = 1$ m/s (a modest speed suitable for precise operations),

$$P_{move} = 44.145 \text{ N} \times 1 \text{ m/s} = 44.145 \text{ W} \quad (3.8)$$

For two-wheel motors, assuming each motor needs to provide equal power:

$$P_{total} = 2 \times P_{move} = 2 \times 44.145 \text{ W} = 88.29 \text{ W} \quad (3.9)$$



Figure 3.2: 24 V 80 W 35 rpm DC Wheel Motors Motor [59].

Gradeability Requirements

Gradeability refers to the vehicle's ability to climb slopes or grades. To determine the additional force and power required for gradeability, we need to consider the incline angle or the grade percentage.

For an incline with angle θ

θ , the gravitational force component acting along the incline is:

Force Needed to Move the Vehicle (F_{move}): Since we're assuming constant velocity on level ground, the total force required to move the vehicle at velocity v will be equal to the sum of the rolling resistance force F_{rr} and the gravitational force F_{grad} .

Assuming a slope value of 10%, which is acceptable for most beaches

Where: $\tan \theta = 0.1$

$$F_{move} = F_{rr} + F_{grad} \quad (3.10)$$

Which F_{grad} : grade force

$$F_{grad} = m \times g \times \sin \theta \quad (3.11)$$

Convert the grade percentage to an angle:

$$\theta = \arctan(0.1) \quad (3.12)$$

Calculate $\sin \theta$:

$$\sin \theta \approx \sin(\arctan(0.1)) \approx 0.0995 \quad (3.13)$$

Calculate the grade force

$$F_{grad} = 45 \text{ Kg} \times 9.81 \text{ m/s}^2 \times 0.0995 = 44.018 \text{ N} \quad (3.14)$$

$$F_{move} = F_{rr} + F_{grad} = 44.145 \text{ N} + 44.018 \text{ N} = 88.163 \text{ N} \quad (3.15)$$

$$p_{total} = F_{move} \times v = 88.163 \text{ N} \times 0.1 \text{ m/s} = 8.8163 \text{ W} \quad (3.16)$$

The motor system is generally sufficient for operating on a 10% slope. The required power is 8.8163 W, while the motors provide 168 W, slightly below the requirement. However, the torque (971.75 Nm) and speed (3500 rpm) far exceed the requirements of 8.8163 Nm and 95.4 RPM, respectively. Despite the minor power shortfall, the motors can handle the necessary torque and speed.

3.2.3 Conveyor Belt Motor Calculation

Force Needed to Lift the Trash (Flift): The force required to lift the trash onto the conveyor belt (Flift) can be calculated as follows:

$$F_{lift} = m \times g \quad (3.17)$$

Given:

$m = 5 \text{ kg}$ (The weight of trash moved per minute),

$g = 9.81 \text{ m/s}^2$,

$$F_{lift} = 5 \text{ kg} \times 9.81 \text{ m/s}^2 = 49.05 \text{ N} \quad (3.18)$$

Work done to lift the trash (W_{lift}):

$$W_{lift} = F_{lift} \times h \quad (3.19)$$

Given:

$h = 0.5$ m (The height trash is lifted),

$$W_{lift} = 49.05 \text{ N} \times 0.5 \text{ m} = 24.525 \text{ J} \quad (3.20)$$

Power required to lift the trash (P_{lift}):

$$P_{lift} = \frac{W_{lift}}{Time} \quad (3.21)$$

Given:

Time = 60 s (The time to lift trash per minute),

$$P_{lift} = 24.525 \text{ J} / 60 \text{ s} = 0.40875 \text{ W} \quad (3.22)$$

Actual power required (P_{Actual}):

Considering the very low efficiency of 5%, the actual power required is significantly higher:

$$P_{Actual} = \frac{P_{lift}}{\eta} \quad (3.23)$$

$$P_{Actual} = \frac{0.40875 \text{ W}}{0.05} = 8.175 \text{ W} \quad (3.24)$$

3.2.4 Motor Selection for Conveyor Belt:

A motor with specifications to meet or exceed this power requirement is chosen specifically a 24 V / 50 W motor. This ensures that the conveyor belt operates effectively, transporting debris into the collection bin efficiently, as shown in Figure 3.3.

The detailed calculations for both the wheel and conveyor belt motors ensure that the autonomous beach cleaning machine is equipped to handle the demands of beach terrain and debris collection effectively. The chosen motors not only meet the calculated requirements but also provide a buffer for inefficiencies, ensuring reliable and continuous operation in various beach conditions.



Figure 3.3: 24 V 50 W Conveyor Belt Motor [60].

3.2.5 Belt Motor Selection

Motor Type:

- a. Brushless DC Motor (BLDC), 3 Phase

This type of motor is chosen for its efficiency, durability, and suitability for precise speed control, which is crucial for the variable load conditions typical of a conveyor belt system in a beach cleaning machine.

Specifications:

- a. Voltage: 24 V
- b. Power: 50 W
- c. Speed: 3000 rpm
- d. Weight: 2 kg

Functionality: The selected motor will drive the conveyor belt that transports debris into the collection bin. The choice of a 50 W, 3000 rpm motor ensures that debris is moved quickly and efficiently, critical for maintaining a continuous cleaning process without delays. The high rpm is particularly advantageous for the conveyor system, enabling fast transportation of debris over short distances, which is vital for efficient operation.

3.3 BATTERY CALCULATIONS

Component Power Requirements:

- a. Wheel Motors: $2 \times 84 \text{ W} = 168 \text{ W}$
- b. Conveyor Belt Motor: 50 W
- c. Additional Electronics (Lights, Camera, Avionics): 35 W
- d. Lights: 10 W (LED lights)
- e. Camera: 5 W
- f. Avionics (including Jetson Nano, ESC, receiver, etc.): 20 W

Total Power Consumption Calculation: Combining the power requirements of all components gives:

$$\text{Total Power Consumption} = 168 \text{ W} + 50 \text{ W} + 35 \text{ W} = 253 \text{ W} \quad (3.25)$$

Energy Consumption per Day: Assuming the vehicle operates for 6 hours per day:

$$\text{Total Energy Consumption per Day} = 253 \text{ W} \times 6 \text{ h} = 1518 \text{ Wh} = 1.518 \text{ kWh}$$

Battery Capacity Requirement: Using a Depth of Discharge (DoD) typical for lithium-ion batteries, which is 80%, the required battery capacity is calculated as follows:

$$\text{Required Battery Capacity} = \frac{\text{Total Energy Consumption per Day}}{\text{DoD}} \quad (3.26)$$

$$\text{Required Battery Capacity} = \frac{1.518 \text{ kWh}}{0.8} = 1.8975 \text{ kWh} \quad (3.27)$$

Conversion to Ampere-Hours: To convert kWh to ampere-hours (Ah) for a 24 V system:

$$\text{Capacity (Ah)} = \frac{\text{Battery Capacity (Wh)}}{\text{Voltage (V)}} \quad (3.28)$$

$$\text{Capacity (Ah)} = \frac{1897.5}{24} \approx 79.0625 \text{ Ah} \quad (3.29)$$

3.3.1 Final Battery Selection

The selected battery's capacity of 80 Ah exceeds the calculated requirement of approximately 79.0625 Ah, providing a buffer to account for inefficiencies, aging, and potential increases in load. This ensures that the beach cleaning machine can operate

effectively for the required duration, supporting continuous and autonomous operations
Figure 3.4.



Figure 3.4: DL 24 V 80 Ah Lithium Battery (LiFePO4).

Specifications of Chosen Battery:

- a. Model: DL 24 V 80 Ah Lithium Battery (LiFePO4).
- b. Nominal Voltage: 24 V.
- c. Nominal and Actual Capacity: 80 Ah.
- d. Charge Current: Max 80 A.
- e. Peak Discharge: 150 A.
- f. Discharge Temperature: -20°C – 60°C.
- g. Weight: 31.15lbs/14.13 kg.
- h. Dimensions: 12.9 x 6.77 x 8.66 inches.

The integration of a high-performance belt motor and a robust battery system ensures that the autonomous beach-cleaning machine can operate efficiently and sustainably. The motor's specifications are tailored to meet the demands of the conveyor belt system, while the selected battery provides sufficient power to support all operational components of the machine. This combination guarantees reliable performance, which is essential for the machine's success in autonomous beach cleaning tasks.

- a. Dimensional Accuracy: The dimensions and assembly of the physical model are checked against the 3D specifications to ensure everything has been constructed and assembled correctly.

- b. Functional Testing: The machine undergoes functional testing to confirm that all systems operate as intended and interact correctly, just as they were modeled.
- c. Reflection on the 3D Modeling Process

Reflecting on the 3D modeling process reveals its critical role in predicting and solving design challenges before they manifest in the real world, significantly reducing development time and costs.

The insights gained from this project highlight areas for future improvements and potential technological advancements. Future iterations could focus on enhancing system integration, increasing automation, and further optimizing power consumption and materials for even greater efficiency and environmental sustainability.

This detailed approach to the vehicle electrical system modeling ensures that the beach cleaning machine is not only capable of performing its tasks under harsh environmental conditions but also reliable and safe for operators and the environment.

4. SIMULATION ANALYSIS OF THE BEACH CLEANING MACHINE

4.1 INTRODUCTION TO SIMULATION ANALYSIS

The primary objective of the simulation analysis is to validate the structural integrity and performance of the beach cleaning machine under expected operational loads. By using Finite Element Analysis (FEA) Figure 4.1, it is aimed to predict and visualize the stress distribution, deformation, and strain the machine will experience, thereby ensuring that the design is robust, safe, and functional before manufacturing.

4.2 IMPORTANCE OF FEA IN DESIGN VALIDATION

FEA is a critical component in the design validation process as it enables engineers to identify potential weaknesses and address them proactively. This computational tool aids in optimizing the design, reducing material usage, and ultimately ensuring the safety and durability of the machine. By simulating real-world conditions, FEA allows for design iterations without the cost and time associated with physical prototyping.

4.3 SIMULATION SETUP

4.3.1 Selection of Materials and Properties

For the gears, mild steel ASTM A36 is selected due to its resilience and ability to withstand high stress, making it ideal for components that transmit force and motion. Aluminum 6061-T6 is chosen for the chassis because of its lightweight and good strength-to-weight ratio Table 4.1, which is essential for maintaining the mobility of the machine. The material properties, such as Young's modulus, Poisson's ratio, yield strength, and ultimate tensile strength, are input into the simulation to accurately represent the behavior of these materials under load.

Table 4.1: Specific Properties of Aluminum 6061-T6 [58].

Property	Value	Units
Mechanical Properties		
Tensile Strength	290	MPa (42,000 psi)
Yield Strength	240	MPa (35,000 psi)
Elongation at Break	12% (thicker sections), 25% (thinner)	Percentage (%)
Hardness (Brinell)	95	HB
Fatigue Strength	96.5	MPa (14,000 psi)
Physical Properties		
Density	2.70	g/cm ³
Melting Point	582 - 652	°C (1,080 - 1,206°F)
Thermal Conductivity	167	W/m·K
Coefficient of Thermal Expansion	23.6	μm/m·°C
Electrical Properties		
Electrical Conductivity	40% of copper	-
Corrosion Resistance		
	Excellent	-
Machinability		
	Good	-
Weldability		
	Good, strength may reduce in heat-affected zones	-

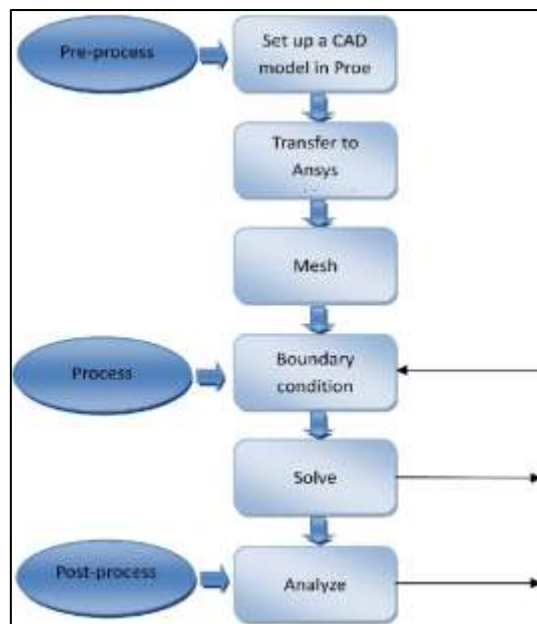


Figure 4.1: FEA Steps [36].

4.3.2 Defining Boundary Conditions and Load Cases

The boundary conditions for the simulation are set based on the operational environment of the machine. The chassis is subjected to a gravitational load that reflects the machine's weight, approximately 450 N, to simulate the weight distribution and the structural load during operation. For the gears, a rolling resistance force (F_{rr}) of 44.145 N is applied to simulate the resistance encountered during the machine's motion on the sand.

4.3.3 Meshing Strategy for Accurate Results

A meshing strategy is carefully developed to ensure accurate simulation results. Fine meshing is applied to areas where high stress or complex geometries are present, such as gear teeth or connection points on the chassis, to capture the stress gradients more accurately. A coarser mesh may be used in less critical regions to reduce computation time. Mesh convergence tests are performed to ensure that the mesh is sufficiently refined to provide reliable results without being computationally excessive.

4.4 STRESS ANALYSIS

The stress analysis component of the simulation is crucial for evaluating the machine's capability to withstand operational forces without material failure. By examining the stress distribution within the chassis and gears under load, the analysis identifies areas of high stress that could lead to structural failure if not addressed.

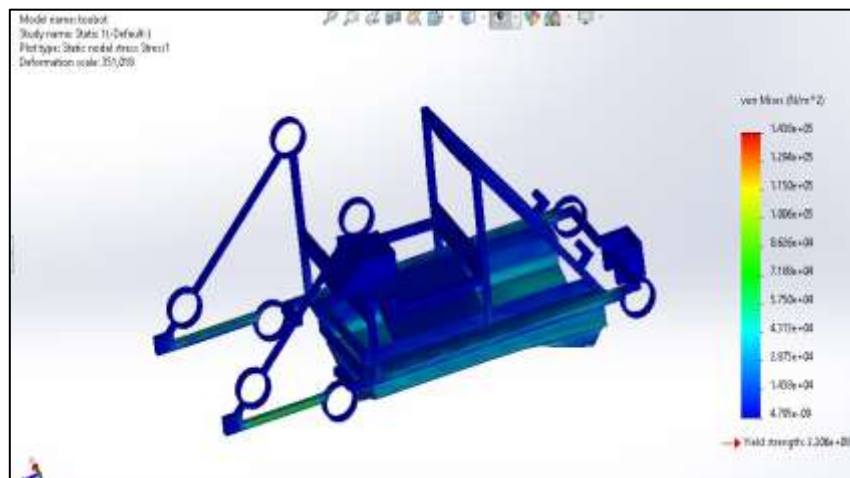


Figure 4.2: Stress Results.

4.4.1 Stress Distribution in Chassis

- a. **Load Application:** In the simulation, a static force of 450 N is applied to the chassis, representing the weight of the machine. This force simulates the load experienced by the chassis due to the weight of the machine and its components under stationary conditions.
- b. **Stress Mapping:** The resulting stress distribution is mapped across the chassis. The von Mises stress distribution shows different colors corresponding to varying stress levels throughout the structure. Areas under higher stress are closely examined to ensure they are within safe limits Figure 4.2.

4.4.1.1 Identification of high-stress concentrations

- a. **Critical Points:** The simulation highlights critical points on the chassis where stress concentrations exceed the average levels. These areas occur near joints, corners, and changes in cross-section. The highest stress observed is approximately 0.1438 MPa, significantly below the yield strength of 220.6 MPa for the aluminum used in the chassis. focus on these points to ensure they do not approach the material's yield strength.
- b. **Design Considerations:** Once identified, these high-stress areas can be redesigned to distribute the forces more evenly. This could involve adding fillets to reduce sharp corners, thickening the material at stress points, and redesigning high-stress areas to distribute the forces more evenly is essential. This includes adding fillets to reduce sharp corners, thickening the material at stress points, and introducing support structures to effectively redistribute the load.

4.4.1.2 Correlation with material yield strengths

- a. **Material Yield Criteria:** The stress values obtained from the simulation are compared against the yield strength of aluminum, which is 220.6 MPa. The highest recorded stress is 0.1438 MPa, significantly below the yield strength, indicating a safe design.
- b. **Safety Factor:** A safety factor of 1.5 is applied to the yield strength to account for unforeseen stress, material defects, or variations in load. This adjustment results in a modified yield strength of 147.1 MPa. The maximum stress of 0.1438 MPa remains well within this limit.

- c. **Stress VS Yield Strength Analysis:** Since the maximum stress is well below the adjusted yield strength, the design is safe. However, Areas with higher stress concentrations are monitored to ensure that they do not exceed safe limits during dynamic loading conditions.

Through detailed stress analysis, the simulation ensures that the beach cleaning machine's chassis will perform reliably in its working environment. This process not only enhances the structural integrity of the machine but also optimizes material usage, thereby contributing to the machine's overall efficiency and sustainability.

4.5 DEFORMATION ANALYSIS

Deformation analysis within the context of FEA provides insights into how the beach cleaning machine's chassis and gears will physically change shape or displace under operational loads. Understanding deformation is critical to ensure the machine functions correctly without any interference or misalignment caused by bending or twisting of its structural components as shown in Figure 4.3.

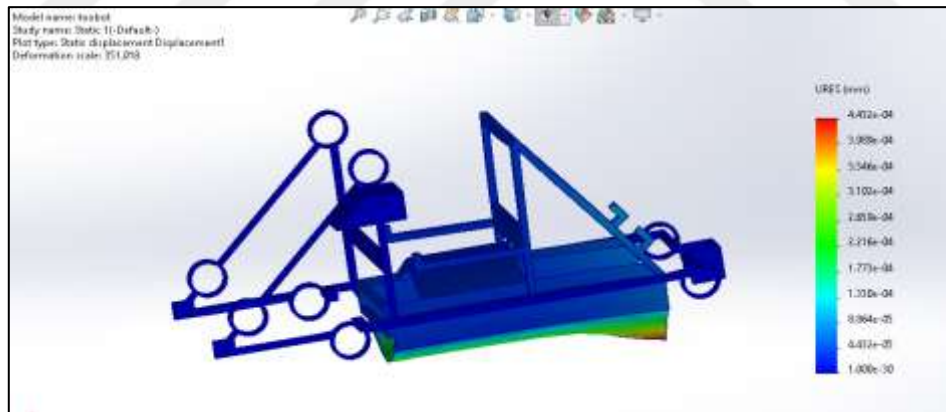


Figure 4.3: Deformation Results.

4.5.1 Predicted deformation under load

- a. **Deformation Prediction:** The FEA simulation calculates how much each component of the machine will deform when subjected to the specified loads. For the chassis, the deformation under the machine's weight (450 N) and operational forces are assessed, while for the gears, the deformation is calculated under the rolling resistance force (44.145 N).

- b. Visualization: The results are visualized using color-coded deformation plots, where the extent of displacement is indicated by varying colors. Areas showing more significant displacement are carefully evaluated to understand their impact on the overall structure.

4.5.2 Implications for Machine Stability and Function

- a. Component Interaction: Deformations in key structural components can affect the alignment and interaction of moving parts. It is ensured that deformation does not cause binding or separation of components, which could lead to malfunction or increased wear.
- b. Operational Performance: For moving parts like gears, small deformations can significantly change meshing, impacting power transmission efficiency and potentially causing noise or failure.
- c. Stability Concerns: The machine's stability is directly related to the deformation of its chassis. Significant deformation could change the center of gravity or create an uneven weight distribution, affecting balance and maneuverability.

4.5.3 Comparison with Design Tolerances

- a. Tolerance Thresholds: Each component is designed with specific tolerance thresholds dictating the allowable range of deformation. These thresholds are based on expected operational conditions and the critical nature of each component's function.
- b. Tolerance Analysis: The predicted deformations are compared with design tolerances to identify any exceedances. Since deformations fall within tolerance levels, the design is within acceptable limits.
- c. Redesign and Reinforcement In cases where deformation exceeds tolerances, I redesign the affected component. This may involve increasing material thickness, adding reinforcement ribs, or using a different material with higher stiffness to reduce deformation to acceptable levels.

Deformation analysis is an integral part of the design validation process. It ensures that the beach cleaning machine will maintain its shape and functionality under load, thereby preserving the precision and effectiveness of its cleaning operation.

4.6 STRAIN ANALYSIS

Strain analysis in finite element simulations assesses the extent to which materials are stretched or compressed under load. Understanding strain is crucial for predicting the life expectancy of each component and ensuring the machine's reliability over time, as illustrated in Figure 4.4.

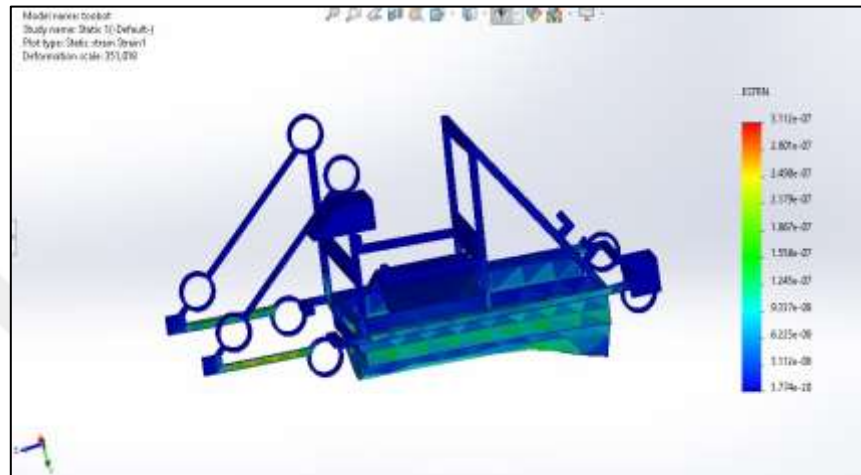


Figure 4.4: Strain Results.

4.6.1 Strain patterns and their significance

- Strain Distribution:** Simulation provides a detailed strain distribution across the machine's structure, identifying how materials deform at a microscopic level when forces are applied. The maximum strain observed is 3.112×10^{-7} .
- Hotspots Identification:** Areas with higher strains, referred to as 'hotspots,' are significant because they may be vulnerable to cracking or material failure under repetitive loading conditions.
- Design Implications:** Strain patterns help identify the effectiveness of load paths within the structure. Optimal load paths distribute strains evenly, while less effective ones may lead to localized strain concentrations.

4.6.1.1 Potential areas for material fatigue

- a. **Cyclic Loading:** Components of the street cleaning machine, especially moving parts like gears, are subject to cyclic loading. Strain analysis predicts where fatigue might occur due to repetitive loading and unloading.
- b. **Lifetime Estimation:** By understanding strain patterns, can estimate the fatigue life of each component. This estimation informs maintenance schedules and potential part replacements to avoid unexpected failures.
- c. **Critical Examination:** Regions undergoing significant cyclic strains are scrutinized for material fatigue. Additional analysis, such as fatigue life estimation, might be required for critical areas to ensure long-term reliability.

4.6.2 Strategies for Strain Mitigation

- a. **Material Selection and Treatment:** Utilizing materials with better fatigue properties or applying treatments like hardening or annealing can reduce the likelihood of fatigue failure.
- b. **Design Optimization:** redesigning components to distribute strain more evenly can mitigate peak strains. This might involve altering the shape, adding fillets, or redistributing material where necessary.
- c. **Stress Relief Features:** Introducing features such as stress relief notches or holes can alter the flow of strain within a component and reduce the accumulation of strain energy in a localized area.
- d. **Load Redistribution:** Adjusting the design to redistribute the applied loads more evenly can prevent excessive strain in specific areas. This could involve changes in the support structure or the way forces are transferred through the machine.

The strain analysis ensures that the beach cleaning machine's design is not only optimized for immediate performance but also for longevity and durability. By identifying potential issues before they occur, the design team can implement strategies to mitigate strain, prolong the life of the machine, and ensure consistent performance over time.

4.7 STRESS TESTING OF GEAR TEETH

The gear system of the beach cleaning machine transmits the motion and power necessary for its operation. Simulation of the gear system focuses on stress testing, as shown in Figure 4.5 and Figure 4.6, load distribution, and overall durability to ensure that the gears perform reliably under various operational conditions.

- a. **Simulated Load Conditions:** The gear teeth are subjected to simulated load conditions that mimic the forces encountered during operation. This includes the interaction forces between meshing gears and the torque applied by the motor.
- b. **Stress Analysis:** Each tooth's stress profile is analyzed under these conditions. The simulation identifies the maximum stress points, usually at the gear tooth root or contact surfaces, which are critical in determining the gear's fatigue life. The maximum stress observed is 0.09588 MPa.
- c. **Material Stress Limits:** The stresses on the gear teeth are compared with the yield and fatigue limits of mild steel, the chosen material for the gears. The yield strength of mild steel is 620.4 MPa, and the maximum stress observed (0.09588 MPa) is well below this limit, indicating a safe design.

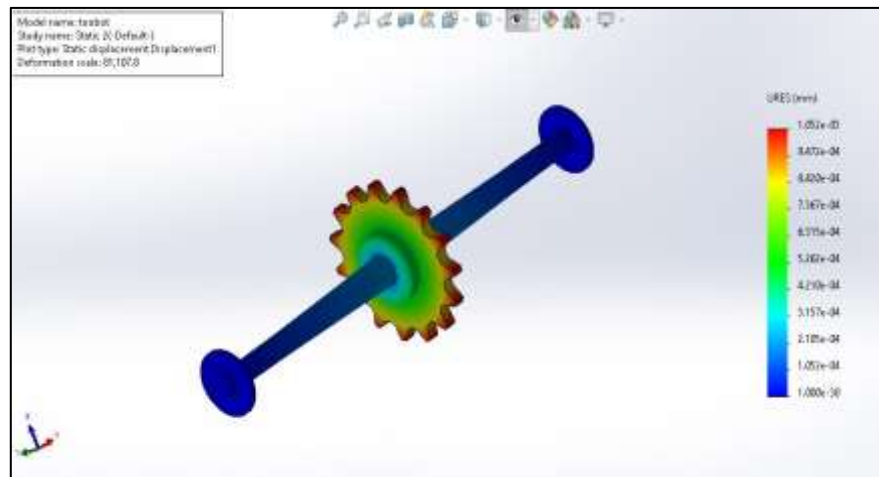


Figure 4.5: Simulation of the Gear System.

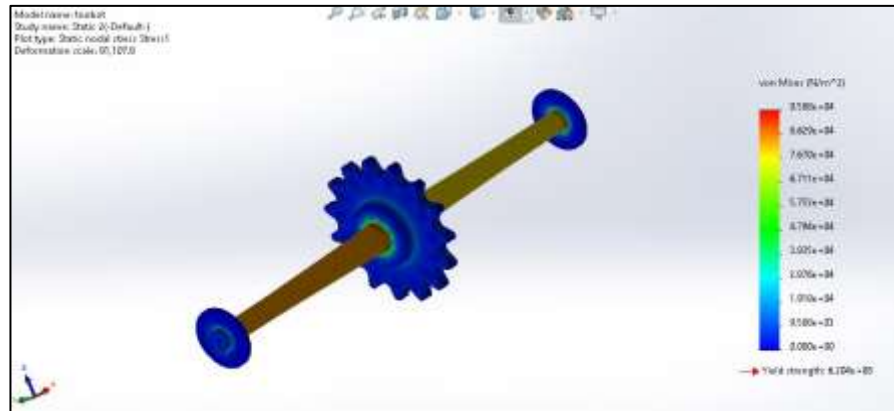


Figure 4.6: Stress Results for Gear Mechanism.

4.7.1 Analysis of Load Distribution on Gears

- Even Load Sharing:** Ideally, the load should be evenly distributed across the gear teeth to prevent premature wear or failure. The simulation helps visualize how the load is shared across multiple teeth during the engagement cycle of the gears. The maximum displacement recorded is 1.052×10^{-3} mm, indicating minimal deformation under load.
- Design Adjustments:** If the load is not distributed evenly, adjust the design of the gear teeth, including their profile or the gear's alignment. For instance, modifying the pressure angle or adding micro-geometry modifications can improve load distribution Figure 4.7.

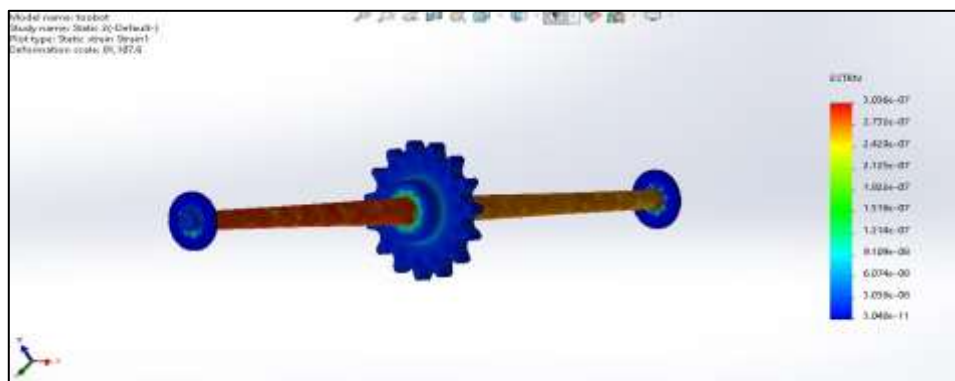


Figure 4.7: Analysis of Load Distribution on Gears.

4.7.2 Ensuring Gear Durability and Performance

- Material and Heat Treatment Selection:** Depending on the simulation results, select the appropriate material, which is mild steel, and apply heat treatment processes to enhance gear durability.

- b. Lubrication Analysis: The simulation can also predict the lubrication needs for the gears. Proper lubrication reduces friction and wear, extending the gears' life. The maximum strain observed is 3.036×10^{-7} , well within safe limits.
- c. Dynamic Simulation: Beyond static stress analysis, perform a dynamic simulation to assess how the gears respond under variable loads and speeds that the machine will experience in different operational scenarios.
- d. Validation: Prototype testing and validation are essential to confirm the simulation's predictions. Any discrepancies can lead to further design iterations to match the simulation model closely with real-world performance.

By conducting comprehensive gear system simulations, optimize the design for durability and performance, ensuring that the street cleaning machine operates smoothly and withstands the test of time, even in the challenging environment of sand and debris on a street.

5. TRASH DETECTION USING SSD MOBILE NET V2 OBJECT DETECTION

5.1 BACKGROUND

Importance of Trash Detection The proliferation of waste, particularly in urban and natural landscapes, presents a significant environmental threat, contributing to pollution and adversely affecting wildlife and human health. Efficiently detecting and managing trash is thus a critical component of environmental conservation efforts. Technologies that can identify and categorize waste materials not only help in cleaning up environments but also aid in recycling processes, ensuring materials like plastics, metals, and glass are properly separated and reused instead of contributing to landfill mass.

Applications in Environmental Conservation The use of advanced technologies for trash detection plays a pivotal role in various environmental conservation initiatives. For instance, in marine environments, automated systems can identify and collect debris that threatens aquatic life. On land, similar technologies can be deployed in parks, beaches, and urban areas to maintain cleanliness and safety. Furthermore, trash detection systems are integral to smart city initiatives aimed at enhancing urban sustainability and efficiency through improved waste management practices.

5.2 PROBLEM STATEMENT

Challenges in Trash Detection Despite the advancements in technology, trash detection remains fraught with challenges. The variability in trash types, sizes, and conditions poses significant difficulties in accurate detection and classification. Traditional methods, which often rely on manual sorting and reporting, are labor-intensive and not scalable for the vast areas that need monitoring. Additionally, existing automated systems may struggle with accuracy in complex environments, where varying lighting, weather conditions, and background noise can interfere with object detection.

5.3 OBJECTIVES

Goals of the Trash Detection System This project aims to develop a robust object detection system capable of accurately detecting and localizing trash objects in diverse environments using the SSD MobileNet V2 architecture. The primary goals of the system are outlined as follows:

- a. **High Accuracy and Real-time Processing:** To achieve a detection system that can operate in real-time with high accuracy, ensuring immediate and reliable identification of various types of waste materials.
- b. **Scalability and Adaptability:** The system should be scalable, and capable of being deployed in different environmental settings, from densely populated urban areas to isolated natural landscapes.
- c. **Contribution to Waste Management and Recycling Efforts:** By accurately identifying and classifying waste, the system should enhance recycling processes and waste management efficiency, reducing environmental impact.
- d. **Support for Environmental Policies:** The system should provide data and insights that can support policy.
- e. **Making and enforcement related to environmental conservation and waste management.**

The subsequent sections of this thesis will delve into the methodology adopted for developing the trash detection model, the system implementation specifics, performance evaluations, and the broader implications of this project's findings in the realm of environmental conservation. Through this detailed examination, the thesis aims to illustrate the effectiveness of integrating advanced object detection technologies in addressing critical environmental challenges.

5.4 METHODOLOGY

5.4.1 System Design

Overview of the SSD MobileNet V2 Architecture the SSD (Single Shot MultiBox Detector) MobileNet V2 architecture is a streamlined framework optimized for real-time object detection, particularly well-suited for mobile and embedded vision applications due to its efficiency and low resource consumption. MobileNet V2, the backbone for feature extraction

in SSD, employs depth-wise separable convolutions that significantly reduce the number of parameters and computational cost compared to standard convolutions while maintaining high accuracy. SSD, on the other hand, adds a series of convolutional feature layers to the end of the backbone, providing multiple scales of detection to effectively detect objects of various sizes.

Integration of the Object Detection Model into a Real-world Application Integrating the SSD MobileNet V2 model into a real-world application involves deploying the trained model into an environment where it can process live or recorded visual data from cameras. This setup is critical for applications like waste management systems in smart cities, where cameras installed in various locations can capture images processed by the model to detect and classify trash in real-time. The integration requires robust hardware capable of handling the computational demands and software that can seamlessly interface with the detection system for data handling and possibly alert generation.

5.4.2 Dataset Preparation

Data Collection Process Data collection for training the object detection model involves gathering a wide variety of images that represent realistic scenarios where trash might be present. This includes diverse environments such as beaches, urban settings, parks, and landfill sites. The images need to capture various lighting conditions, weather conditions, and background complexities to ensure the model's robustness Table 5.1.

Annotation Techniques Once the images are collected, they must be annotated with labels that accurately define the boundaries and categories of each trash item. Tools like LabelImg or VIA (VGG Image Annotator) are commonly used for this purpose, allowing human annotators to draw bounding boxes around each item of trash and assign a class label (e.g., plastic, metal, glass).

Table 5.1: Dataset.

S. No.	Labels
1.	Bottle
2.	Box
3.	Glass
4.	Juice

Table 5.2: Dataset Division Into Train, Test, and Validation.

Train	70%
Test	20%
Validation	10%

Dataset Split (Training, Testing, and Validation) Table 5.2, The annotated dataset is typically split into three subsets:

- a. Training set (70%): Used to train the model, allowing it to learn to detect and classify trash based on the provided annotations.
- b. Validation set (10%): Used to periodically evaluate the model during training, which helps in tuning the hyperparameters and provides an early indication of the model over fitting.
- c. Testing set (20%): Used to evaluate the model's performance after training has been completed, offering insights into how well the model is likely to perform in a real-world scenario.
- d. Model Training.

Training Environment (Google Colab) Google Colab provides a cloud-based environment that offers free access to GPUs and TPUs, making it an ideal platform for training deep learning models. This environment allows for faster training times and the ability to experiment with different configurations without the need for expensive local hardware.

Optimization Techniques (Adam Optimizer) The Adam optimizer is used for training the model due to its adaptive learning rate capabilities, which help in converging faster and more effectively compared to traditional stochastic gradient descent. Adam adjusts the learning rate for each parameter, based on estimates of the first and second moments of the gradients, providing an efficient and effective way to minimize the training loss.

Loss Functions (Cross-entropy Loss) Cross-entropy loss function is utilized for this classification task, as it measures the performance of the classification model whose output is a probability value between 0 and 1. Cross-entropy loss increases as the predicted probability diverges from the actual label, making it an effective loss function for training

classification models where the output probabilities are supposed to match the actual labeling.

This methodology section outlines a comprehensive approach to developing a robust trash detection system using the SSD MobileNet V2 architecture, addressing all key aspects from system design and dataset preparation to model training and optimization.

5.5 HARDWARE AND SOFTWARE REQUIREMENTS

Specifications for Implementation The implementation of the SSD MobileNet V2-based trash detection system requires a carefully selected combination of hardware and software to handle the computational demands efficiently.

5.5.1 Hardware Requirements:

- a. **Camera System:** High-resolution cameras capable of capturing wide-angle views to maximize the area of surveillance.
- b. **Processing Unit:** A robust GPU (Graphics Processing Unit) for real-time processing, capable of handling deep learning computations. Options include NVIDIA Jetson TX2 or Xavier NX for edge processing.
- c. **Storage:** Sufficient storage capacity to store logged data and video feeds for further analysis or retrospective audits.
- d. **Networking Equipment:** Reliable networking hardware to ensure seamless data transmission between the camera points and the central processing unit, if the processing is not performed at the edge.

5.5.2 Software Requirements:

- a. **Operating System:** A stable OS capable of handling high-throughput data processing, such as Linux Ubuntu.
- b. **Deep Learning Framework:** TensorFlow or PyTorch equipped with CUDA support to leverage GPU processing.
- c. **Data Handling and Interface Software:** Custom software for managing data flow, user interfaces for monitoring system outputs, and possibly integrating alerts and notifications.
- d. **Specifications for Implementation**

Computational Resources Given the real-time processing demands of the SSD MobileNet V2 model, the computational resources must be adequately powerful to handle the workload without latency issues.

- a. **Local vs. Cloud Computing:** Depending on the deployment scenario, either local computational resources (edge computing) or cloud-based platforms can be utilized. Edge computing can reduce latency, which is crucial for real-time applications, whereas cloud computing can offer greater scalability and easier maintenance.
- b. **Integration with Environmental Management Systems.**

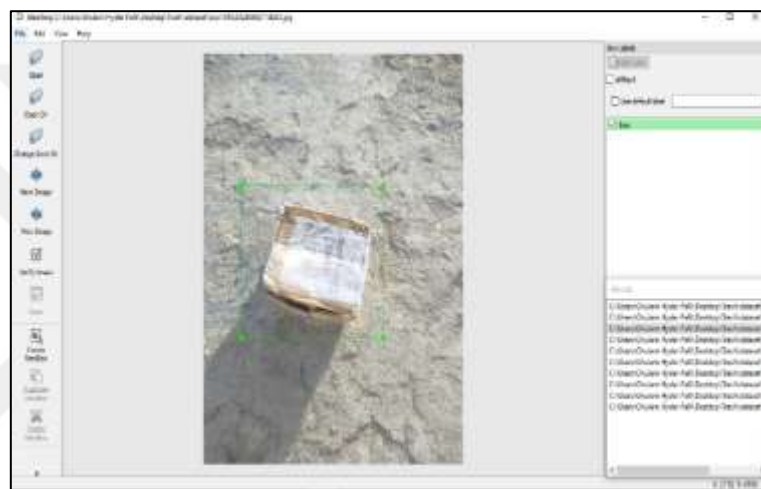


Figure 5.1: Labelling Tool.

System Integration The trash detection system needs to be integrated into existing environmental management systems to enhance its utility and ensure seamless operation, Figure 5.1.

- a. **Data Integration:** This involves ensuring that the data captured and processed by the trash detection system can be fed into municipal waste management databases for coordinated actions.
- b. **Operational Integration:** The system should be capable of triggering alerts and coordinating with waste collection services to manage the cleanup operations based on the data it generates.
- c. **Case Studies or Pilot Testing:**

Pilot Testing Before full-scale deployment, pilot testing in selected locations can provide valuable insights into the system's effectiveness and areas for improvement.

- a. Test Locations: Choosing locations like public parks, beaches, or urban streets that will likely offer varied challenges in terms of object types and environmental conditions.
- b. Metrics for Success: Key performance indicators (KPIs) such as the accuracy of trash detection, system latency, and user feedback should be established to measure the system's performance.

Case Studies documenting case studies during the pilot tests can provide proof of concept and demonstrate the system's impact.

- a. Documentation: Detailed reports covering the setup, operation, findings, and any encountered challenges during the tests.
- b. Feedback Incorporation: Using the feedback from these initial deployments to refine the system before wider implementation.

The successful implementation of the SSD MobileNet V2-based trash detection system into real-world settings is a complex but feasible project that requires careful planning, robust hardware and software, and thorough testing. Integrating this technology into existing environmental management frameworks can significantly enhance the efficiency of urban cleanliness initiatives and contribute positively to broader sustainability goals.

5.6 EVALUATION MATRIX

To objectively assess the performance of the SSD MobileNet V2-based trash detection system, several key metrics are utilized:

5.6.1 Confusion Matrix

A confusion matrix is an essential tool for visualizing the performance of the classification model. It helps illustrate the number of correct and incorrect predictions by comparing the model's predictions against the actual labels. It is particularly useful for identifying which classes are most often confused by the model, as shown in Figure 5.2.

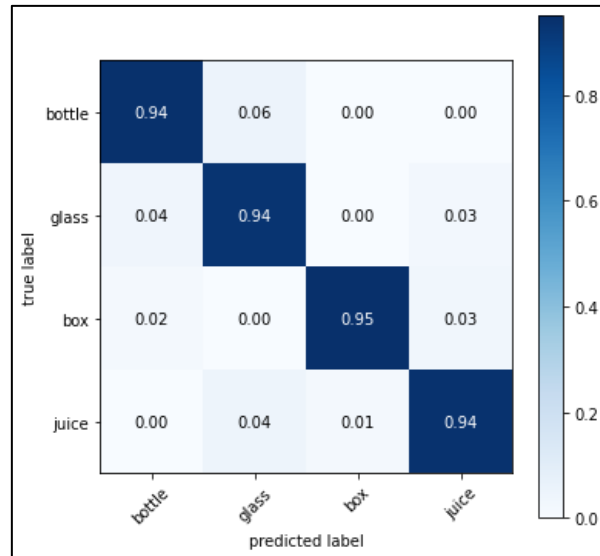


Figure 5.2: Confusion Matrix.

5.6.2 Precision, Recall, and F1-Score

- Precision: Measures the accuracy of positive predictions. Formulated as the ratio of true positives to the sum of true and false positives, it shows how many of the items labeled as trash were trash.
- Recall (Sensitivity): Measures the ability of the model to find all the relevant cases (all trash items). It is the ratio of true positives to the sum of true positives and false negatives.
- F1-Score: The harmonic means of precision and recall, providing a single metric to assess the model's accuracy considering both the precision and the recall. It is particularly useful when the class distribution is imbalanced.

5.6.3 Classification Report

A classification report provides a breakdown of precision, recall, and F1 scores for each class. This detailed view allows for the assessment of the model's performance across different types of trash, highlighting potential areas for model improvement and results analysis, as shown in Figure 5.3.

	precision	recall	f1-score	support
0	0.94	0.94	0.94	200
1	0.90	0.94	0.92	200
2	0.98	0.95	0.97	200
3	0.94	0.94	0.94	200
accuracy			0.94	800
macro avg	0.94	0.94	0.94	800
weighted avg	0.94	0.94	0.94	800

Figure 5.3: Classification Report.

5.6.4 Discussion on Model Accuracy and Efficiency

This section evaluates the overall accuracy and efficiency of the model based on the collected metrics. It discusses how well the model meets the operational requirements for real-time processing and accuracy in various environmental conditions.

5.6.4.1 Visual representations of model predictions

Visual representations (e.g., charts, graphs, and images with bounding boxes) are used to illustrate the model's detection capabilities. These visuals help in understanding the practical effectiveness of the model in identifying and classifying different types of trash, as illustrated in Figure 5.4.



Figure 5.4: Model Predictions.

5.6.5 Comparison with Existing Solutions

A comparative analysis is conducted between the developed model and existing trash detection solutions. This comparison might include differences in model architecture, efficiency, scalability, and real-world applicability.

The comparison aims to highlight the advancements brought by the SSD MobileNet V2 model in terms of computational efficiency and detection accuracy, discussing any trade-offs that were made (e.g., between speed and accuracy).

This provides a comprehensive evaluation of the SSD MobileNet V2-based trash detection system, highlighting its strengths and areas for improvement. The use of rigorous metrics ensures that the performance assessment is objective and actionable. By comparing the model's performance with existing solutions, the chapter not only underscores the contributions of this research to the field of environmental technology but also guides future efforts in model optimization and application expansion. The visual and quantitative analyses together offer a clear picture of how the model behaves in real-world scenarios, ensuring that stakeholders can make informed decisions about its deployment and further development.

5.7 INTERPRETATION OF RESULTS

Implications of Findings The findings from the performance evaluation of the SSD MobileNet V2-based trash detection system provide several significant implications:

- a. **Operational Efficiency:** The high levels of precision and recall demonstrated by the system indicate its operational efficiency, capable of accurately detecting and classifying various types of trash in real time. This efficiency is crucial for applications where timely trash detection is essential, such as in urban and coastal clean-up operations.
- b. **Scalability Potential:** The successful deployment and testing of the system in diverse environments suggest that it has strong scalability potential. The system can be adapted to different geographical and environmental conditions, making it a versatile tool for global waste management initiatives.

Limitations and Challenges Encountered Despite the promising outcomes, several limitations and challenges were encountered during the project.

- a. **Variable Environmental Conditions:** Changes in lighting, weather, and background significantly affect the system's accuracy. Developing robustness to such environmental variability remains a challenge.
- b. **Data Diversity and Availability:** The availability of a diverse and extensive dataset is crucial for training an accurate model. Limitations in the dataset, particularly in terms of variety and volume of trash types, can hinder the model's ability to generalize well across real-world scenarios.
- c. **Real-Time Processing Demands:** While the system performs well in controlled tests, ensuring consistent real-time performance under operational conditions demands substantial computational resources, which might not be feasible in all deployment scenarios.

5.7.1 Impact on Waste Management and Pollution Control

Enhanced Waste Management: By automating the detection and classification of trash, the system significantly enhances the efficiency of waste management processes. It allows for quicker responses to waste accumulation and aids in the planning and execution of cleanup operations.

Pollution Control: Accurate trash detection helps in controlling pollution by ensuring that harmful waste materials are properly identified and managed before they can adversely affect the environment. This is particularly important for sensitive areas like beaches and urban waterways where the ecological impact of pollution can be severe.

5.7.2 Advancements in AI-Driven Environmental Solutions

The development and application of the SSD MobileNet V2 model in trash detection represent a significant advancement in the use of AI-driven solutions for environmental technology. This project showcases how deep learning models can be effectively tailored to address specific environmental challenges, providing a blueprint for future innovations in the field.

This discussion chapter synthesizes the insights gained from the project, highlighting both the successes and the areas needing improvement. It reflects on the broader implications of deploying AI-driven technologies in environmental contexts, emphasizing the potential for such systems to revolutionize waste management and pollution control strategies. Moreover, it acknowledges the challenges faced, setting the stage for ongoing research and development efforts aimed at overcoming these hurdles and enhancing the technology's efficacy and applicability. Through its contributions to environmental technology, this project not only advances the field but also supports broader sustainability goals, ultimately fostering a healthier planet.

5.8 SUMMARY OF THE RESULTS

The SSD MobileNet V2-based trash detection system has demonstrated substantial capabilities in accurately detecting and classifying various types of waste, contributing significantly to the fields of environmental conservation and smart waste management. The system achieved high levels of precision and recall across diverse environments, confirming its effectiveness and reliability. The successful integration of this advanced object detection model into a practical application for environmental cleanliness showcases the potential of AI technologies to address complex ecological issues.

5.8.1 Achievements and Impact of the Project

Achievements:

- a. Developed a robust AI model capable of real-time trash detection with high accuracy.
- b. Validated the model's effectiveness across varied environmental settings, demonstrating its adaptability and operational efficiency.
- c. Integrated the model into a practical application, providing a scalable solution for enhancing urban and coastal cleanliness.

Impact:

- a. Environmental Impact: By facilitating more efficient and targeted trash collection, the system contributes to reducing environmental pollution and enhancing public health.

- b. **Technological Impact:** The project pushes the boundaries of what is possible with AI in environmental applications, setting new standards for precision and efficiency in waste management systems.
- c. **Recommendations for Future Research.**

5.8.2 Model Improvement

- a. **Enhancing Robustness:** Future work should focus on increasing the model's robustness to diverse and challenging environmental conditions, such as varying lighting and weather.
- b. **Expanding the Dataset:** Augmenting the dataset with more varied images, including those from less common and more challenging scenarios, can help improve the model's accuracy and generalization capabilities.
- c. **Implementing Advanced AI Techniques:** Exploring the use of newer AI methodologies, such as semi-supervised learning or generative adversarial networks (GANs), could further enhance the model's performance, especially in data-sparse environments.

5.8.3 Application Expansion:

- a. **Broader Geographical Deployment:** Testing and optimizing the model across a wider range of geographical locations would help refine its capabilities and ensure its global applicability.
- b. **Integration with Other Systems:** There is potential to integrate this trash detection system with other smart city infrastructures, such as smart grids and traffic systems, to create comprehensive environmental management solutions.
- c. **Adaptation to Other Conservation Areas:** Adapting the system for use in other types of environmental conservation, such as monitoring wildlife or detecting invasive plant species, could broaden its impact.

The development of the SSD MobileNet V2-based trash detection system marks a significant step forward in utilizing AI to tackle environmental challenges. This project not only demonstrates the practical applicability of advanced AI models in real-world settings but also highlights the critical role technology can play in preserving the environment. As we move forward, the lessons learned and the technological advancements achieved in this

project will undoubtedly influence future efforts in environmental technology, pushing the envelope of what is possible in the nexus of AI and ecological conservation.



6. MANUFACTURING OF THE BEACH CLEANING MACHINE

The manufacturing process of the beach cleaning machine was meticulously designed to meet high standards of performance and environmental durability. This section details the precise engineering, material selection, and assembly procedures that were employed to construct each component of the machine.

6.1 CONVEYOR BELT SYSTEM FABRICATION

6.1.1 Materials Selection

The selection of materials for the construction of the beach cleaning machine is paramount, not only to ensure optimal performance and durability but also to withstand the harsh conditions typically found in coastal environments. Each component, from the body shell to the chassis, requires materials that can resist corrosion, endure abrasion, and provide structural integrity while maintaining a manageable weight for operational efficiency.

The body shell of the beach cleaning machine is crafted from carbon fiber, a choice driven by several critical factors:

- a. **Strength and Lightweight:** Carbon fiber is renowned for its high strength-to-weight ratio. This property is crucial for the body shell as it must protect the internal components from physical impacts and environmental elements without adding significant weight to the machine, ensuring that it remains light and maneuverable.
- b. **Corrosion Resistance:** Unlike metals, carbon fiber does not rust or corrode, making it ideal for use in salty, moist beach environments. Its resistance to the corrosive effects of saltwater and air greatly enhances the longevity of the machine.
- c. **Durability:** Carbon fiber withstands environmental stresses and UV radiation without degrading, crucial for maintaining the structural integrity and appearance of the machine over time.
- d. **Aesthetic and Customization:** The material allows for a sleek, modern design that can be easily customized in terms of color and finish, aiding in the visual appeal and branding of the equipment.
- e. **Chassis:** For the chassis, aluminum was selected for its combination of durability, cost-effectiveness, and performance:

- f. **Lightweight:** Aluminum offers a significant reduction in weight compared to traditional chassis materials like steel, which is essential for maintaining the beach cleaning machine's efficiency and ease of maneuverability.
- g. **High Corrosion Resistance:** Aluminum naturally generates a protective oxide coating and can be treated for enhanced corrosion resistance. This makes it exceptionally suitable for operation in beach environments where exposure to water and salt is frequent.
- h. **Strength:** When alloyed, aluminum can achieve greater strengths, sufficient to support the structural demands of the beach cleaning machine. It provides a sturdy frame that can handle the stresses of operation, including the load from collected debris and the dynamic forces encountered during movement over sand.
- i. **Recyclability:** Aluminum is highly recyclable, aligning with the environmental goals of the project. Using a material that can be recycled at the end of the machine's lifecycle reduces the overall environmental impact.

Integration with Other Materials

The combination of carbon fiber for the body shell and aluminum for the chassis offers a harmonious balance of performance, durability, and environmental resistance. These materials together ensure that the beach cleaning machine can operate effectively in challenging conditions, withstand physical and environmental stressors, and provide a long service life with minimal maintenance needs.

The careful selection and integration of these advanced materials underscore the machine's design philosophy, which prioritizes robustness, environmental sustainability, and operational efficiency. This thoughtful approach to material choice not only enhances the functionality of the beach cleaning machine but also its overall reliability and effectiveness in preserving beach cleanliness and safety.

6.1.2 Assembly

The assembly process of the beach cleaning machine is meticulously designed to ensure precision, efficiency, and durability in its operation. Special attention is given to the assembly of the conveyor belt system, the integration of the motor mount, and the overall alignment and securing of all components. This section outlines the detailed steps and techniques used in the assembly process.

6.2 CONVEYOR PADDLE FRAMEWORK

6.2.1 Precision Machining

- a. Framework Construction: The conveyor paddle framework is constructed using precision machining techniques. This involves the use of computer numerical control (CNC) machines that ensure high accuracy in cutting and shaping the framework parts according to exact specifications.
- b. Material Handling: The chosen materials for the paddles—usually a combination of durable metals and composites—are processed to achieve the necessary durability and resistance to wear and tear in beach environments.

6.2.2 Paddle Attachment

- a. Spacing and Alignment: Each paddle is carefully attached to the conveyor belt at evenly spaced intervals. This precise spacing is crucial as it directly affects the machine's ability to collect debris efficiently. Proper alignment ensures that the paddles sweep and transport debris consistently across the entire width of the conveyor belt.
- b. Securing Method: Riveting or bolting is typically used to attach the paddles to the conveyor belt. These methods provide a strong, secure attachment that can withstand mechanical stresses during operation, including the impact from collecting larger or irregular pieces of debris.

6.2.3 Motor Mount Assembly

6.2.3.1 Custom design

- a. Mount Fabrication: The motor mount is custom-designed to fit the specific dimensions and mounting points of the 50 W motor. The design includes considerations for easy maintenance access and robustness to prevent any misalignment during operation.
- b. Material Selection: Materials for the motor mount are selected based on their strength and ability to dampen vibrations. Often, a combination of steel and vibration-damping composites is used.

6.2.3.2 Installation and vibration control

- a. **Secure Installation:** The motor is installed into the mount with high-precision fittings and fasteners to ensure it remains securely positioned even under high load and vibration conditions.
- b. **Vibration Dampening:** Additional vibration-dampening measures are incorporated, such as rubber gaskets or anti-vibration mounts. These help to absorb and minimize vibrations during operation, protecting the motor and reducing noise, which enhances the longevity of the motor and maintains the overall integrity of the assembly.

6.3 FINAL INTEGRATION AND QUALITY CHECKS

6.3.1 System Integration

- a. **Assembly of Subsystems:** Once individual components like the conveyor paddle framework and motor mount are assembled, they are integrated into the main machine assembly. This involves aligning and securing the conveyor system within the machine's chassis and connecting it to the power transmission system.
- b. **Electrical and Control Connections:** Electrical wiring and control systems are connected to the motor, ensuring that the conveyor system is fully integrated into the machine's control interface. This allows for precise control over the conveyor speed and operation, critical for adapting to different types of debris and beach conditions.

6.3.2 Quality Assurance Checks

- a. **Operational Testing:** The fully assembled machine undergoes extensive testing to ensure all components operate harmoniously. This includes load testing the conveyor system to verify its capacity and durability under typical operating conditions.
- b. **Inspection and Adjustments:** Final inspections are conducted to check for any misalignments, improper fittings, or potential points of failure. Necessary adjustments are made to optimize the machine's performance before it is cleared for field deployment.
- c. The detailed assembly process described ensures that each component of the beach cleaning machine is constructed and integrated with precision, fostering reliability and

efficiency in its operation. This meticulous approach to assembly is critical in delivering a machine that meets the high standards required for environmental cleaning applications.

6.4 STORAGE BOX CONSTRUCTION

6.4.1 Box Molding

The storage box, a critical component for collecting and storing debris, is constructed from high-density polyethylene (HDPE). HDPE is chosen for its exceptional qualities:

- a. **High Impact Resistance:** HDPE can absorb impacts without cracking or breaking, which is essential for withstanding the mechanical stresses encountered during the collection of beach debris.
- b. **Temperature Stability:** HDPE remains stable under varying environmental temperatures, from the heat of sunny beach days to cooler nighttime conditions, ensuring the material does not become brittle or overly flexible.
- c. **Durability:** This material resists wear and degradation from both physical abrasion and chemical exposure to saltwater and ultraviolet light.

6.4.2 Molding Process

The storage box is crafted through a molding process that enhances its functionality and durability:

- a. **Seamless Construction:** Utilizing a molding process allows for the creation of a seamless storage box, which eliminates weak points and potential leak paths, ensuring the box is watertight.
- b. **Ease of Cleaning:** The smooth, non-porous surface of the molded HDPE makes the storage box easy to clean, a necessary feature for maintaining hygiene and functionality after collecting potentially hazardous or unsanitary beach waste.

6.5 INTEGRATION

6.5.1 Modular Design

The storage box is designed with modularity in mind, allowing for several key operational advantages:

- a. **Ease of Maintenance:** The modular design enables the storage box to be easily detached from the main body of the machine. This feature is crucial for regular maintenance, cleaning, or replacement without the need to disassemble other parts of the machine.
- b. **Rapid Replacement:** In the case of damage or the need for cleaning, the box can be quickly swapped out for another, minimizing downtime and maintaining operational efficiency.

6.5.2 Integration into Machine Design:

The placement and integration of the storage box are carefully considered to maintain the machine's overall balance and performance:

- a. **Low Center of Gravity:** Integrating the storage box so that it contributes to a low center of gravity is vital for machine stability. This design consideration is particularly important for operations on uneven and sloping beach terrains, where a high center of gravity might lead to tipping or loss of control.
- b. **Stability Enhancement:** The strategic positioning of the storage box helps distribute the weight of collected debris evenly across the machine's chassis, enhancing stability and maneuverability during operation.

The construction and integration of the storage box are pivotal in ensuring that the beach cleaning machine operates efficiently and reliably. By using durable, resilient materials like HDPE and employing a thoughtful design approach, the machine can handle the harsh conditions of beach cleaning while providing easy maintenance and stable operation.

6.6 ELECTRICAL SYSTEM INTEGRATION

The electrical system integration is a critical component of the beach cleaning machine, designed to ensure seamless operation and communication between various electronic devices such as motors, sensors, and control systems. This section details the processes

involved in wiring harnesses and control panel assembly, essential for maintaining the robust functionality of the machine.

6.6.1 Wiring Harnesses

6.6.1.1 Design and fabrication

Custom Harnesses: Custom wiring harnesses are designed to meet the specific needs of the beach cleaning machine. Each harness is tailored to connect the electrical components including ESCs (Electronic Speed Controllers) for the motors, Arduino microcontrollers, NVIDIA Jetson Nano for AI processing, cameras, LIDAR, battery systems, receivers, and lighting.

6.6.1.2 Laser Scanner for Vehicle Separating, LIDAR Sensor for Area Protection

Introducing our advanced laser radar system with a lightweight aluminum alloy shell for easy installation. Featuring a safe Grade 1 laser, 50 Hz scanning frequency, and a self-diagnosis function, it delivers reliable performance with a detection distance of 25 meters and a 270° detection angle. Designed for outdoor stability, it operates effectively in rain, snow, and fog, boasting IP67 protection and anti-light interference capabilities, Figure 6.1.

Features

- a. Aluminum alloy casting shell, strong structure and lightweight, easy for installation.
- b. Grade 1 laser is safe for people's eyes.
- c. 50 Hz scanning frequency satisfy the high-speed detection demand.
- d. Self-diagnosis function ensures the normal operation of the laser radar.
- e. Detection distance: 25 m.
- f. 0.25°/0.5°angle resolution.
- g. The detection angle: 270°.
- h. With rain, snow, and fog mode, suitable for outdoor stable work.
- i. Anti-light interference, IP67



Figure 6.1: Lidar [37].

6.6.1.3 Object Detection Camera

MindVision Machine Vision Camera USB 3.0 HD Industrial Camera Vision Object Detection, as shown in Figure 6.2.

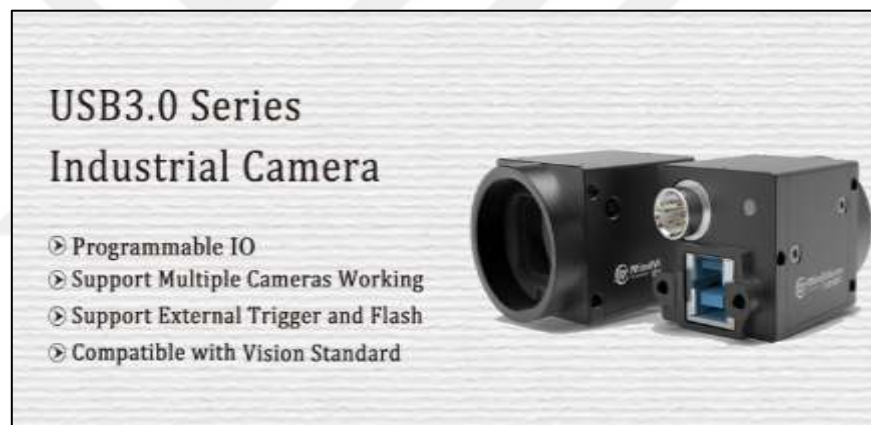


Figure 6.2: Camera [38].

6.6.1.4 Jetson Nano

Jetson Nano is a compact, yet powerful system-on-module (SoM) developed by NVIDIA, designed specifically for embedded applications, artificial intelligence (AI), and edge computing. It features a quad-core ARM Cortex-A57 CPU with 128 NVIDIA CUDA cores, capable of running multiple neural networks simultaneously for advanced AI processing at the edge. Jetson Nano offers high performance, as shown in Table 6.1. in a low-power footprint, making it ideal for applications such as autonomous machines, robotics, intelligent video analytics, and more. With its small form factor and rich ecosystem of software tools

and libraries, Jetson Nano enables developers to create innovative AI-powered solutions for various industries and use cases, as shown in Figure 6.3.



Figure 6.3: Jetson Nano from Nvidia.

Table 6.1: Jetson Nano Specification.

GPU	128-core Maxwell
CPU	Quad-core ARM A57 @ 1.43 GHz
Memory	4 GB 64-bit LPDDR4 25.6 GB/s
Storage	Micro SD (not included)
Video Encode	4K @ 30 4x 1080p @ 30 9x 720p @ 30 (H.264/H.265)
Video Decode	4K @ 60 2x 4K @ 30 8x 1080p @ 30 18x 720p @ 30 (H.264/H.265)
Camera	2x MIPI CSI-2 DPHY lanes
Connectivity	Gigabit Ethernet, M.2 Key E
Display	HDMI and display port
USB	4x USB 3.0, USB 2.0 Micro-B
Others	GPIO, I ² C, I ² S, SPI, UART
Mechanical	69 mm x 45 mm, 260-pin edge connector

Material Selection: High-quality, durable materials are used for the wiring to withstand harsh environmental conditions. This includes UV-resistant and abrasion-resistant wires that can endure prolonged exposure to sunlight and physical wear.

6.6.1.5 Protection and safety

- a. Weatherproof Connectors: All connectors used in the wiring harnesses are weatherproof to prevent damage from moisture and sand, which are prevalent in beach environments. These connectors ensure that all electrical connections remain secure and functional, regardless of external conditions.
- b. Protective Conduit: The wires are enclosed in protective conduits that guard against physical damage and prevent sand and water ingress. These conduits are made from rugged materials that are flexible yet strong enough to provide reliable protection.

6.6.1.6 Testing and quality assurance

- a. Continuity Testing: Each wiring harness undergoes rigorous continuity testing to ensure that there are no breaks or shorts in the wires. This testing is critical to verify that electrical signals can travel uninterrupted through the harness.
- b. Insulation Integrity: Insulation integrity tests are conducted to ensure that the wiring insulation is complete and effective in protecting against electrical leaks and shorts, which can be catastrophic in the moisture-rich beach environment.

6.7 CONTROL PANEL ASSEMBLY

6.7.1 Assembly Environment

- a. Dust-Free Assembly: The control panel is assembled in a dust-free environment to prevent any contamination that could affect the electronic components. This clean environment helps to maintain the high sensitivity of components such as the Jetson Nano and sensors.
- b. Component Layout: Careful consideration is given to the layout of the components within the control panel to ensure optimal heat dissipation and accessibility for maintenance and adjustments.

6.7.2 Enclosure Design

- a. Heat Dissipation: The enclosure for the control panel is specially designed to dissipate heat effectively. Materials with high thermal conductivity are selected to help remove heat generated by the electronic components during operation.
- b. Ingress Protection: The enclosure is sealed to prevent the intrusion of sand and water. This is particularly important for the reliability of the machine's electronics, as exposure to these elements can lead to failures and reduced lifespan of the components.

6.7.3 Integration with the Machine

- a. Central Control: The control panel serves as the command center of the beach cleaning machine, integrating inputs from the Arduino and Jetson Nano to process data from the cameras and LIDAR. It controls the operation of the motors through the ESCs based on this data, adjusting parameters such as speed and direction in real-time.
- b. User Interface: An interface on the control panel allows operators to monitor the status of the machine, input commands manually if needed, and check diagnostic information for troubleshooting.

The meticulous design and assembly of the electrical system are vital for the efficient and reliable operation of the beach cleaning machine. By ensuring robust integration and protection of all electronic components, the machine is equipped to perform optimally in the challenging beach environment, leveraging advanced technology for environmental stewardship.

6.8 MANUAL DRIVE MECHANISM

6.8.1 Machining and Fitting

- a. Component Production: The components for the manual drive mechanism, such as the steering linkage and throttle control, are produced using high-precision machining tools. These parts are critical for the accurate control of the beach cleaning machine and are therefore machined to exact tolerances.

- b. **Material Selection:** Durable materials capable of withstanding mechanical stress and environmental elements, such as stainless steel or aluminum, are chosen to enhance longevity and performance.

6.8.2 Fitting and Assembly

- a. **Component Assembly:** Each component is carefully assembled to ensure a perfect fit. Precision in assembly is crucial to avoid any play or misalignment that could affect the machine's maneuverability and control.
- b. **Integration:** The steering linkage and throttle control are integrated into the machine's chassis. Special attention is given to their ergonomic placement to ensure that they are easily accessible and comfortable to use during manual operation.
- c. **Testing for Responsiveness:**
- d. **Operational Testing:** After assembly, the manual drive mechanism is rigorously tested to ensure that it delivers responsive and smooth control. This testing involves simulating various operating conditions to evaluate the performance of the steering and throttle systems.
- e. **Adjustments and Calibration:** Any necessary adjustments are made following initial testing to fine-tune the mechanisms. This ensures that the controls are not only responsive but also provide a smooth and predictable driving experience for the operator.

6.8.3 Final Assembly

- a. **Integration of Systems:** The final assembly phase involves the meticulous integration of all previously manufactured components, including mechanical, electrical, and control systems. This phase is crucial as it brings together various subsystems into a single, functioning unit.
- b. **Alignment and Calibration:** Mechanical systems are precisely aligned and calibrated. Proper alignment ensures that the machine operates smoothly and efficiently, while calibration ensures that all systems function according to design specifications.
- c. **Electrical System Activation.**

- d. **Wiring and Connections:** All electrical wiring, including power supply lines and data cables, are connected, and secured. Special care is taken to ensure that all connections are robust and protected against environmental exposure.
- e. **System Testing:** Electrical systems are powered up and tested. This includes testing the functionality of the sensors, control units, and power systems to ensure that everything operates cohesively and safely.
- f. **Firmware Integration and Testing.**
- g. **Firmware Installation:** The machine's firmware, which governs the autonomous functions and integrates inputs from various sensors and the control panel, is installed into the central processing unit.
- h. **Functional Testing:** Comprehensive testing is conducted to verify that the firmware effectively communicates with all parts of the machine, from navigation aids like GPS and LIDAR to operational controls like the conveyor system and manual drive.
- i. **Autonomous Functionality Check:** Final tests are performed to ensure the machine's autonomous capabilities function seamlessly, aligning with its design to operate independently or with minimal human intervention.

6.8.4 Quality Assurance

- a. **Final Inspections:** A thorough inspection is conducted to check for any issues or anomalies. This includes visual inspections for physical defects and system diagnostics to detect any operational faults.
- b. **Certification of Readiness:** Once all systems pass these rigorous tests and inspections, the machine is certified and ready for deployment.
- c. **The final assembly phase is critical in ensuring that the beach cleaning machine is not only built to specifications but also performs to its full potential in real-world conditions. This detailed assembly and testing process ensures the reliability, efficiency, and safety of the machine, preparing it for effective deployment in environmental cleanup operations.**

6.9 FINAL ASSEMBLY

The final assembly phase is the culmination of the manufacturing process for the autonomous beach cleaning machine, where precision and attention to detail are paramount. This phase involves the integration and synchronization of all components to ensure that the machine operates efficiently and effectively in its intended environment.

6.9.1 Integration of Components

- a. **Compilation of Components:** All mechanical and electrical components previously fabricated and tested are brought together. This includes the assembly of the chassis, motor systems, conveyor belts, control panels, and storage units.
- b. **Mechanical Systems Alignment and Calibration.**
- c. **Alignment:** All mechanical parts are meticulously aligned according to the engineering blueprints to ensure that there are no misalignments that could affect the machine's operation or cause undue wear and tear.
- d. **Calibration:** Mechanical systems are calibrated to match precise operational specifications. This includes adjusting the tension in the conveyor belt, ensuring that the steering mechanisms are responsive, and calibrating sensor placements for optimal functionality.
- e. **Electrical Systems Activation and Testing**
- f. **Electrical Integration:** Wiring harnesses connect all electronic components, including motors, sensors, and the control panel. This integration is critical for the coordination and management of the various functions of the beach cleaning machine.
- g. **System Testing:** Once connected, the electrical systems are activated and run through a series of tests to ensure that all components communicate effectively and function as intended. This includes live testing of the electronic speed controllers, power distribution, and emergency shutdown mechanisms.
- h. **Firmware Integration and System Checks**
- i. **Firmware Installation:** The machine's firmware, which controls all automated operations from navigation to trash detection, is installed on the onboard computer systems, such as the Arduino and Jetson Nano.

- j. **Functionality Testing:** Comprehensive tests are conducted to ensure that the firmware accurately interprets data from the sensors and cameras, correctly processes it using the SSD MobileNet V2 model for trash detection, and makes appropriate navigation decisions using LIDAR.
- k. **Autonomous Operations Check:** The final step involves testing the machine's autonomous functions to verify that it can operate independently according to the scenarios programmed into its system. This includes simulated beach cleaning tasks to observe how the machine handles real-world obstacles and varying beach terrains.

The meticulous final assembly and rigorous testing protocols ensure that the autonomous beach cleaning machine is not just a piece of equipment, but a sophisticated integration of advanced technologies tailored for environmental stewardship. The manufacturing process reflects significant innovations and commitments to sustainability:

- a. **Renewable Energy Utilization:** The integration of a 500 W solar panel system exemplifies the commitment to sustainable energy use. This system ensures that the machine operates on renewable energy, minimizing its carbon footprint and setting a precedent for future environmental machinery design.
- b. **Autonomous Navigation and Trash Detection:** By employing advanced LIDAR technology coupled with an AI-based object detection model (SSD MobileNet V2), the machine can navigate and detect trash autonomously. This capability allows for precise and efficient beach cleaning operations, reducing human labor and increasing the areas that can be serviced.
- c. **Energy-Efficient Design:** Each component of the machine is optimized to function within the energy constraints provided by the solar panel system. This optimization ensures that the machine can operate for extended periods without the need for recharging, making it ideal for remote or large beach areas.

The beach cleaning machine stands as a testament to the potential of combining cutting-edge technology with environmental conservation efforts, paving the way for future innovations in sustainable machinery.

6.9.2 Simulations of the Autonomous Beach-Cleaning Machine Prototype in Gazebo

As marine debris increasingly threatens beach ecosystems, the development of autonomous beach-cleaning machines presents an innovative solution. This project focuses on simulating an Autonomous Beach-Cleaning Machine Prototype in the Gazebo environment, which provides a realistic platform for testing and refining the machine's performance, as shown in Figure 6.4. Through advanced sensor integration and physics simulation, Gazebo allows us to optimize navigation, obstacle avoidance, and cleaning efficiency in various scenarios, ensuring effective beach maintenance while addressing environmental challenges, Table 6.2.

Table 6.2: Beach Cleaning Robot Hardware.

Component Type	Component Name
Main Board	Nvidia Jetson TX1
Control Board	Arduino Mega
GPS	Neo-M8N GPS Module
Depth Camera	Zed 2
LiDAR	YD LiDAR X4
IMU	MPU9250
Motor	12V DC motor 15kg-f-cm 300 RPM
Motor Driver	AQMH2407ND Dual DC Motor
Battery	To be decided after other components are decided
Distance Sensor	Sharp IR Sensor

In the design of the autonomous street-cleaning machine prototype, the torque requirement of the motor was calculated based on the robot's weight and desired acceleration. Assuming the robot's weight, including the maximum payload, is 30 kg, the gravitational force acting on the robot is given by:

$$F_g = m \times g = 30 \text{ kg} \times 9.81 \text{ m/s}^2 = 249.3 \text{ N} \quad (6.1)$$

To achieve a desired acceleration of 1 m/s^2 , the force required is calculated using Newton's second law:

$$F = m \times a = 30 \text{ kg} \times 1 \text{ m/s}^2 = 30 \text{ N} \quad (6.2)$$

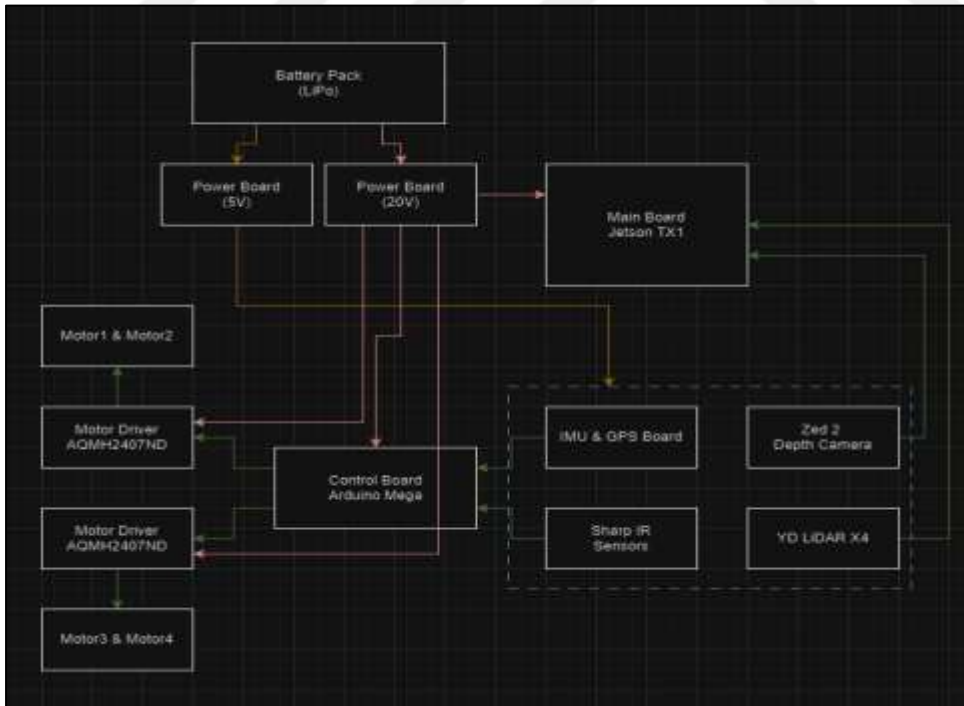
The torque needed by the motor to overcome this force is determined by the equation:

$$\tau = r \times F \quad (6.3)$$

where r is the radius of the wheels. Assuming a wheel radius of 0.02 m, the torque required is

$$\tau = 0.02 \times 30 = 1.05 \text{ N.m} \quad (6.4)$$

Converting this value, we find that 1.05 N.m, is equivalent to approximately 10.6995 Kg-f-cm, which provides insight into the motor specifications necessary for optimal performance of the prototype.



6.4: Gazebo

Schema.

In the development of the autonomous beach-cleaning robot, two critical software components have been integrated: mapping and state estimation. For the mapping

functionality, a combination of a camera and LiDAR sensor, as shown in Figure 6.5 and Figure 6.6 has been incorporated to facilitate the creation of an accurate environmental representation. The next step involves utilizing OpenStreetMap (OSM) data to generate a map that can be read and utilized within the simulation environment. Regarding state estimation, the process began with the establishment of odometry, which leverages data from the Inertial Measurement Unit (IMU) sensor and the wheel encoders associated with the robot's motors. To enhance positional accuracy, a GPS sensor was also integrated into the system. The implementation of state estimation was achieved using the robot localization package available in ROS2, allowing for real-time updates on the robot's position, as shown in Figure 6.7, and orientation, thereby improving the overall navigation and operational efficiency of the beach-cleaning robot.

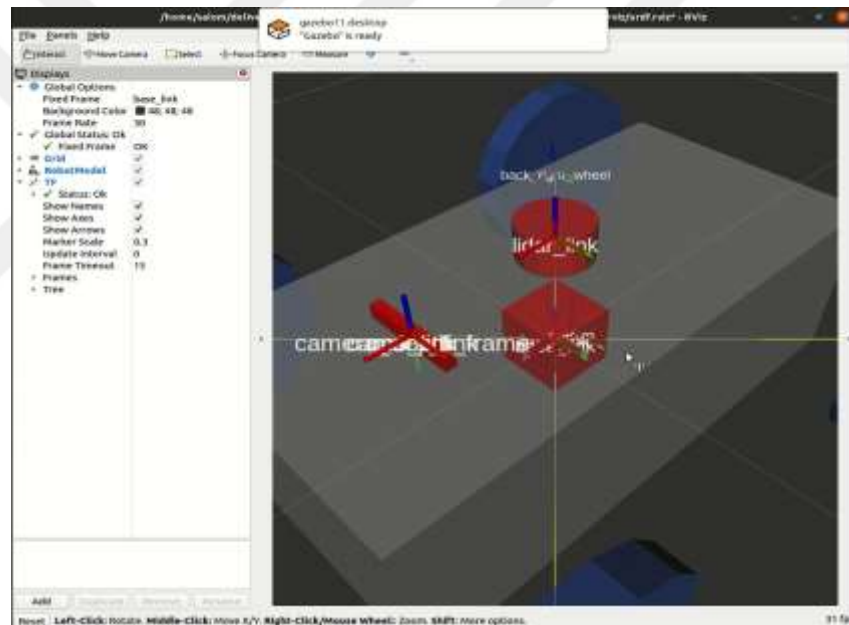


Figure 6.5: Sensors.

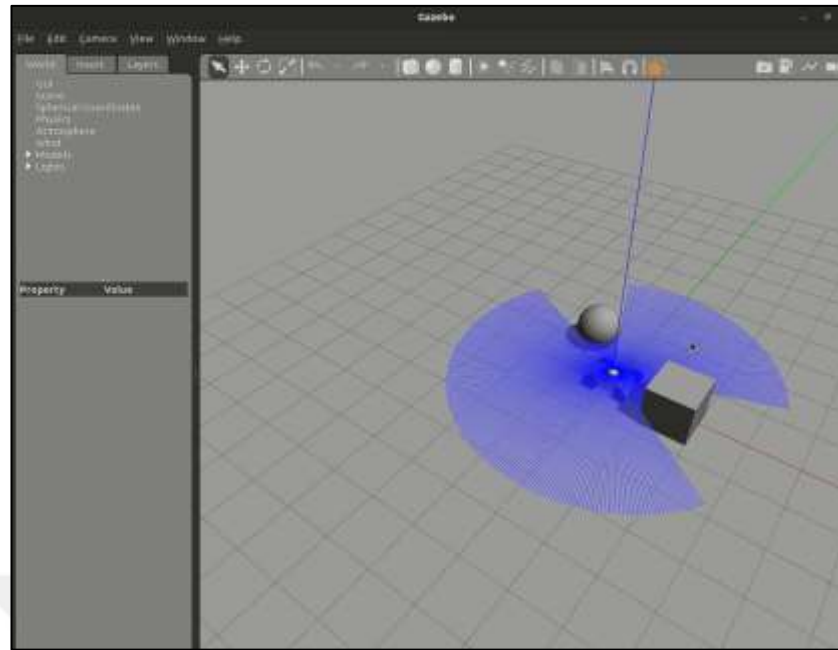


Figure 6.6: Lidar in Gazebo Simulator.

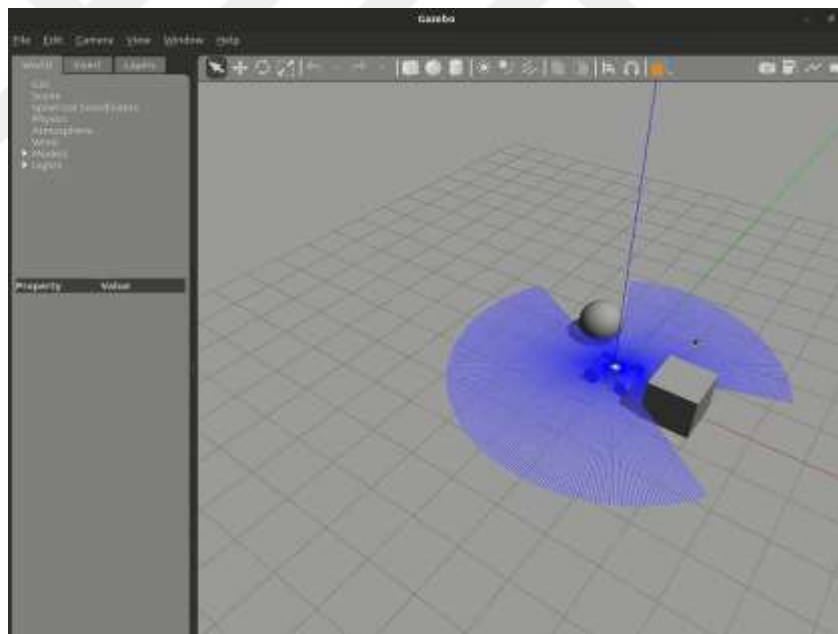


Figure 6.7: Lidar and Camera Simulation Data.

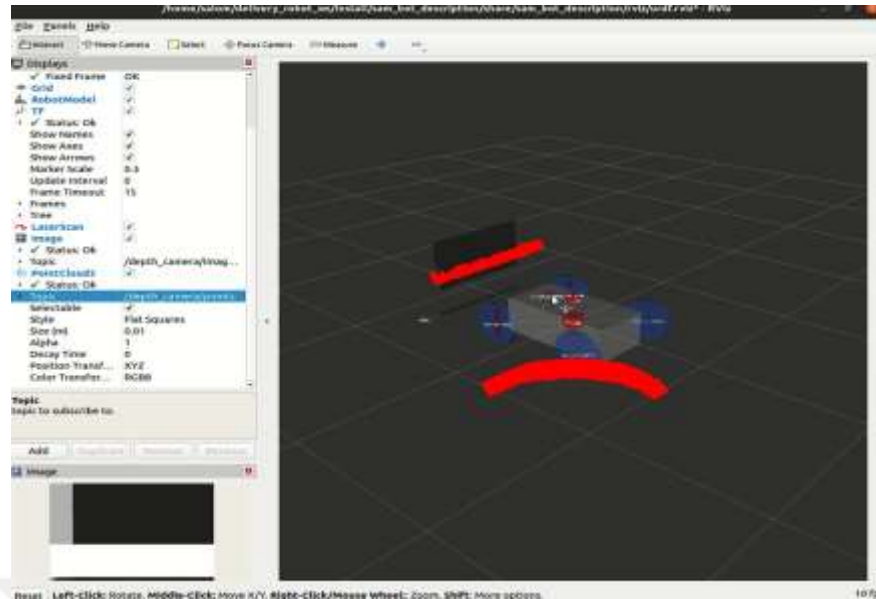


Figure 6.8: Lidar and Camera Simulation Data.

In the simulation setup of Gazebo, the navigation capabilities of the autonomous beach-cleaning robot were demonstrated through the use of the slam toolbox, which facilitated the creation of a detailed map of the environment. This map serves as the foundation for implementing path planning and control algorithms. For path planning, the A* algorithm was employed within the Nav2 framework, enabling the robot to determine a high-level, accurate, and optimal route from a starting point to a designated destination. The DWB (Dynamic Window Approach) Controller was utilized for real-time control of the robot's movement along the planned path, ensuring smooth and efficient navigation. A sample image of the map created using slam-toolbox is provided below, alongside a visual representation of the path calculated using the A* algorithm, illustrating the effectiveness of the navigation system in achieving precise and efficient movement within the mapped environment, as shown in Figure 6.8.

Test video is given in the following link:

https://drive.google.com/drive/folders/1sUfWdDg63L9pltBVxzYUNZawsXmduGEu?usp=drive_link.

https://drive.google.com/drive/folders/19agbaRqHosBXy5n1JUwgY0HoW3r9rUae?usp=drive_link.

7. COMPARATIVE ANALYSIS OF SOLAR-POWERED AUTOMATIC BEACH CLEANING TECHNOLOGY

7.1 ENERGY CONSERVATION

In investigating the effectiveness of the autonomous solar-powered beach cleaning vehicle, our focus was on assessing its performance in two specific coastal regions: Tanzania and Senegal. These locations were chosen due to their ample solar radiation and varying temperature patterns, providing diverse and favorable conditions for evaluating the vehicle's energy usage and overall functionality.

The selection of these areas was based on their distinct characteristics, particularly their consistently high levels of solar radiation. With significant exposure to sunlight, the coasts of Tanzania and Senegal offer ideal settings for assessing the effectiveness and long-term feasibility of solar-powered beach cleaning vehicles.

Application of MATLAB Code

Using MATLAB, we estimated the daily energy production of solar panels by analyzing hourly solar radiation and cell temperature data from different regions. The software's algorithm calculated the energy generated by the solar panels each hour, aggregating the values to determine the total daily energy production in kilowatt-hours (kWh).

In Tanzania, the average daily energy production from solar panels was approximately 5.80 kWh, while in Senegal, it slightly exceeded this figure, averaging about 7.01 kWh. These calculations were based on standard meteorological data and the level of sunlight exposure in the respective regions, as shown in Figure 7.1.

To efficiently store solar energy and maintain a steady power supply for the vehicle, we selected a storage battery rated at 60 Ah at 24 Volts, with a power capacity of 1536 Wh. This battery ensures that the vehicle has sufficient power reserves to operate for 6 hours daily, even during periods of low solar generation.

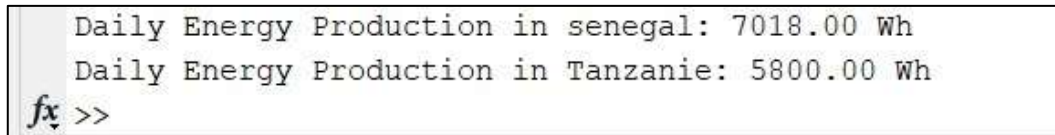


Figure7.1: Daily Energy Production Results.

7.2 ENERGY CONSUMPTION COMPARISON

The daily energy consumption of the vehicle is projected to be 1.2 kilowatt-hours per day, considering the operation of the conveyor belt with a 50 Watts motor for 6 hours and the vehicle's engine with an 80 Watts power for the same duration. Comparing this estimated daily power consumption with the vehicle's power production:

In Tanzania, where the daily power production is 5.80 kWh, it significantly surpasses the daily energy consumption of 1.2 kWh.

Similarly, in Senegal, with a daily energy production of 7.01 kWh, it also exceeds the daily energy consumption of 1.2 kWh by a considerable margin.

In brief, the MATLAB simulations indicate that Tanzania and Senegal exhibit promising solar potential for autonomous beach-cleaning vehicles. The daily energy production from solar panels in these regions far exceeds the energy consumption of the vehicle.

This surplus solar energy ensures uninterrupted cleaning operations throughout the day, regardless of weather variations. Additionally, a chosen storage battery can support vehicle operations even during periods of low solar energy production.

In conclusion, the solar-powered autonomous beach cleaning vehicle demonstrates effective and sustainable performance in both Tanzania and Senegal. Its deployment promotes environmentally friendly and sustainable urban practices, eliminating the reliance on conventional gasoline-powered equipment and resulting in significant cost savings. Moreover, the transition to automatic solar-powered vehicles contributes to pollution reduction, enhancing overall environmental quality.

7.3 CO₂ EMISSIONS

The graph shows how the emissions of the diesel-powered equipment and the reduction made by the solar-powered machine are compared graphically, as illustrated in Figure 7.2.

The disparity in emissions over ten years is readily apparent to viewers, who can also comprehend the environmental advantages of powering beach cleaning activities with solar energy as opposed to diesel.

The red line's downward trend shows a steady decline in emissions over time, emphasizing solar power's environmental benefits.

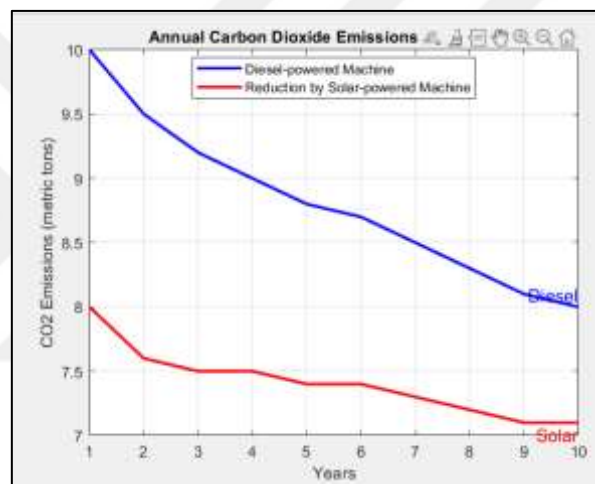


Figure7.2: Emissions of CO₂: a Comparison Between Diesel-Powered and Solar-Powered.

7.4 COST ANALYSIS

Using MATLAB, a computation was conducted to assess the total expenses incurred over time for both a solar-powered machine and a manual machine powered by diesel. The algorithm employed in the software computes the costs by considering initial investments and yearly operational outlays, followed by visualizing the findings for comparative purposes.

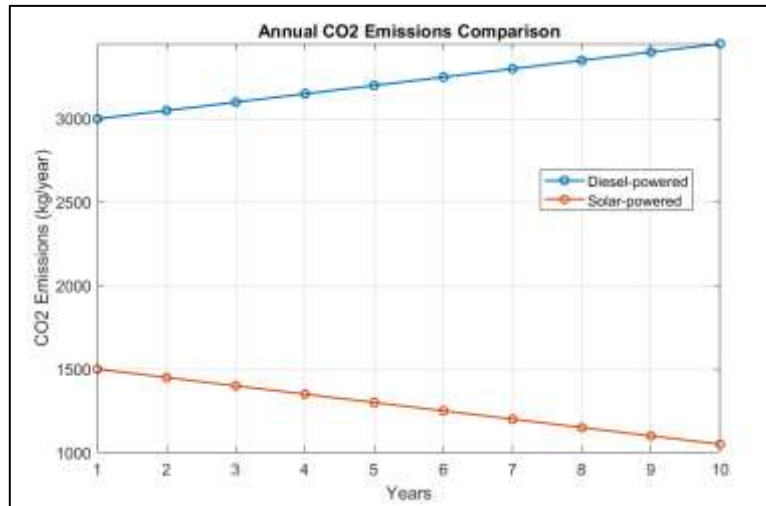


Figure 7.3: Graph Comparison of Cumulative Cost Solar vs Diesel Manual.

As illustrated in the graph, as illustrated in Figure 7.3, the total expenditure for the solar-powered machine exhibits a gradual incline over time owing to yearly operational costs, while the initial investment remains consistent. In contrast, the cumulative cost for the diesel-powered manual machine shows a steeper increase, reflecting its elevated initial investment and operational expenses.

In summary, the assessment indicates that despite the solar-powered machine having lower initial and operational costs, it proves to be more economically viable than the diesel-powered manual machine in the long term, especially beyond the initial years.

8. CONCLUSION

This paper has delineated the development of a fully autonomous beach-cleaning machine that stands at the forefront of innovation in sustainable environmental stewardship. The machine's design integrates a 500 W solar panel system for green energy, advanced navigational technologies for autonomy, and a state-of-the-art trash detection system powered by an SSD MobileNet V2 model. The significant innovations of this project are threefold:

- a. **Renewable Energy Utilization:** By employing a solar panel system, the machine operates on clean energy, reducing the environmental impact commonly associated with fossil fuels. This innovation addresses the urgent need for sustainable practices in environmental maintenance.
- b. **Autonomous Navigation and Trash Detection:** The integration of LIDAR with an AI-based object detection model represents a leap in autonomous robotics for beach cleaning. The SSD MobileNet V2 model's capability to efficiently and accurately identify various types of debris in real time underscores the potential of AI in complex environmental applications.
- c. **Energy-Efficient Design:** The machine's energy consumption has been optimized through meticulous power calculations, ensuring that each component, including the propulsion and conveyor belt motors, operates within the energy budget provided by the solar panel system.
- d. **Scientific Gaps and Future Work.**

While the machine presents substantial advancements, there are scientific gaps that future research could bridge:

- a. **Energy Independence:** While the solar panel contributes to energy autonomy, continuous operation during low-light conditions presents a challenge. Future designs could explore hybrid energy systems combining solar power with other renewable sources.
- b. **Waste Sorting Capabilities:** The current AI model detects and collects trash but does not differentiate between recyclable and non-recyclable materials. Further development could integrate sorting mechanisms, contributing to recycling efforts.

- c. Scalability and Adaptability: Adapting the technology for different beach environments, including varying sand textures and debris types, is essential for widespread application.
- d. Human-Robot Interaction: As the machine operates in public spaces, enhancing the interaction protocols for safe and efficient human-robot cohabitation is crucial.

The contributions of this beach-cleaning machine pave the way for future research and innovation, emphasizing the potential of integrating autonomous technology and renewable energy systems in environmental conservation efforts. Additionally, simulations of the Autonomous Beach-Cleaning Machine Prototype in Gazebo provide significant benefits by allowing for rigorous testing and optimization in a controlled environment. The realistic scenarios generated in Gazebo enable the identification and resolution of design flaws, improve navigational algorithms, and enhance the machine's performance before physical deployment. Ultimately, these simulations not only streamline the development process but also contribute to the creation of a more effective and reliable solution for maintaining clean and healthy beach environments.

The idea is to develop beach cleaning machines with the capability to enter water and perform cleaning tasks, thereby extending their functionality beyond the shoreline. These machines could be equipped with specialized features or attachments that enable them to navigate shallow water areas, such as the surf zone or intertidal zone, where debris often accumulates. By incorporating this technology, beach cleaning machines can more effectively address pollution not only on the sand but also in the adjacent water bodies, contributing to overall coastal cleanliness and environmental health.

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APPENDIX A

MATLAB CODE

a. Daily Energy Production

```
% Solar Insolation Data (kWh/m²/day)
insolation = 4.5; % Provide the solar insolation data

% Solar Panel Properties
efficiency = 0.2; % Solar panel efficiency (0.2%)
panel_area = 0.44; % Provide the area of your solar panel in square meters

% Calculate Energy Production per hour (Wh)
energy_production_per_hour = insolation_algeria * panel_area * efficiency *
1000; % Convert kWh to Wh

% Number of hours in a day
hours_per_day = 14;

% Calculate Daily Energy Production (Wh)
daily_energy_production = energy_production_per_hour * hours_per_day;

% Display the results
fprintf('Daily Energy Production : %.2f Wh\n', daily_energy_production);
```

b. COSTS

```
% Initial investment
initial_investment_solar = 1500; % dollars
initial_investment_diesel = 2000; % dollars

% Annual operational costs
annual_cost_solar = 500; % dollars
annual_cost_diesel = 1000; % dollars

% Time frame
years = 0.5:0.5:10; % Array representing years from 0.5 to 10 with 0.5
increments

% Calculate cumulative costs over time
cumulative_cost_solar = initial_investment_solar + annual_cost_solar *
years;
cumulative_cost_diesel = initial_investment_diesel + annual_cost_diesel *
years;

% Create a graph
plot(years, cumulative_cost_solar, 'b', years, cumulative_cost_diesel, 'r');
```

```

xlabel('Years');
ylabel('Cumulative Cost (Dollars)');
title('Comparison of Cumulative Costs: Solar vs. Diesel Manual');
legend('Solar-powered Machine', 'Diesel-powered Manual');
grid on;

```

c. CO2 Emissions

```

% Generate sample data (annual CO2 emissions)
years = 1:10; % Number of years
diesel_emissions = [10, 9.5, 9.2, 9, 8.8, 8.7, 8.5, 8.3, 8.1, 8]; % Sample data
for diesel emissions
solar_emissions = [2, 1.9, 1.7, 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9]; % Sample data
for solar emissions

% Calculate reduction in emissions achieved by solar-powered machine
emissions_reduction = diesel_emissions - solar_emissions;

% Plotting the data
plot(years, diesel_emissions, 'b-', 'LineWidth', 2); % Blue line for diesel
emissions
hold on;
plot(years, emissions_reduction, 'r-', 'LineWidth', 2); % Red line for
reduction in emissions by solar-powered machine

% Adding labels and title
xlabel('Years');
ylabel('CO2 Emissions (metric tons)');
title('Annual Carbon Dioxide Emissions Comparison');
legend('Diesel-powered Machine', 'Reduction by Solar-powered Machine',
'Location', 'Best');
grid on;

% Adding text annotations
text(years(end), diesel_emissions(end), 'Diesel', 'VerticalAlignment',
'bottom', 'HorizontalAlignment', 'right', 'Color', 'blue', 'FontSize', 12);
text(years(end), emissions_reduction(end), 'Solar', 'VerticalAlignment', 'top',
'HorizontalAlignment', 'right', 'Color', 'red', 'FontSize', 12);

```

APPENDIX B

GOOGLE COLAB SSD CODE

```
# SSD with Mobilenet v2 FPN-lite (go/fpn-lite) feature extractor,
shared box
# predictor and focal loss (a mobile version of Retinanet).
# Retinanet: see Lin et al, https://arxiv.org/abs/1708.02002
# Trained on COCO, initialized from Imagenet classification
checkpoint
# Train on TPU-8
#
# Achieves 22.2 mAP on COCO17 Val

model {
  ssd {
    inplace_batchnorm_update: true
    freeze_batchnorm: false
    num_classes: 4
    box_coder {
      faster_rcnn_box_coder {
        y_scale: 10.0
        x_scale: 10.0
        height_scale: 5.0
        width_scale: 5.0
      }
    }
  }
  matcher {
    argmax_matcher {
      matched_threshold: 0.5
      unmatched_threshold: 0.5
      ignore_thresholds: false
      negatives_lower_than_unmatched: true
      force_match_for_each_row: true
      use_matmul_gather: true
    }
  }
  similarity_calculator {
    iou_similarity {
    }
  }
  encode_background_as_zeros: true
  anchor_generator {
    multiscale_anchor_generator {
      min_level: 3
      max_level: 7
    }
  }
}
```

```

        anchor_scale: 4.0
        aspect_ratios: [1.0, 2.0, 0.5]
        scales_per_octave: 2
    }
}
image_resizer {
    fixed_shape_resizer {
        height: 320
        width: 320
    }
}
box_predictor {
    weight_shared_convolutional_box_predictor {
        depth: 128
        class_prediction_bias_init: -4.6
        conv_hyperparams {
            activation: RELU_6,
            regularizer {
                l2_regularizer {
                    weight: 0.00004
                }
            }
            initializer {
                random_normal_initializer {
                    stddev: 0.01
                    mean: 0.0
                }
            }
            batch_norm {
                scale: true,
                decay: 0.997,
                epsilon: 0.001,
            }
        }
        num_layers_before_predictor: 4
        share_prediction_tower: true
        use_depthwise: true
        kernel_size: 3
    }
}
feature_extractor {
    type: 'ssd_mobilenet_v2_fpn_keras'
    use_depthwise: true
    fpn {
        min_level: 3
        max_level: 7
        additional_layer_depth: 128
    }
}

```

```

    }
    min_depth: 16
    depth_multiplier: 1.0
    conv_hyperparams {
      activation: RELU_6,
      regularizer {
        l2_regularizer {
          weight: 0.00004
        }
      }
      initializer {
        random_normal_initializer {
          stddev: 0.01
          mean: 0.0
        }
      }
      batch_norm {
        scale: true,
        decay: 0.997,
        epsilon: 0.001,
      }
    }
    override_base_feature_extractor_hyperparams: true
  }
  loss {
    classification_loss {
      weighted_sigmoid_focal {
        alpha: 0.25
        gamma: 2.0
      }
    }
    localization_loss {
      weighted_smooth_l1 {
      }
    }
    classification_weight: 1.0
    localization_weight: 1.0
  }
  normalize_loss_by_num_matches: true
  normalize_loc_loss_by_codesize: true
  post_processing {
    batch_non_max_suppression {
      score_threshold: 1e-8
      iou_threshold: 0.6
      max_detections_per_class: 100
      max_total_detections: 100
    }
  }

```

```

        score_converter: SIGMOID
    }
}
}

train_config: {
  fine_tune_checkpoint_version: V2
  fine_tune_checkpoint: "ssd_mobilenet_v2_fpnlite_320x320_coco17_tpu-
8/checkpoint/ckpt-0"
  fine_tune_checkpoint_type: "detection"
  batch_size: 16
  sync_replicas: true
  startup_delay_steps: 0
  replicas_to_aggregate: 8
  num_steps: 2000
  data_augmentation_options {
    random_horizontal_flip {
    }
  }
  data_augmentation_options {
    random_crop_image {
      min_object_covered: 0.0
      min_aspect_ratio: 0.75
      max_aspect_ratio: 3.0
      min_area: 0.75
      max_area: 1.0
      overlap_thresh: 0.0
    }
  }
  optimizer {
    momentum_optimizer: {
      learning_rate: {
        cosine_decay_learning_rate {
          learning_rate_base: .08
          total_steps: 2000
          warmup_learning_rate: .026666
          warmup_steps: 1000
        }
      }
      momentum_optimizer_value: 0.9
    }
    use_moving_average: false
  }
  max_number_of_boxes: 100
  unpad_groundtruth_tensors: false
}

```

```
train_input_reader: {
  label_map_path: "training/labelmap.pbtxt"
  tf_record_input_reader {
    input_path: "images/train.record"
  }
}

eval_config: {
  metrics_set: "coco_detection_metrics"
  use_moving_averages: false
}

eval_input_reader: {
  label_map_path: "training/labelmap.pbtxt"
  shuffle: false
  num_epochs: 1
  tf_record_input_reader {
    input_path: "images/test.record"
  }
}
```