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SandKBot: Prototype All-Terrain Vehicle for Beach Bottle and Can Collection

Abstract—The SandKBot project addresses beach pollution in Honduras, particularly in areas like Puerto Cortes and Omoa impacted by the Motagua River's trash flow, by developing a remote-controlled, all-terrain vehicle designed to collect nonbiodegradable waste such as cans and bottles. Optimized for sandy environments, SandKBot minimizes sand intake while efficiently gathering debris, aiming to reduce manual labor, enhance sustainability, and support environmental preservation through automation. Real-world testing at San Lorenzo beach demonstrated its ability to navigate stony and muddy terrain, though challenges included shovel deterioration (brittle acrylic) and 3D-printed component deformation at high temperatures (40°C), with optimal performance between 15°C and 30°C. Key features include a 5168.84 cm^3 shovel capacity, a 150-meter camera range, 5–10 second communication latency, and a 2-hour battery life (10 hours for the camera). The 4x4 tires provided excellent grip, and the vehicle successfully minimized sand buildup, operated steadily, and collected waste effectively, proving its utility in reducing beach pollution.

Index Terms—All-terrain robot, Beach pollution, Environmental sustainability, Waste collection

I. Introduction

The increasing accumulation of waste along the northwestern coasts of Honduras, and particularly in Puerto Cortes,´ represents a significant environmental challenge. The annual transfer of 600 to 700 tons of waste, mostly plastics, across the Motagua River from Guatemala to the Honduran Caribbean compromises the natural integrity and tourism value of these areas. The degradation of these plastics into microplastics results in pollution that not only harms marine life and infiltrates the food chain, but also projects a future where plastics could outnumber fish in our oceans by 2050. [1] [2] [3] [4] [5]

In the face of this situation, technological innovation offers a glimmer of hope: the development of a remotely operated beach cleaning vehicle. This robot, designed to navigate sandy terrain and collect debris efficiently, promises to be a scalable and practical solution to manual cleaning methods. The vehicle allows for more frequent and extensive cleanups, which could translate into a significant improvement in beach preservation. In addition, by minimizing the physical effort required for cleaning, it promotes more sustainable and effective coastal maintenance. This project not only aims to improve the beach cleaning process, but also seeks to be a catalyst for the adoption of technological solutions in waste management and the preservation of the marine environment. [6] [14] [7] [8] [9] [10]

II. Objectives

A. General Objective

- Design and build a remote-controlled vehicle that will be in charge of cleaning up waste such as plastics, glass bottles and some other non-degradable waste found on beaches.

B. Specific Objectives

- Identify and evaluate the most appropriate traction mechanisms that guarantee optimal mobility of the robot on beach terrain.
- To design and optimize the robot's shovel to pick up cans and bottles while minimizing sand accumulation and maintaining its durability.
- Determine the robot's operating parameters for effective and efficient operation on the beach.
- Analyze the impact of the robot on plastic waste reduction and collection efficiency on the beach.

III. State of the Art

In recent years, several specialized beach cleaning vehicles and robots have been developed, each with different approaches and technologies [11] [12] [13]. The most recent and relevant advances in this field are described below.

A. Design of an Autonomous Robot for the Cleaning of 100m x 40m Areas of Sand Beach [14]

This project focuses on the design of an autonomous robot capable of cleaning an area of 100m x 40m, collecting litter up to 10cm x 10cm x 4cm. The design includes mechanical and electrical subsystems, with energy consumption and cost estimates as seen in Fig.1. The VDI 222 methodology, a German standard for the design of technical products, ensures a structured development process. Azanedo concludes that his˜ robot can cover the area in 3.5 hours with an autonomy of 70 minutes per recharge. Although the cost of the robot exceeds USD 22,000, improvements such as the use of more advanced suspensions and an intercommunicated fleet of robots to cover larger areas are suggested.

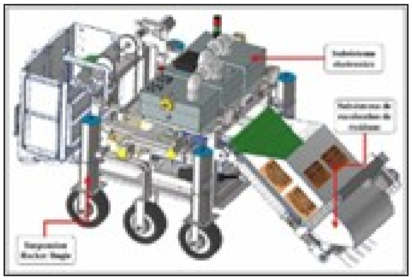

Fig. 1. Final design of the autonomous robot for cleaning of areas.

B. Design and Simulation of a Robot Solid Waste Collector Using Machine Vision on Pebble Beaches [15]

This robot, seen in Fig. 2, is designed to operate on pebble beaches in Lima and employs a YOLO-based machine vision system to detect plastic bottles up to 2 kg. Mejia uses a 6wheeled Rover model with a 4-degree-of-freedom Scara-type robotic arm for collection. The system includes solar panels that give it an autonomy of 3 hours. Simulations and tests confirmed the robot's ability to operate efficiently on uneven terrain and handle bottles with precision.

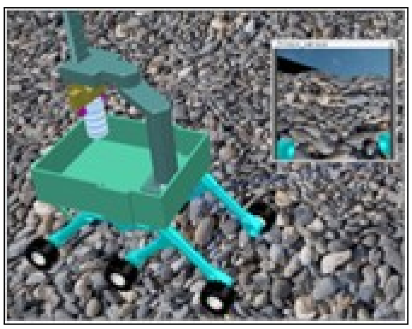

Fig. 2. Collection process

C. Development of a Mobile Robot with Artificial [16]

This mobile robot uses artificial intelligence algorithms to detect plastic bottles in real conditions, depicted in Fig. 3. Salinas designed a modular system with mechanical and electronic control subsystems integrated using an RCNN-based algorithm. The network was trained with images of beaches, achieving accurate recognition of bottles and people. Simulation tests demonstrated the robot's ability to avoid obstacles and recognize objects, optimizing its movement towards the waste.

D. Scarbat Sargassum Cleaner [17]

The Scarbat is a robust beach cleaner designed to operate on a variety of beach surfaces. It utilizes a screening system with a vibrating screen that separates debris from the sand, while a rear hopper allows for efficient discharge of the collected material. This vehicle is ideal for large beaches and offers efficient performance with a cleaning capacity of up to 2.5m³ per operation.

Fig. 3. Identification and recognition of plastic bottles using Artificial Intelligence

Fig. 4. Front roller, movable

E. DronyX Solarino Beach Sand Cleaning Robot [18]

The DronyX Solarino is a remotely operated, environmentally friendly robot designed to clean beaches using GEL batteries and solar panels. Its working capacity is 3000 m²/hour, with a maximum cleaning depth of 15 cm. It stands out as an efficient and environmentally friendly solution, suitable for both wet and dry beaches.

IV. Methodology

This investigation adopts a mixed approach, combining qualitative and quantitative methods. The qualitative aspect includes observational studies to better understand the current state of beach pollution and existing cleanup efforts. The quantitative aspect includes the collection and analysis of data on robot performance, such as debris collection efficiency, sand mobility and impact on beach cleanliness. This mixed approach ensures a thorough understanding of the problem and the effectiveness of the proposed solution.

A. Variables

1) Independent Variables:

- Traction mechanism: The choice of wheel and materials used to evaluate mobility on sand.

Fig. 5. Scarbat Cleaner

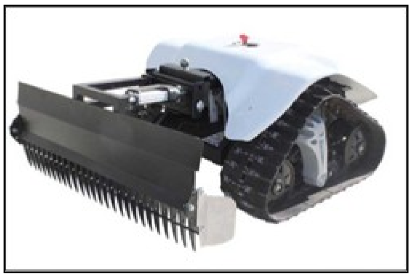

Fig. 6. Dronyx Salarino Robot Cleaner

- Shovel design: Changes in shovel design to improve debris collection and reduce sand accumulation.
- Operational parameters include robot speed, power consumption, and control settings.realistically.

2) Dependent Variables:

- Mobility on sand: Ability of the robot to move over sandy terrain without getting stuck.
- Impact on beach cleanliness: The reduction of debris found on the beach after the robot's operation.
- Durability: Lifetime for equipment, and the maintenance requirements of the robot components during and after field testing.

V. Results

Throughout the development and testing of the robot designed for waste collection on beaches, several tests were carried out to ensure its functionality and adaptability to different terrains, highlighting the tests both at the university and on the beach. The final assembly process was carried out by dividing the casing into several sections, using techniques such as laser cutting and 3D printing. Although the process was lengthy due to the complexity of the parts, it resulted in a functional and aesthetically pleasing structure. In addition, the use of a MS-1200 drone camera, with a range of 150 meters, allowed for extensive visualization and control of the vehicle during operation. Range tests were performed with the HC12 modules, which control the motor, achieving ranges similar to those of the camera. This ensures that the operator can remotely control the trash collection without losing efficiency. The final design can be seen in Fig.7.

Fig. 7. (a)Final Design

A. Vehicle Testing at the University

The first tests were conducted on university, including areas of the soccer field, slopes and varied inclines. These evaluations verified the all-terrain capability of the vehicle, confirming its viability for moving over complex surfaces. The robot demonstrated remarkable stability and mobility, suggesting that it could also adapt well to beach conditions. Although these tests did not fully replicate the actual working environment (the beach), they served to evaluate the strength of the chassis and wheel system, crucial to ensure operability on uneven surfaces.

Fig. 8. Vehicle being tested on the soccer field

B. Beach Testing

Once the basic functionality of the robot was confirmed at the university, tests were conducted on a beach with 81% of the casing completed. These tests were key in determining how the vehicle coped with more challenging conditions, such as sand, branches, coconuts and bottles, successfully overcoming all of these obstacles. One of the critical aspects evaluated was the robot's ability to avoid sand buildup on internal components. Comparing the condition of the parts before and after the tests, it was confirmed that there was no internal sand accumulation, even though the vehicle did not have a completely finished housing. This validated the protective design of the components, ensuring their durability under extreme

Fig. 9. POV from the vehicle's perspective

conditions. In addition, it was verified that the vehicle could cover large extensions of terrain without obstacles, which is essential to optimize its performance in open environments such as beaches. One factor to highlight is the large amount of garbage present on the Tela beach, which reaffirms the importance of the project in contributing to the cleanliness of these areas.

Fig. 10. Vehicle surrounded by obstacles in trials

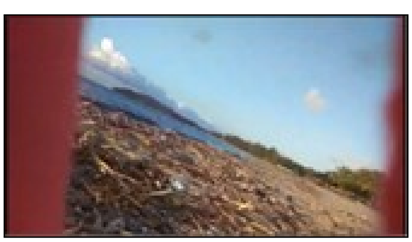

Fig. 11. POV of the vehicle overcoming several obstacles 1

C. Final Tests

The completed vehicle was tested on the beach of San Lorenzo, whose conditions differed significantly from those of Tela, as there were more rocks and dirt instead of fine sand. The robot managed to move smoothly, overcoming small obstacles such as rocks, and the shovel worked well in filtering the soil and sand mixture. However, the acrylic of the shovel, a material that had already suffered damage in previous tests, fractured again, highlighting the need to improve the strength of the material used. The tests also revealed an important temperature-related issue. Under the intense beach sun, some 3D printed parts deformed due to heat buildup, reaching surface temperatures of up to 40°C. This evidences the need to operate the robot in a safe temperature range, estimated between 15°C and 30°C, to avoid damage to components and reduce the loss of efficiency of batteries and motors.

Fig. 12. POV of the vehicle overcoming several obstacles 2

Fig. 13. Vehicle attempting to pick up a bottle

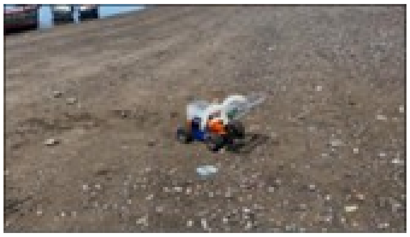

Fig. 14. Vehicle successfully picking up a bottle and carrying it

D. Final Vehicle Characteristics Overview

The vehicle, seen in Fig.15, has been designed with several key features to ensure efficient waste collection on sandy terrains. Below are the main characteristics:

- Battery Life: The NEMA motor operates for approximately 2 hours, while the camera can function for up to 10 hours on a single charge.
- Shovel Capacity: The shovel has a collection capacity of 5168.84 cm^3, allowing it to gather a substantial amount of waste in one go.
- Camera Range: The camera can transmit live footage from up to 150 meters away, offering a broad operational scope.
- Communication Delays: A delay of 5 to 10 seconds is experienced in communication with the NEMA motor, influenced by the distance between the vehicle and the controller.
- Operating Temperature: The vehicle operates optimally within a temperature range of 15°C to 30°C, ensuring reliable performance under these conditions.

Fig. 15. Final Vehicle Assembly

VI. Conclusions

The project focused on designing and constructing a remotecontrolled vehicle casing for efficient beach waste collection, particularly in sandy conditions. The main objectives included ensuring stability on sandy terrain, avoiding sand accumulation, and enhancing system performance by separating control and power components.

- 4x4 Tires: 4x4 tires were selected for their excellent traction and stability on sand, allowing the vehicle to overcome obstacles like branches and bottles.
- Shovel Design: The shovel design was optimized with a capacity of 5168.84 cm^3, minimizing sand accumulation and improving waste collection, aided by a mesh for sand filtration.
- Operational Tests: Tests demonstrated prolonged beach operation, with a 150-meter remote control range and effective maneuverability across various terrains.
- Beach Test Outcomes: Tests on beaches revealed a large amount of accumulated garbage, confirming the vehicle's potential as a valuable tool for collecting plastic waste and debris, thus mitigating beach pollution.

VII. Future Work

To further improve SandKBot's efficiency and adaptability, several enhancements are proposed for future iterations:To further improve SandKBot's efficiency and adaptability, several enhancements are proposed for future iterations:

- Single-Piece Housing: Use a larger 3D printer to avoid weak points from assembly.
- Second NEMA 23 Motor: Add a second motor to increase lifting power and stability.
- Larger Tires: Improve traction and mobility on sandy terrains.
- Motorized Camera: Enable a near 360-degree view for better environmental assessment.
- Infrared Sensor: Enhance night-time operation and object detection.
- Extended Communication Range: Improve control range without compromising data speed.
- Mobile App: Offer more control flexibility through a mobile interface.
- AI for Autonomy: Implement AI for self-navigation and autonomous cleaning.

11

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