Developmental Process and Application of an Eco-Friendly, Autonomous Beach-Cleaning Robot

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***Abstract*—Beaches are vital for the tourism sector of an area that is a significant portion of the economy, meaning pollution affects the economy by infecting the beach; many different sources have discussed the development of beach-cleaning robots, many of which are human-controlled. This is where an autonomous and eco-friendly beach-cleaning robot (ABCbot) differs from the competition, it has the power and capability to rid beaches of pollution by itself. It intends to drive automatically using GPS. The robot also is designed to utilize a LiDAR aimed at avoiding collisions with obstacles as well as proximity sensors and camera to further aid the detection and movement systems. This paper goes in depth on the process of creating a beach-cleaning robot that keeps the beach clean without the need for labor and to save the various costs that come with it.**

***Index Terms*—eco-friendly, autonomous, Computer Vision, GPS, ROS2**

I. Introduction

Trash that beach-goers throw away and has been washed up by natural disasters contribute to beach pollution [1]. Beach pollution is harmful to the wildlife that lives on the beach, the residents, tourists, and especially the beach itself. According to the research, implementing all feasible interventions that a human has the potential to contribute, approximately 710 million metric tons of plastic waste will occur and affect all ecosystems [2]. In addition, pieces of glass along the beach have a chance to hurt people and wildlife [3]. Trash also causes the reduction of tourists and makes around 85% of residents lose up to about 8.5 million dollars since picking up 15 pieces of trash per square meter is the equivalent of roughly 8.5 million dollars [4].

There are multiple different types of beach-cleaning machines that have been developed and implemented due to the limitation of the human ability to clean up beaches. Looking around at robots that are already on the market, many beach-cleaning machines are automatic robots; however, they are not completely automatic in the sense that it requires a human operator. Even though several studies have been conducted on automatic beach-cleaning robots, existing ones have a limited range of only twenty square meters utilizing a scanning range finder or they are remotely controlled via Bluetooth or autonomously driven following trash detected through a camera.

ABCbot automatically drives using GPS which means that it minimizes human interference and clears a wider range. Based on the aforementioned autonomous driving, ABCbot uses proximity sensors, 2D LIDAR, and a camera to avoid colliding with obstacles as well as remove litter. Furthermore, it utilizes renewable eco-friendly energy. During the day, sunlight supplies power through solar panels. If the solar panels is not available to supply as much desired power due to low insolation such as cloudy weather, then a wind turbine supplies power. In that case, it is assumed that the wind is utilized without intervention and there is minimal obstruction against the wind on a beach, i.e., a lack of buildings.

In this study, trashes are defined as anything from plastic straws to two-liter plastic bottles. Obstacles are defined as objects with sizes comparable to those of people. The objects include people and inanimate objects, which are easily observed on the beach, such as parasols, sunbeds, mats, and so on.

This research aims to create a robot clearing trash more efficiently than other automatic beach-cleaning robots. Due to the automation of the robot and its goal to clean up the beach, the proposed robot enhances the condition of the beach itself so that it improves the safety of visitors and protects marine life. In addition, as the robot uses eco-friendly energy consumption methods, it contributes to keeping the environment clean and minimizing pollution. Moreover, the idea of employing ABCbot instead of humans or other types of robots makes the beach cleaning process more efficient and cost-effective. After all, those expected effects mean that ABCbot is able to broaden the usage of robots in an environmentally friendly area.

II. Literature Review

A. The Different Types of Robots and Cleaning Methods

In recent years, multiple different types of beach-cleaning machines have been developed and implemented. They are categorized into three different types based on how they are controlled; (1) tractor-towed machines; (2) walk-behind machines; (3) remote-controlled machines.

The machines also are grouped into two categories based on how they pick the trash. The two categories are raking and screening. Raking involves picking up trash on the beach using rakes and turning them over continuously until a sufficient amount of trash is disposed of accordingly. Screening involves shoveling the sand initially and then proceeding to disintegrate the sand and the trash. Both methods of cleaning have their benefits. Raking is good for beaches that are concerned with erosion owing to the fact raking involves digging sand sparsely [5].

Screening is better for beaches with fine sand and beaches with small-sized trash or pollution covered with oil due to the filtration process of screening. For example, BARBER [6] and SCAM [7] were two sources that sold beach cleaner machines, which utilized raking and screening methods. BARBER and SCAM had tractor-towed and walk-behind products; however, they are currently not holding any remote-controlled models. 4Ocean [8] provided BeBot, which is a screening-based remote-controlled model. It used solar panels as the more eco-friendly method of energy consumption.

B. The Problem with Using Humans to Clean Up Beaches

The prominent limitation of current market beach-cleaning machines is the fact that they require human operators. When the operators are with the machines to control them, safety problems arise due to the proximity of the trash. In addition, cleaning costs are increased as a result of labor costs. Furthermore, considering cleaning is a repetitive task, operators might lose their concentration gradually, leading to a decline in performance and motivation. Therefore, to reduce the reliance on humans and make beach cleaning more effective, several studies have been conducted on self-sufficient beach cleaning robots.

C. Researches on Two Different Robots that Pick Up the Trash with a Repetitive Motion

A portion of studies described collecting the garbage on the beach as an autonomous operation. *Dhole et al.* [9] proposed the design of a beach-cleaning machine that collected wastes such as bottles, plastic, and cans. The machine utilized rakes attached to the lifter with a conveyor to pick up the trash. It could additionally be used for drainage. Two hoppers were used to separate pieces of trash through density differences. *Balasuthagar et al.* [10] designed and fabricated a beach waste collector machine operated via human power or electric motors. The design of machine shared similarities to the design of *Dhole et al.* [9]. The main difference between the two machines was that the method of *Balasuthagar et al.* [10] involved human-driven pushing power or a separate electronic motor charged via solar panels which in turn powers the conveyor movement system. In addition, the machine fitted within the rear of a car. Though these two sources handled a simple method that picked up the trash in a repetitive motion, an autonomous working machine works better than humans manually picking up the trash.

D. Papers of Remote-controlled Robots and How They Pick Up the Trash

Multiple researches attempted to develop a remote-controlled beach cleaning robot. Watanasophon and Ouitrakul [11] built a remote controllable garbage collector robot that works via Bluetooth. It collected different types of garbage such as glass bottles and plastics, as large as 12.5*49 cm using its sieve-like shovel. The installed IP camera on the robot was there so that the human operator was able to see through the robot's point of view. It was controlled remotely as far as 20 meters away, however, there was a delay time. The delay time varied with the distance between the robot and the operator. The robot used solar panels as a source of power while making sure to stay environmentally safe. *Bano et al.* [12] developed a radio-controlled beach cleaning robot. The robot was designed to collect small litter; for instance, plastic pieces, glass pieces, cans, cigarette butts, and so on. Therefore, it utilized a sieve and oscillatory motion to filter the sand. Its operator exploited radio waves via Bluetooth modules. It swept the beach and moved following the commands sent through radio signals. *Shelke et al.* [13] presented a remote-controlled robot operated by an android device via Bluetooth connection. It gathered plastic wrappers and bottles through the arm with rakes. It worked through three photo sensors that detected the size of obstacles or trash. In the case that one or two photo sensors out of three photo sensors placed on different heights sense an object, the object was considered the trash due to its size and caused the robot to pick up the trash accordingly. Otherwise, if all three sensors sensed an object, it was considered excessively large, to which the robot would deem the object as an obstacle and proceed to avoid it. Despite there still being a need for a human to be operating the machine, this method separated the human from the waste, minimizing any potentially dangerous outcomes. Nonetheless, there is always room for improvement and growth such as many technological advances.

E. Studies of the Different Ways Robots that Detect Trash

Several papers are written to create a robot that automatically detected the trash and tracked it. *Cieza et al.* [14] assembled a beach cleaner robot named "Esperanza Negra". It detected, navigated, and collected wastes via stereoscopic vision and object detection using a 3D camera and a bucket with holes. The scope of the study was quite small, as the robot only dealt with cans. *Apaza et al.* [15] developed a beach cleaner robot named "HS-GreenFist". The design of the robot was similar to the model of *Cieza et al.* [14], it only collected cans. It detected cans by calculating depth using cameras, segmenting objects through HSV, and detecting cans

through SVM. In the case it detected a can, it proceeded to scoop up the can with its arm. The arm itself was a single-body entity with a claw at the end. It was worth indicating that the robot practiced machine learning techniques instead of hard explicit rule-based classification. Additionally, the robot was equipped with a ramp that brings waste downhill when dumping. *Roza et al.* [16] created an autonomous beach cleaner that collected cans using its arm which was made up of an upper and lower claw that was likened to teeth. The machine detected cans and obstacles by processing RGB and HSV image channels obtained by a single camera. The robot used RGB and HSV range preset to segment the area of an object. Through this method, the robot detected cans that were partially buried. In addition, it was possible to calculate the position of objects via an optical flow algorithm. Nevertheless, it only detected moving obstacles due to its single camera. Though the robot used rule-based recognition when it scanned for cans, the vision system worked since that can recognition was a relatively simple task. There was an attempt that centered around focusing on object detection using several labels conducted by *Priya et al.* [17]. The robot utilized a conveyor belt with sharp spikes along the edges to pick up the trash scattered on the beach. In addition, the robot had a camera that detected and classified objects. When it found the trash, it scooped it up, otherwise, it moved forward. The object detection algorithm of the robot was Faster-RCNN trained with a database of debris images which assisted the collection system of the project. Object detection that used a deep learning model was a more advanced technique in comparison to explicit rule-based algorithms and SVM, as it classified different types of images. Furthermore, as data on the types of trash being picked up was sent to a database for analysis, this enabled people to recognize that the beach looks significantly cleaner. It was an appropriate decision in the research to adopt object detection into the beach cleaning robot.

F. Examination on a Specific Robot that is Completely Autonomous

All the robots suggested by *Cieza et al.* [14], *Apaza et al.* [15], *Roza et al.* [16], and *Priya et al.* [17] achieved detecting, following, and picking up the trash on the beach within the limited range. However, it is not possible to localize itself on the beach and develop its systematic path plan for the whole beach. Accordingly, they are semi-autonomous robots. *Ichimura and Nakajima* [18], [19] built a beach cleaning robot named "Hirottaro". The robot had been developed and redeveloped 3 times in the aspect of its trash collecting method; (1) forklift-bucket; (2) chain-conveyor system; (3) broom, dustpan. A broom and a dustpan were the final choices by the developers as this method was seen as being the most reliable on uneven terrain. The robot intermittently cleaned the surface of beach by repeatedly going forward and brooming alternately. It executed self-localization by scanning range finder and using two poles to define and to mark landmarks and work areas. The robot calculated its location within a 20m*20m rectangle. The robot was tested at the sandy beach and picked up cans and plastic bottles proficiently. In addition, the robot successfully used a systematic traveling strategy by defining subgoals in the work area to reduce errors and clean all ranges of work area. Nonetheless, its coverage was insufficient when dealing with a large area, since it required more than poles per 20m*20m. The paper mentioned that GPS is largely utilized as a self-location system for several robots, but they selected the scanning range finder owing to its simplicity. Hence, a robot that has a GPS demonstrates better performance in terms of coverage and effectiveness.

In conclusion, there have been copious amounts of research concerning the development of diverse beach cleaning robots that differ in cleaning methods, i.g., raking and screening method. However, most of them picked up the trash with simple repetitive motions or were remote-controlled by human operators or detected, followed, and picked up the trash without a sound a strategy that would consider the whole beach. There was one research that defined strategy of how to move and clean in the work area, but its coverage only worked within a 20m*20m area. Moreover, few of them considered clean energy like solar power. Furthermore, none of them considered any sea animals or organic debris. Multiple papers have discussed the capabilities of beach cleaning robots; however, there is still plenty of room for improvement. Consequently, this research aims to develop a beach-cleaning robot that makes up for the weaknesses of the existing robots such as partial automation, range limitation, and polluting energy.

III. METHODOLOGY

The methodology of this research starts with reviewing previous beach-cleaning robots and extracting the shortcomings from the existing robots. The primary problem of current beach-cleaning robots is that they need humans in order to function. Hence, this paper suggests the development of autonomous beach-cleaning robot. The dimensions of trash size as well as of beach area are defined prior to the goals of paper. Then the creating process of robot is sketched out into three parts. One of the sectors is centered around transportation, another deals with obstacle detection and the last one describes physical elements. The transportation portion contains brief obstacle detection, path deduction, and motor control. The detection portion covers computer vision. The physical component describes the platform and the use of eco-friendly power supply which means the utilization of solar panels and a wind turbine. When the three parts are individually built, the first two parts are assembled as they communicate with each other and then loaded onto the platform. Lastly, the robot is tested in two environments, an indoor and real-world outdoor environment. The tests aim to evaluate how accurately the robot drives itself and picks up the trashes that are defined within the paper. The next six paragraphs intend to describe the details of the process outlined in the aforementioned paragraph.

A. Definition of the trash and the beach

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