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

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***Abstract*—Beach pollution is an issue for coastal area economies due to the fact that pollution deters tourism; marine pollution is a problem in many coastal areas of the United States as it affects tourism and recreation which contributes approximately $124 billion in gross domestic product. To address this problem, many different sources have discussed the development of beach-cleaning robots, which are mostly 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 at the same time, saves the various costs that come with it.**

***Index Terms*—ROS2, LiDAR, autonomous, GPS tracking, eco-friendly**

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 plastic pollution 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 tourism and causes approximately 85% of residents to 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. 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.

ABCbot automatically drives using GPS which means that it minimizes human interference and clears a wider range. ABCbot drives autonomously; uses proximity sensors and a 2D LIDAR to avoid colliding with obstacles as well as remove litter. Furthermore, it utilizes renewable energy. During the day, sunlight supplies power through solar panels.

For this study, trash is defined as anything from plastic straws to two-liter plastic bottles. Obstacles are defined as objects with sizes comparable to humans. 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 that can clear 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. 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 eco-friendly area.

II. Literature Review

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, (2) walk-behind, and (3) remote-controlled.

The machines also are grouped into two categories based on how they clear the trash; raking and screening. Raking involves picking up trash and turning the rakes 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 as raking involves digging sand sparsely [5]. Henceforth, elaborate in detail from the next paragraph.

A. The Problem with Using Humans to Clean Up Beaches

The prominent limitation of current market beach-cleaning machines is 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 increase because of labor costs. Furthermore, since cleaning is a repetitive task, operators might lose their concentration gradually, leading to a decline in performance. Therefore, to reduce the reliance on humans and make beach cleaning more effective, several studies have been conducted on self-sufficient beach-cleaning robots.

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

Multiple researchers have 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 like glass bottles and pieces of plastic 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 which varied depending on distance between the robot and the operator. The robot used solar panels as a source of power to stay environmentally safe. *Bano et al.* [12] developed a radio-controlled beach cleaning robot, designed to collect small litter; for instance, plastic pieces, glass, cans, cigarette butts, etc. 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 robot operated by an android device via Bluetooth connection. It gathered plastic wrappers and bottles through arm rakes. It used three photo sensors, all placed at different heights, that detected the size of obstacles or trash. In the case that one or two photo sensors out of three, sensed an object, the object was deemed trash due to its size and had the robot pick up the trash accordingly. Otherwise, if all three sensors sensed an object, it was considered excessively large, deeming the object as an obstacle, causing the robot 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.

C. 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 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.

D. 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 a limited range. However, it is not possible to localize itself on the beach and develop a 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 the beach by repeatedly going forward and brooming alternately. It executed self-localization by scanning the range finder and using two poles to define and 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 a strategy by defining subgoals in the work area to reduce errors and clean all ranges of the 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.e., 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 strategy that considered 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 starts with reviewing previous beach-cleaning robots and extracting shortcomings from them. Then the creating process of robot is sketched out into three parts. One is centered around transportation, another deals with obstacle detection and the last describes physical elements. Finally, the robot is tested in two environments, an indoor and outdoor.

A. Definition of the Trash and the Beach

The proposed robot targets a specific scope of trash. The size of trash is between maximum 110*110*315 mm and minimum 6*6*200 mm. The robot aims to pick up plastic materials such as beverage bottles and straws since they make up a significant portion of beach litters [20]. The minimum size of trash is limited by straw size and the maximum size of trash is designated by the size of a two-liter plastic bottle.

The robot covers a predefined range of an area by following GPS coordinates. It focuses on the section of the beach with a surface area.

B. The Architecture of ABCbot

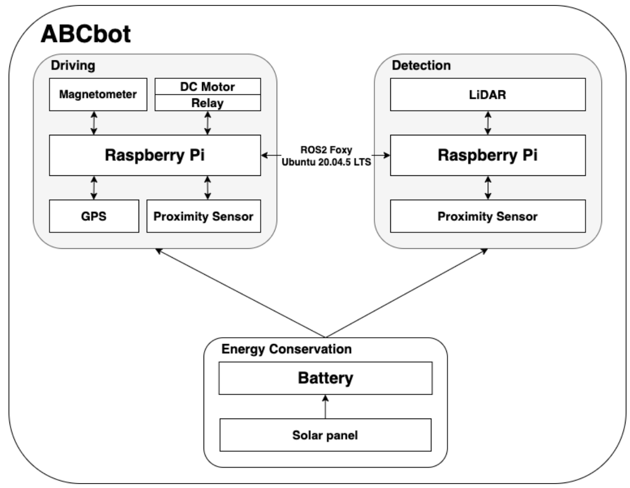

Fig. 1. Physical Structure of ABCbot

ABCbot consists of two control units; the driving unit and the detection unit. By dividing functions, the task of calculating becomes more straightforward and the ability to operate efficiently becomes achievable.

Basically, the driving unit takes charge of running two motors for the wheels and one motor for the broom. Utilizing a broom proves to be the most advantageous compared to other methods due to its ability to run continuously and sweep over an extensive area, exposing trash hidden under the sand. Two driving motors allow ABCbot to move along a path defined by multiple GPS coordinates, which is defined as subgoals. In scenarios that require movement flexibility on a path such as facing an obstacle, the driving unit has the ability to sense obstructions using its proximity sensor and avoid them. However, the detection unit improves the adaptivity of the robot as it provides more detailed and accurate information about the surroundings. The detection part utilizes a camera, a LiDAR, and a proximity sensor simultaneously and communicates with the driving unit via ROS2 Foxy [21]. The entire machine is powered by batteries which are charged via solar panels and a wind turbine.

C. GPS Path Planning

GPS is ideal for establishing the path on the beach due to the following three reasons; (1) GPS provides landmarks of a broad range which are required for larger areas such as beaches; (2) GPS is the easier method for indicating the absolute location even with beaches having vague borders; (3) GPS performs well on open plots of land like beaches owing to the fact that the rarity of distractions to satellites. Therefore, ABCbot utilizes a GPS-based navigating method. The robot receives a group of GPS coordinates and establishes the set as the beach-cleaning route, next it tracks the coordinates one by one sequentially. ABCbot calculates the bearing of the subgoal from the current location, adjusts its heading by bearing, and reaches the subgoal. After arriving at the point, ABCbot then repeats the search for the next subgoal. A decision on whether the robot reaches its target location or not depends on the distance between the robot and the target location.

D. Vision of ABCbot

For safe driving in real-time, it is essential for the robot to avoid obstacles. On the beach, obstacles can be anything from humans to beach chairs to umbrellas. 2D LiDAR and a proximity sensor are responsible for returning to scanning points of the obstacles. The range of 2D LiDAR is a full 360 degrees, which is more efficient to detect objects than a proximity sensor. Furthermore, it is cheaper in terms of price and faster compared to 3D LiDAR.

However, ABCbot manipulates with 2D LiDAR, which causes hazard detection depends on the location of LiDAR, and it is difficult to accurately distinguish between garbage and obstacles. To remedy this, the proximity sensor is connected to an raspberry pi to improve detection accuracy.

Fig. 2. Detection Unit Structure

E. Communication

Since the robot needs to execute every sensor, robot operating system (ROS) is implemented as the networking system. ROS works in a similar fashion to an operating system in a computer, but ROS works within the context of a robot. Considering ABCbot needs real-time processing, version 2 is the more viable option.

IV. Implementation

The implementation portion of this paper goes in depth on how ABCbot operates. Specifically by describing the physical components of the system initially. The next part of the implementation involves elaborating on the driving, detection, and communication systems. Lastly, the criteria for testing is defined.

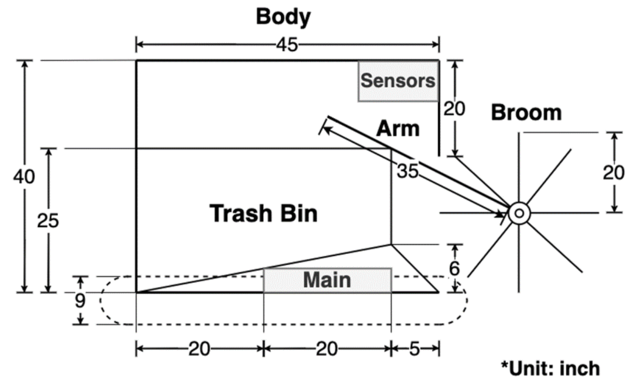

Fig. 3. Side View of ABCbot

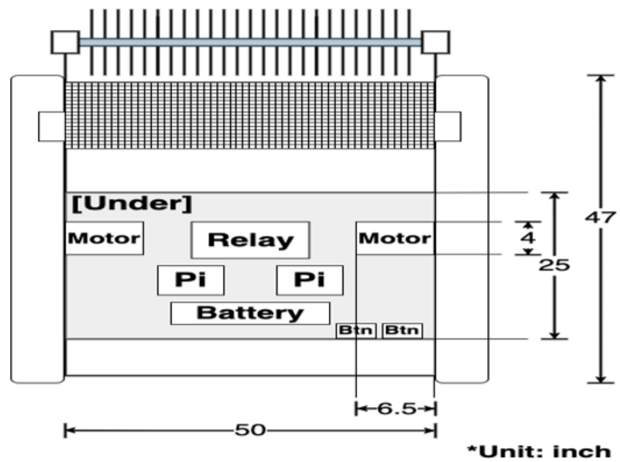

Fig. 4. Top View of ABCbot

A. Physical Elements

Base platform of ABCbot is a rectangular box that has room for waste unloading; there is a door at the rear for removing trash from the storage. At the bottom, the ramp makes space for the control units, batteries, relays, and wheel motors. Each motor is connected to a caterpillar wheel. Since the caterpillar wheel has a large area of contact with the ground, it balances securely on the beach. On top of the platform, curved solar panels cover the upper and side surfaces. In front of the robot, there is a LiDAR and proximity sensors located on the upper front side for obstacle detection. The broom consists of blades of following two different types; a soft blade and hard blade. While the blades sweep the trash; the sand goes through the sieve on the ramp before the trash reaches the bin. There is a core bar at the middle of the broom which rotates continuously at (*fill in speeds*) due to the motor which is located at the end of the shaft. Each edge of the core bar is attached to the side section of the robot adjacent to the robot arms.

B. Driving

Let a point *P* represented by GPS coordinate system, while *P = (latitude, longitude)* and where both latitude and longitude

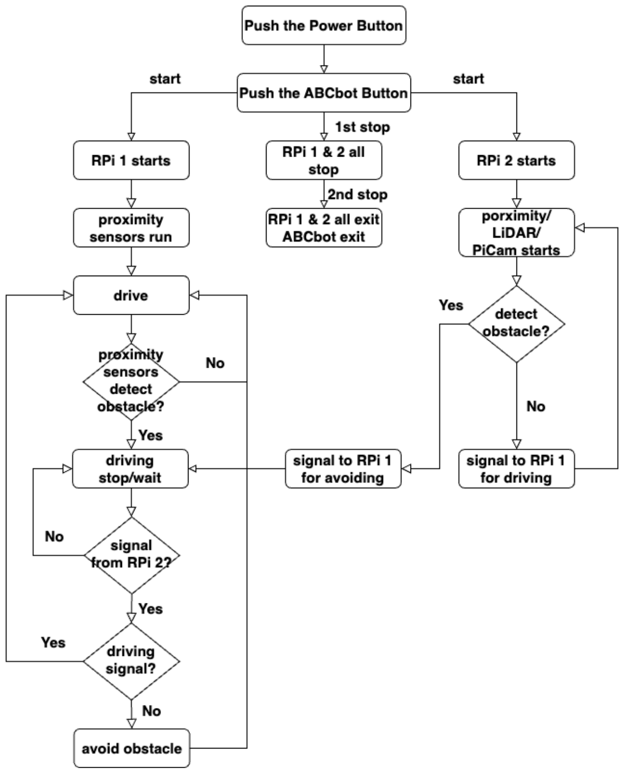

Fig. 5. Control Flow

are represented by the radian. When the current location coordinate *S = (*ϕ_1*,* λ_1*)* and the subgoal coordinate *D = (*$\phi 2$*,* λ_2*)*, bearing β is calculated as follows [22]:

$$\begin{aligned} N &= (0, 0, 1) \\ S &= (cos\phi_1, 0, sin\phi_1) \\ D &= (cos\phi_2 * cos\Delta\lambda, cos\phi_2 * sin\Delta\lambda, sin\phi_2) \end{aligned} \quad (1)$$

In the assumption that the earth is the unit sphere whose north pole is on the z-axis, (1) denotes north pole coordinate N, the current location coordinate S, and the subgoal coordinate D in the Cartesian coordinate system. In addition, the bearing β is represented as $\angle NSD$ which is the acute angle between $Plane\ NSD$ and $Plane\ OSD$.

$$Y = \quad (2)$$

equation (2) description

$$\beta = arctan(\frac{cos\phi 2 * sin\Delta\lambda}{sin\phi 1 * cos\phi 2 * cos\Delta\lambda - cos\phi 1 * sin\phi 2}) \quad (3)$$

equation (3) description
distance formula Will be added

C. Detection Algorithm

The object detection algorithm is based on a voting method. There are two sensors involved; 2D LIDAR, proximity sensor, and camera respectively. Initially, 2D LIDAR uses a 120-degree field of range to scan an area in front of the robot, this is divided into three sectors. If one sector, which detects near obstacles, is higher than the other sectors, then the proximity sensor is executed for accuracy. Next off, real-time object detection results are being received from a node that is implemented through YOLOv7 using Pi Camera. If the total results verify the object as an obstacle, a warning message appears. The warning message has three variations, each being related to the affected side of the robot; left, front, or right.

D. Communication

On top of communication, there is a workspace named ros2_ws which has two packages and one interface file used for custom messages. As has seen on the ABCbot architecture section, there is a motor package and an obstacles_detection package which represent the driving unit and detection unit, respectively. In order to initiate a build type, ament_python is used for the packages and all the nodes are written in python. The obstacles_detect_node package collects information from the camera_node which provides detection results by using YOLO v7. In turn, the motor_subscriber node gets information from the obstacles_detect_node and utilizes said information to control the direction of wheels. If the motor_subscriber_node receives an alert to stop from the obstacles_detect_node, the motor will stop. The other direction works in the same way.

When it comes to GPS, it slightly differs from the mechanics of ros2_ws. There is a workspace named path_ws which has a path_package. The path_package collects information such as subgoals from the GPS and saves it as a path_info file.

E. Criteria of Test

This part will be changed for software part. Process of Refactoring or other added software part will be added.

V. Conclusion

The premise of ABCbot is to clean beaches autonomously using eco-friendly energy, which seemingly has not been done before. After hours of researching existing beach cleaning robots, the vision for ABCbot was finalized. Programming the robot was done through a multitude of programs and devices, mainly centering around the technology of the Raspberry Pi. Creating the machine itself involved acquiring different materials as well as 3D printing off other materials, all of which came together in the building process. Now, based off of the number of tests conducted on indoor and outdoor surfaces, the machine proved to . . . (this is where I would put the results of the tests taken on ABCbot). Considering the test results of the robot, it is concluded that ABCbot has the potential to play a part within the future of using beach cleaning robots. Since ABCbot is autonomous, future developers are also able to utilize the same technology to make machines self-sufficient. Surely the creation of ABCbot benefits the environment and the economy by efficiently cleaning up pollution that lies on the beach; if not by its own accord, then definitely by inspiring future robots that are tasked with cleaning natural landscapes.

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