Autonomous Garbage-Collecting Robot For Beaches With Deep Learning Approach and Improved Cleaning Technique

Kong Ke Long
School of Engineering
Asia Pacific University of Technology and Innovation (APU)
Kuala Lumpur, Malaysia
tp041899@mail.apu. edu.my

Chandrasekharan Nataraj
School of Engineering
Asia Pacific University of Technology and Innovation (APU)
Kuala Lumpur, Malaysia
Chandrasekharan@staffemail.apu.edu.my

Yvette Shaan-Li Susiapan
School of Engineering
Asia Pacific University of Technology and Innovation (APU)
Kuala Lumpur, Malaysia
dr.shaan@staffemail.apu.edu.my

***Abstract*— This research is to develop autonomous garbage collecting robot deep learning approach and improved cleaning technique. In the proposed methodology, the system can distinguish between the garbage and non-garbage items by the technology of CNN which is one of the deep learning approaches. By using pi camera, the system can obtain raw images of surrounding and undergo the process of image recognition and feature extraction with help of TensorFlow to perform object detection. Based on the bounding box surrounding the object, the system is obtaining the box's coordinate and performing the ability of object tracking by detecting the object's position and motor controlling for position adjustment. The cleaning technique implemented in the system is using a series of rotary blades for sweeping the garbage toward a mesh-net platform for collecting mechanism. If the storage compartment is full, the movable gate will be opened for disposing of the garbage inside. By these, the robot can imitate human behavior of detecting, distinguishing, and collecting garbage.**

Keywords*— Autonomous garbage collecting robot, deep learning, improved cleaning technique, GUI.

I. Introduction

The purpose of this research mainly is to reduce the problems of plastic waste and other garbage deposition at beaches. This work intends to find the intelligent system that performs automatic detection and collection of items that has been considered as garbage on beaches by a pre-trained system. Besides, the battery used was rechargeable Li-ion batteries and charged by solar panel installed on the robot. Hence, solar charging and rechargeable batteries are said to be eco-friendly since no deposit is used batteries that cause environmental issues. In past research, the model designed is mostly in the form of the machine means no involvement of detection system, sensing system and wireless communication. Furthermore, it was connected and pulled by a tractor moving around the beach for garbage collection. Next, most of them are not involved in image processing or other related techniques for item detection and classification. However, some of the ideas that past researchers had involved such as raking or sifting techniques were able to be used for improving the system in the research. The ideas of machine or deep learning for detecting and classifying items, solar power for batteries charging approach and combining of raking and sifting beach cleaning techniques were able to construct autonomous garbage collecting robots. This could allow to ease the cleaning works at the beaches especially after the events that are organized at beaches. The events organized were for attracting beach-goers to come to the beach but the garbage could also be seen anywhere after the event. Therefore, the use of garbage collecting robots was able to reduce the time, cost, and efforts spent on cleaning beaches and also maintain the beauty of beaches. The Internet of Things (IoT) is a concept in which surrounding objects are connected (Haziq et al., 2022; Izni Binti Zainudin et al., 2022; Kalilani et al., 2021; Moneer Rasheed et al., 2021; Murugiah et al., 2021; Singh et al., 2021) and with the ongoing advances of the IoT technology in our day-to-day lives, there appears to be no shortage of the potential applications for IoT in the cleaning industry.

II. Literature Review

The problem of deposition of waste at beaches is nowadays becoming more serious. The human effort, cost, and time spent on cleaning beaches can be said to be a waste since the speed of depositing waste somewhere are always faster than the garbage cleaning process (J. Bai et al., 2018). Therefore, to increase the efficiency of beach cleaning, a beach cleaning machine is designed and existed currently in the market. The beach cleaning machine is pulled by a vehicle or pushed by human efforts and move over the beach sand to remove the rubbish and debris and other foreign.

The beach cleaning machine that is dragged by vehicle over the sand beach is also known as beach cleaner or Sandboni, back-formation-referencing from ice-surfacing machine (Y. Bai et al., 2015). The use of beach cleaning machines is common in seaside cities for combating the problem of garbage or litter left by the beach patrons or washed up to the beach by other pollutions (Dhole et al., 2008). The working principle of a beach cleaning machine is to collect the sand by way of scooping or dragging mechanism, then raking or sifting out anything large enough to be considered a foreign matter. With beach cleaners, municipalities and resorts could clean up their beaches with fewer invested hours, especially after natural disasters. There are three common beach cleaning technologies involved in these machines, raking, sifting, and combining of both (Cruz et al., 2020). On a dry or wet sand bed, raking technology is a technology that is suitable to be used. There is a rotating conveyor system with hundreds of tines combs on its belt.

During its operation, these tines combs are passing through sand and removing, lifting the garbage from the surface or even buried in sand bed at the same time the sand collected were left on the beach. Besides, if the sand beaches are in dry condition and soft surfaces, sifting or screening technology can be used as a method applied for beach cleaning (Zielinski et al., 2019).

There is 2 pick-up blade allocated on the vehicle for collecting the sand and waste (Calle et al., 2020). By using different sizes of screens, the sand and waste collected are then transferred onto a vibrating screening belt to leave the sand behind. Furthermore, the garbage or waste left on the screening belt is then transferred into the storage compartment allocated at the back of the vehicle. It was able to combine both cleaning techniques with the use of rotating tine to scoop up and collect sand and garbage onto a vibrating screen other than that of relying simply on a pic-up blade. There is a benefit in adjusting rotating tines for guiding different-sized materials onto the screen efficiently. After the materials collected are passed onto the screen, the machines with combined technique use similar technology with common sifters to separate the garbage collected from sand (M.Bhavani et al., 20 C.E.).

According to A. Sengupta et al. (2019), the existing autonomous garbage collection system has a high manufacturing cost but negligible maintenance costs. One of the issues raised in this study is the global focus on garbage generation. Furthermore, improper waste and garbage management is the root cause of several impediments (Sengupta et al., 2019). It also stated a major problem of cleanliness of unwanted waste or garbage that may pose a threat to human health and the environment in the surrounding area (Gourav, et al., 2017). The research proposed a method for designing and modeling an automatic garbage collector to solve the problem. Using a microcontroller and Bluetooth technology, the robot was designed to clean up unwanted items or garbage in the home or office (Gourav et al., 2017).

The researchers proposed that manual garbage collection and cleaning be replaced by an autonomous robot. Despite a lack of recognition ability in the related field, developing an autonomous cleaning robot that operates on grass has remained a difficult task. As a result, the study proposed a deep learning robot for automatic garbage collection on grass. The same type of research revealed that the traditional method of manual sand sieving consumed a significant amount of time, money, and human labor. Extra funds are required for a specific size or category of sand sieving (Roza et al., 2016). The researcher P. R. Gajbhive, et al., (2019) had proposed a design and fabrication of an automatic drive sieving machine to replace the traditional method. There was another research had explained a machine to minimize the problem of wastage in rivers, lakes, and sea. The problem had the potential to cause water pollution that had direct effects on aquatic animals and human life (Gajbhiye et al., 2019).

The researcher (Arun. A et al., 2018)had proposed a design and fabrication of a beach cleaning machine. The machine was placed across beaches and sea to ensure only beach sand passed through machine's basement. Another research had also explained the problem of waste deposition in the world. The amount of plastic waste deposited on beaches was more than that in urban places. This caused land pollution and harm to the environment and humans. In this research, Arun A. et al.(Kumar et al., 2018) had proposed garbage collector on beaches using solar power. The limitation found in this research was that the machine-designed robot is not autonomous hence still requiring human power major involved. Besides, the machine was unable to differentiate between garbage and non-garbage on beaches and obstacle avoidance.

Amit K. Y. et al.(Yogesh Malhotra, 2018) had proposed Eco beach cleaner. With comprising a standard form of track laying tractor, the machine was mounted a conveyor belt having plurality sets of rakes extending around the belt, one side of the belt being swingable to engage with beach surface for the rakes to pick up garbage deposited on beach effectively. This work was produced to solve the trash and litter left on beaches that could cause danger to coastal animals' life and also damage tourism industries by diminishing the natural beauty of beaches.

Also, there was a problem with the insufficient power supply to the system since the solar energy supply rate was not greater than the usage rate. Hence, the research had proposed a modular beach cleaner robot. It is highlighted the major consequence of cleaning waste chemicals causing respiratory disease to the worker due to the derbies of waste from houses, factories, commercial places. Therefore, mechanization became important in sewage disposal from industries.

The results of object detection for shape- and motion-based classification was having moderate accuracy while the accuracy of texture-based classification was high. However, the computational time required for texture-based classification was high and this was the same as motion-based classification even it had lower accuracy of 21 compared with texture-based. It was required low computational time only for shape-based classification. It also proposed the system had stated that the proposing of technology for transferring image taken from real-world, removing its background details and keeping image only. It also stated the essential use of vision systems in mobile robot building which will complete certain assigned tasks such as navigation, surveillance, and explosive ordnance disposal (F B Sayyad, 2019).

In a summary, the machine or 'robot' designed were said not to be autonomous since the system was unable to differentiate between garbage and non-garbage item even though involving a sensing system. The most suitable way for garbage detection was image recognition. This technique was able to pre-train the system with pre-fed images and match them with captured images to determine the items is whether considered garbage and this was similar to obstacle avoidance. The recommended way was Convolutional Neural Network (CNN), a class of deep neural networks most commonly used to analyze visual imagery. It also observed that most of the existing work was just designed a storage compartment for garbage collected and be located at either on top or back of the robot. However, it was still requiring the human operator to take out the compartment manually to empty the garbage collected.

To achieve autonomously, auto-garbage disposing system should be developed for depositing garbage in a fully occupied compartment. With the reason of eco-friendly system, some researchers had proposed solar power system for their proposed garbage cleaner. However, the rate of power consumption in the system was always greater than the charging rate of batteries. Hence, a possible improvement in solar power system was providing with switching use of two different energy packs, one will be undercharging while another was supplying to the system.

III. Proposed System and Its Operations

Fig.1 shows the block diagram of entire system for the autonomous garbage colleting robot. Firstly, there was a pack of lithium-ion batteries that took placed as power supply to the system. Each of the batteries provided about 3.7 V hence three batteries were connected in series to achieve the purpose of supplying voltage of 11.1V to ensure the entire system was working in desired condition. Furthermore, the battery pack was able to be charged either by solar power or electricity. To be charged with solar power, there was a solar panel installed to the robot hence the charging process could be taken place during the movement of robot.

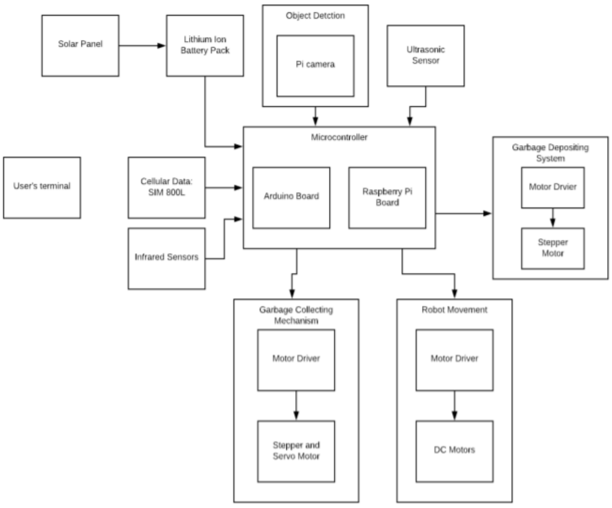

Fig. 1. General block diagram

In terms of object detection, there was a pi camera installed. The pi camera was able to obtain the view from surrounding and undergoing CNN and image processing by the program in Raspberry Pi board to classify the target object as either garbage or not. The views gathered from pi camera were said as the trigger for the robot's movement. When the camera was detected garbage, the system would operate 61 DC motors to move toward the target and move into the next step of collecting. When the robot was stopped in front of garbage, the collecting mechanism was started to operate. There were two stepper motors which one for lowering the meshed-net platform for preparing to transfer the collected object while other motor for controlling the spinning of the rotary blade to push the garbage toward the platform.

When the garbage was on the platform, it was detected by an IR sensor. The sensor would then send the signal to the Arduino Mega board for raising up the platform. The raising of the platform was causing an inclined surface and hence the object on top would slide down toward the garbage collecting compartment allocated at the back of the robot. There was an ultrasonic sensor allocated on top of the compartment for detecting the height of garbage inside. When the garbage collected in the compartment had reached a certain height, the ultrasonic sensor was sending a signal to the Arduino board to operate the third stepper motor for opening the gate of the compartment to depose the garbage. When the garbage was below the specified height, there would have a delay time for the stepper motor to close the gate. To achieve the objective of wireless communication, a SIM808 module was used to build up a cellular data transferring. This would allow the user to acquire the current condition of the robot such as its location, process ongoing from the user's terminal anytime, anywhere. All the information would be updated on the GUI designed for monitoring the garbage collecting process of the robot.

A. Constructional Details

Fig. 2 displays an overall wiring diagram of the autonomous garbage collecting robot. On the power charging part, the system was able to be charged by electricity or solar power. As shown in the Figure above, a solar charging system was built up with solar panels and batteries that connected to a solar charge controller to perform solar charging. When exposed to sunlight, solar power was generated from the solar panel and therefore charging the batteries through the solar charge controller. The output of the solar charge controller was connected to a 4-channel relay as a power supply.

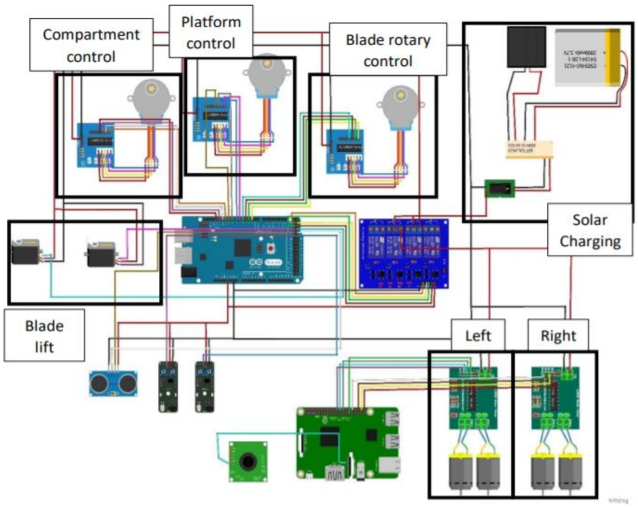

Fig. 2. Constructional diagram

There were 6 pins on the input side of the relay that should be connected to Arduino Mega which were VCC, GND, IN1, IN2, IN3 and IN4. The pins of VCC and GND were connected to 5V and GND pins respectively on Arduino Mega. The pin IN1 of the relay was connected to a digital pin, D22 while IN2 to D23, IN3 to D24 and IN4 toD25. On the output side of the relay, the common pin of the second channel of the relay was connected to the positive output terminal of the solar charge controller while pin of normally close, NC was connected to the positive terminals of L298N motor drivers. The common pin of the third channel of the relay was connected as the connection of the second channel but the output of NC was connected to positive terminals of servo and stepper motors. The negative terminals of motors and motor drivers were connected to the negative output terminal of the solar charge controller while the pins of motor drivers were also connected to the GND pin on Arduino Mega. There were three sensors, two IR sensors and one ultrasonic sensor used in the system. The VCC and GND pins of two IR sensors and ultrasonic sensors were connected to the VCC and GND pins on the Arduino Mega board. Next, the analog pin on the first IR sensor was connected to a digital pin, D on Arduino Mega while the second IR sensor's analog pin was connected to D. Besides, there were two pins, Trigger and Echo pins on ultrasonic sensor required to be connected for interfacing it with Arduino Mega. The Trigger pin was connected to D while Echo pin was connected to D.

There were three stepper motors used in this system. The first stepper motor was used to control the rotation of the rotary blade designed for raking and collecting garbage. The stepper motor was connected to driver board ULN2003 and there were 4 input pins on the board that needed to be connected to Arduino Mega board. The wiring of the stepper motor was connected as pin IN1 to digital pin D2, IN2 to D3, IN3 to D4 and IN4 to D5. Next, the second stepper motor was used to lift the meshed-net platform designed for transferring garbage collected to a compartment for storage. The connection of the second motor was IN1 to D6, IN2 to D7, IN3 to D8 and IN4 to D9. For the third stepper motor, it was used to control the opening or closing of the compartment when the garbage collected was fully occupied or vice versa. The stepper motor's connection was IN1 to D10, IN2 to D11, IN3 to D12 and IN4 to D13. All the VCC pins and GND pins of these stepper motors were connected to the output of the solar charge controller to have voltage supply from batteries. There was a pair of servo motors used in the system for controlling the lifting of the rotary blade. In the design, the rotary blades were supported by pair of blade holders 64 on one end while another end of holders was connected to servo motors located at left and right sides by couplings for raising or lowering the blade holder according to the condition. There were three pins, VCC, GND and pulse pin on each servo motor that needed to be connected. The pulse pin of the left servo motor was connected to the digital pin of D26 while the pin of the right servo motor was connected to D27. Besides, the pins of VCC and GND of both servo motors were connected to the output of the solar charge controller for the same reason as a connection of stepper motors.

For the connection of SIM808 module, its TXT pin was connected to while RXT pin connected to On the side of the raspberry pi board, the inputs pins on each L298N motor driver were connected to the GPIO pins on Raspberry pi 4B board. On the motor driver that controls the left side DC motor, its pin of IN1 was connected to, IN2 to, IN3 to and IN4 to. The pin of IN1 on the motor driver controlling the right side DC motor was connected to while IN2 to, IN3 to and IN4 to. The Pi camera has connected to a 2-lane MIPI CSI camera port on the Raspberry Pi board. On the output side of the motor driver, there were four DC motors connected to the corresponding terminals. On the left side motor driver, the first DC motor's positive terminal was connected to OUT1 while the negative terminal is connected to OUT2. It was followed with a connection of the second DC motor by connecting its positive and negative terminal to OUT3 and OUT4 respectively. On the right-side motor driver, there were also two DC motors connected by each positive terminal to OUT1 and OUT3 while their negative terminals were connected to OUT2 and OUT4 respectively.

IV. Performance Testing and Simulation Results

The overall performance of the developed system has been evaluated by conducting various simulations and relevant tests.

A. *Solar Charging Efficiency Test*

The solar charging efficiency test is a test that carried out to observe the voltage input received from solar panels and the voltage output from solar charge controller that is used for charging the batteries. The test was carried out under different light intensities. As shown in Fig. 3, it is a line graph that shows the difference of light intensity in different periods. The starting period was set to be started at 11:11. The reason for starting the testing at the period was it could be said that the energy conversion from solar energy to electrical energy. The electrical energy which in terms of DC energy was generated from the solar panel and then converted into usable AC energy with help of inverter technology. Hence, the intensity of sunlight is an important factor that affects the efficiency of output voltage from the system to use as energy for charging the LiPo battery.

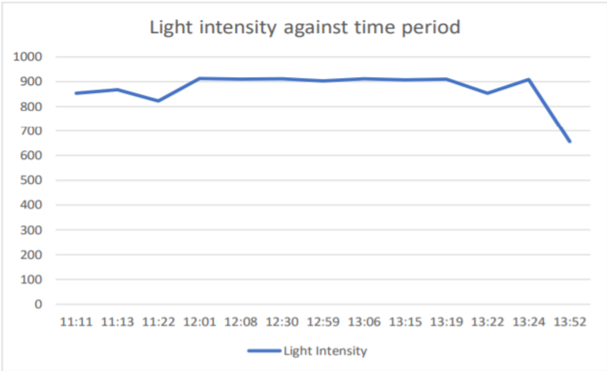

Fig. 3. Line graph of light intensity against time period

Thus, the testing time was started at 11:11 was due to the sunlight at this period being relatively stronger in the morning time and it was near to noontime. The line graph was showing a small fluctuation on light intensity. At the time of 11:22 am, it was a decrease in light intensity because the sun was covered by clouds and hence resulting in low light intensity to be recorded. As close to the noontime, the light intensity was observed to be increased to around 900 and this condition was continued until the time of 13:24. The time of 13:22 in between was having a decrease in light intensity with the reason of sun covered by cloud. Besides, during the time of 13:52, it was having a significant dropping in light intensity because the weather was turned into a windy day. The condition was continued and hence the testing was stopped at the time.

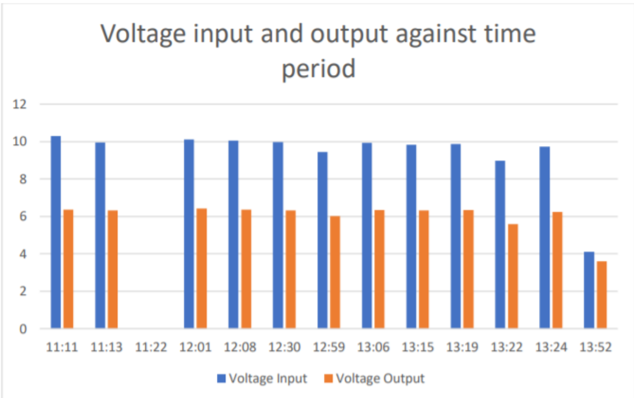

Fig. 4. Bar chart of voltage input and output against time period

As shown in Fig. 4, it was a bar chart for showing the effect of light intensity at the different period on the voltage input received from the solar panel and output voltage for charging the battery. At 11:11, the voltage input from the solar panel was 10.29V while the output voltage was 6.36. Next, the input voltage at 11:13 was 9.95V and the output voltage was 6.32V. At these two periods, there was a small difference of light intensity and hence resulting small change in input and output voltages. At the period of 11:22, there was no voltage input and output observed since the solar power at this light intensity of 822 was not sufficient for the solar panel to generate electrical energy.

However, at the period of 13:52, there was a large drop in input and output voltage with a value of 4.11V and 3.61V since the light intensity was dropped to 6.56V. This happened due to lesser sunlight.

B. *Object detection Accuracy test*

Object detection test was a test that carried out for observing and recording the percentage of confidence when the system was started to detect an object. Once the program started, the pi camera was started to obtain the view of the surroundings and interpret the images for differentiating whether the object was considered garbage or not. The test was using a bottle and Plastic bag as a sample to be detected by the system. Each test of a single sample was repeated for few times to obtain accurate results.

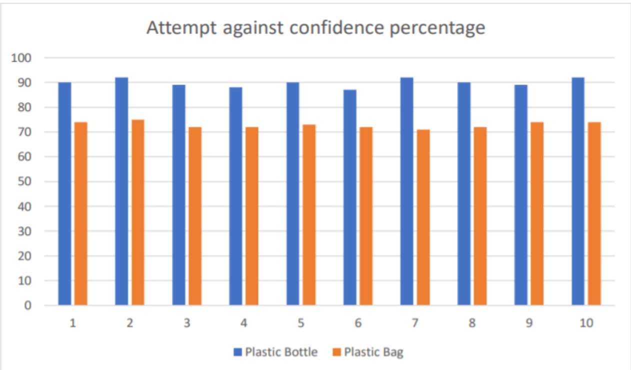

Fig. 5. Bar chart of attempt against confidence percentage

It was a bar chart that showed the results of confidence percentage for object detection as shown in Figure 5.3. The value was observed to have fluctuated between 71 to 75. The confidence percentage for detecting plastic bottle was 90%, 92%, 89%, 88%, 90%, 87%, 92%, 90%, 89% and 92% with first until 10th attempts respectively. For the confidence percentage for detecting plastic bag, it was started with percentage of 74%, 75%, 72%, 72%, 73%, 72%, 71%, 72%, 74% and 75% from first until 10th attempts respectively. As what could be observed from bar chart, the overall value fluctuation was controlled within the range of 1 to 2 value difference. Hence, it could be concluded that the object detection was stable during the detecting distinguishing of a sample.

C. *Location tracking*

The location tracking test was a test that was carried out for observing the accuracy of a GPS antenna located on the robot to show its current location. In this test, the GPS antenna was located at different locations and the values of latitude and longitude were recorded. After that, these set of values were compared with the values obtained from Google Maps for measuring its accuracy of location tracking ability.

The bar chart as shown in Fig. 6is about the actual and experimental latitude of different locations. The actual latitude of Vista Komanwel A on Google Map was 3.06030oN while the experimental latitude was 3.06015oN.

This was the same as the latitude of Endah Parade, APU, IMU and NSK Trade City with actual latitudes of 3.06330oN, 3.05330oN, 3.05970oN and 3.08520oN while their experimental latitudes were 3.06315oN, 3.05522oN, 3.05980oN and 3.08541oN respectively. The error percentage of these five locations were 0.004901%, 0.004897%, 0.002618%,0.003268% and 0.006807%. The error percentage in between was 0.004901%. All the errors were even less than 0.01% and these could show that the actual and experimental latitudes were in the same area but their pin-point latitudes were different.

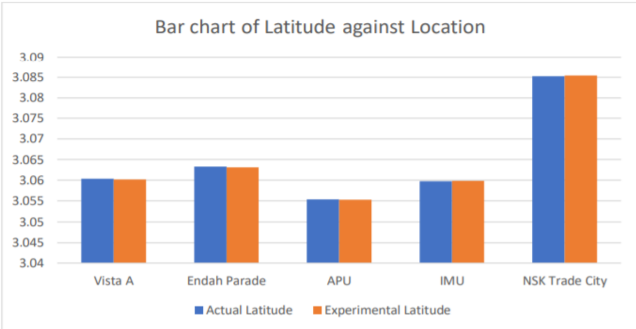

Fig. 6. Bar chart of latitude against location

D. *Robot movement efficiency test*

A motor movement efficiency test was a test carried out for testing the time required for the robot to move from one location to another location.

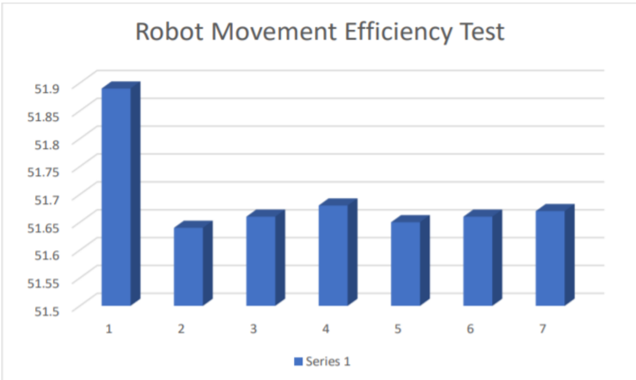

Fig. 7. Bar chart for robot movement efficiency test

The bar chart in the Fig. 7 shows the time required for robot moving from one location to another location with distance of one meter. In the first attempt, the time required for the robot to move was 51.89s. It was followed by 51.64s, 51.66s, 51.68s, 51.65s, 51.66s, and 51.67s for the second until the seventh attempt respectively. It was observed that the time required for the first attempt was the most among the seven attempts because the test preparation for the robot was not set up properly yet. After the warming up of the DC geared motor, it was seen that the time required for robot moving started from the second attempt had been reduced until 56.64s. The time required in the following attempts for the robot movement efficiency test was within 51.64s to 51.67s. There were slight changes in the second decimal of the time required due to the skidding of the track caterpillar. Even though there was skidding on robot movement, the time required from second to seventh attempts could say to be constant and hence the system was stable.

E. Discrepancy between the theoretical and experimental results

It was observed there is a difference between the actual and experimental values of latitude and longitude in the location tracking test. The actual latitude and longitude were obtained from the Google Map which was a common source for obtaining the values for latitude and longitude of a specific location. These location data could be obtained from the scanning of satellite or recorded by a professional tester. Besides, the experimental results for latitude and longitude were obtained by carrying the GPS module and going to the location physically. The values obtained from theoretical and experimental results were approximately the same but there was an offset in the distance if looking into the pin-point location. For example, the results obtained from the source of Google map could be pinpointed at any point in the area such as the guardhouse, main gate, one of the building blocks as long as the location was within the area.

On the other hand, a tester who carried a GPS module was going to the specific location and this may most probably be based on his or her favorite of choice. By this, the latitude and longitude for the results was having offset in distance with that obtained from Google map in terms of pinpoint location.

V. Conclusion

An autonomous garbage collecting robot deep learning approach and improved cleaning techniques are designed and developed. The system can distinguish between the garbage and non-garbage items by the technology of CNN which is one of the deep learning approaches. The cleaning technique has been implemented using a series of rotary blades for sweeping the garbage toward the mesh-net platform for the collecting mechanism. If the storage compartment is full, the movable gate will be opened for disposing of the garbage inside. By these, the robot can imitate human behavior of detecting, distinguishing, and collecting garbage.

References

Arun. A, Nagasankar.P, Amirthalingam. P, Barath kumar. E, Janarthanan. G, & Magesh. AS. (2018). Design and Fabrication of Garbage Collector on the Beach Using Solar Power. In *International Journal of Engineering & Technology* (Vol. 7). www.sciencepubco.com/index.php/IJET

Bai, J., Lian, S., Liu, Z., Wang, K., & Liu, D. (2018). Deep Learning Based Robot for Automatically Picking Up Garbage on the Grass. *IEEE Transactions on Consumer Electronics*, *64*(3), 382–389. https://doi.org/10.1109/TCE.2018.2859629

Bai, Y., Yin, J., Yuan, Y., Guo, Y., & Song, D. (2015). An innovative system for promoting cleaner production: mandatory cleaner production audits in China. *Journal of Cleaner Production*, *108*, 883–890. https://doi.org/https://doi.org/10.1016/j.jclepro.2015.07.107

Calle, M. A. G., Salmi, M., Mazzariol, L. M., & Kujala, P. (2020). Miniature reproduction of raking tests on marine structure: Similarity technique and experiment. *Engineering Structures*, *212*, 110527. https://doi.org/https://doi.org/10.1016/j.engstruct.2020.110527

Cruz, C. J., Muñoz-Perez, J. J., Carrasco-Braganza, M. I., Poullet, P., Lopez-Garcia, P., Contreras, A., & Silva, R. (2020). Beach cleaning costs. *Ocean & Coastal Management*, *188*, 105118. https://doi.org/https://doi.org/10.1016/j.ocecoaman.2020.105118

Dhole, V., Doke, O., Kakade, A., Teradale, S., & Patil, R. (2008). DESIGN AND FABRICATION OF BEACH CLEANING MACHINE. *International Research Journal of Engineering and Technology*. www.irjet.net

F B Sayyad. (2019). Design and Development of Beach Cleaning Machine. *International Journal for Research in Applied Science and Engineering Technology*, *7*(6), 1943–1948.

Gajbhiye, P. R., Khode, R., Sukhadeve, P., & Chaple, V. (2019). DESIGN AND FABRICATION OF AUTOMATICALLY DRIVEN SAND SIEVING MACHINE. *Journal of Emerging Technologies and Innovative Research (JETIR)*, , *6*(5), 396–405. www.jetir.org

Gourav, S., Singh, A., Singh, B., Singh, J., Singh, H., & KC, H. (2017). Designing and Modeling of Automatic Garbage Collector. In *International Journal of Scientific Research in Science and Technology* (Vol. 3, Issue 7, pp. 458–465). https://doi.org/10.13140/RG.2.2.27402.16329

Haziq, M. I., Binti, I. M., Noor, M., & Abdulla, R. (2022). Smart IoT-based security system for residence. In *Journal of Applied Technology and Innovation* (Vol. 6, Issue 1).

Izni Binti Zainudin, Z., Yee San, L., & Abdulla, R. (2022). Smart hand sanitizer dispenser. In *Journal of Applied Technology and Innovation* (Vol. 6, Issue 1).

Kalilani, M., Shyan Lai, N., & Abdulla, R. (2021). IOT based neonatal incubator for the developing world and conflict zones. In *Journal of Applied Technology and Innovation* (Vol. 5, Issue 4).

Kumar, A., Singh, A., Murtaza, M., & Singh, A. (2018). Eco Beach Cleaner. *International Journal of Engineering and Management Research*, *8*(3), 1–4. https://doi.org/10.13140/RG.2.2.24262.11846

M.Bhavani, S.Kalaiselvan, S.Jagan, & S.Gopinath. (20 C.E.). Semi Automated Wireless Beach Cleaning Robot Vehicle. *International Journal of Recent Technology and Engineering (IJRTE)*, *8*(1S2), 108–110.

Moneer Rasheed, W., Abdulla, R., & Yee San, L. (2021). Manhole cover monitoring system over IOT. In *Journal of Applied Technology and Innovation* (Vol. 5, Issue 3).

Murugiah, K. van, Subhashini, G., & Abdulla, R. (2021). Wearable IOT based Malaysian sign language recognition and text translation system. In *Journal of Applied Technology and Innovation* (Vol. 5, Issue 4).

Roza, F., Silva, V., Pereira, P., & Bertol, D. (2016). Modular robot used as a beach cleaner. *Ingeniare. Revista Chilena de Ingeniería*, *24*, 643–653. https://doi.org/10.4067/S0718-33052016000400009

Sengupta, A., Varma, V., Kiran, M. S., Johari, A., & Marimuthu, R. (2019). Cost-Effective Autonomous Garbage Collecting Robot System using IoT and Sensor Fusion. *International Journal of Innovative Technology and Exploring Engineering*.

Singh, H., Abdulla, R., & Selvaperumal, S. K. (2021). Carbon monoxide detection using IoT. In *Journal of Applied Technology and Innovation* (Vol. 5, Issue 3).

Yogesh Malhotra. (2018). AI, Machine Learning & Deep Learning Risk Management & Controls Beyond Deep Learning and Generative Adversarial Networks. *SSRN Electronic Journal*.

Zielinski, S., Botero, C. M., & Yanes, A. (2019). To clean or not to clean? A critical review of beach cleaning methods and impacts. *Marine Pollution Bulletin*, *139*, 390–401. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.12.027