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DETECTION AND COLLECTION OF WASTE USING A PARTIALLY SUBMERGED AQUATIC ROBOT

BY

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ABSTRACT

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Title: Detection and Collection of Waste Using a Partially Submerged Aquatic Robot

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With the amount of waste being dispersed into oceans on the rise, mitigating this issue has become a global concern. In the past few decades, governments, scientists, organizations, and individuals have been attempting to attenuate the effects of global warming, partially caused by improper waste disposal into oceans. This study presents a solar powered partially submerged aquatic robot constructed from recycled, recyclable, upcycled, and sustainable materials. The robot aims to provide flexibility in the choice of construction materials by not being limited to what operating system, microcontroller, motors, and robot floaters are used. This robot detects and collects 7 different categories of commonly littered waste namely cardboard (95.3%), wrappers (94.1%), metal cans (93.8%), surgical face masks (93.2%), plastic bags (96.2%), polystyrene (92.6%), and plastic bottles (93.8%). The custom detection system was evaluated based on whether it is capable of detecting waste and how well if little, medium, and high movement was introduced to the robot. Furthermore, the detection system's performance in low light situations along with the drivetrain's effectiveness were tested. Future improvements include forming larger dataset, enhancing the detection system's low light capabilities, and attaching a larger battery.

DEDICATION

To my family and friends.

Thank you for your love, support, and prayers.

ACKNOWLEDGMENTS

Alhamdulillah for he who granted me patience, strength, and commitment to accomplish my thesis.

I would like to express my sincere gratitude to Dr. Uvais Qidwai, my supervisor, for his constant guidance, round-the-clock availability, and enthusiasm. Your unbelievable encouragement and feedback sparked innovation and passion.

"My Lord, increase me in knowledge." [20:114]

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LIST OF ACRONYMS

YOLO	You Only Look Once
YOLOv3	You Only Look Once version 3
R-CNN	Regions with Convolutional Neural Networks
SSD	Single Shot Detector
CPU	Central Processing Unit
GPU	Graphics Processing Unit
CUDA	Compute Unified Device Architecture
IOU	Intersection Over Union
mAP	mean Average Precision
e-waste	electronic waste
FPS	Frames Per Second
PWM	Pulse Width Modulation
JPEG	Joint Photographic Experts Group

CHAPTER 1: INTRODUCTION

Due to rising environmental pollution concerns, it is vital that effective solutions are formed to address and mitigate this issue [1]. Environmental pollution is simply the introduction of harmful materials and substances into an environment [2]. There are three main categories of environmental pollution namely, air pollution, land pollution, and water pollution [3]. Air pollutants have devastating negative effects on organisms as they degrade the quality of the earth’s air. It is estimated that air pollution result in the death of seven million individuals yearly [4]. Smog and soot are the most common culprits for air pollution and are mainly produced through burning fossil fuels [5]. Land pollution is the second main category of environmental pollution and is mainly caused by high-energy demanding processes such as agriculture, mining, and deforestation. These activities introduce harmful materials, such as lead and metal sulphides, into the soil making it unusable [6]. Consequently, the health and lives of approximately 3.2 billion individuals are at risk [7]. Finally, the last category of environmental pollution is water pollution. Water pollution is the contamination of water sources making them unfit for consumption and usage by their beneficiary [8]. Water pollution can be categorised into anthropogenic, caused by humans, and non-anthropogenic, caused by natural events [9]. Furthermore, water sources can be classified into surface water, such as oceans, rivers, and lakes [10], and groundwater, such as wells and springs [11]. Surface water contaminants range from waste chemicals, such as petrochemicals, to common landfill waste, such as plastic bottles, plastic bags, cans, and more [12].

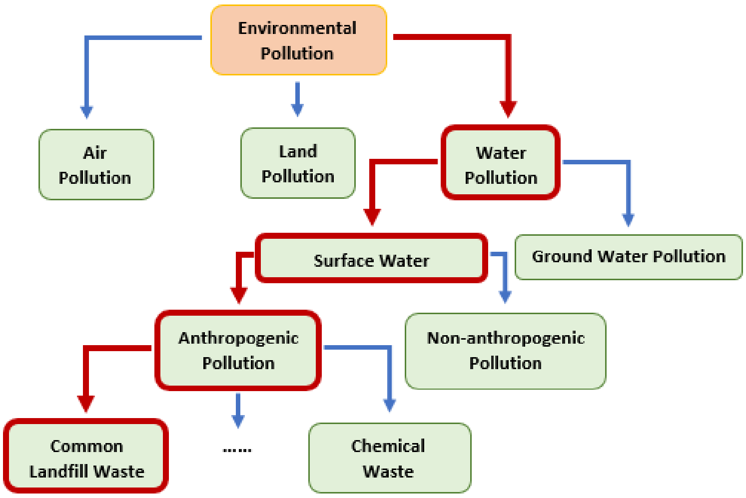

Figure 1. Environmental pollution categories.

This thesis focuses on tackling the problem of commonly littered anthropogenic environmental pollutants in surface water. More specifically, this project proposes a sustainable, eco-friendly, and partially submerged autonomous aquatic craft that detects and collects commonly found waste categories namely, (1) plastics; plastic bottles, plastic bags, packaging wrappers, polystyrene, and surgical facemasks, (2) metal cans, such as beverage containers and food tins, and (3) cardboard, mainly laminated cardboard. As for the first main category, plastics, 4.98 billion tonnes of plastic have ended up in landfills since the 1960's [13]. 14 million tonnes of plastic are dispersed into natural bodies of water yearly [14]. The introduction of plastic waste into bodies of water may occur by littering, flushing them down drains, or by falling off waste management ships during their transportation to landfills [15]. Furthermore, due to the Coronavirus disease 2019 (COVID-19), production of facemasks has increased leading to them being more commonly found in bodies of water [16]. All this plastic waste dumping has led to the alarming issue of microplastics, which their effects are still being investigated by scientists and researchers. Microplastics are simply tiny pieces of plastic, smaller than five millimetres in size, that are harming the environment [17] and are usually formed when a larger piece of plastic fragments into smaller ones

[18]. Due to their small nature, microplastics have been found in soil [19], food [20], oceans [21], and even in human placentas [22]. Metal cans are the second main category of waste that this aquatic robot detects and collects. Cans are usually made from Aluminium, Tin, and stainless steel [23]. These metal cans may corrode, generally by forming metal oxides [24], which may have devastating effects on the quality of water. These effects include manipulating the PH levels, of the body of water, which negatively affects beneficial algae present [25]. Cardboard is the third and final main category of waste that the proposed robot detects and collects. Cardboard is common way to package goods. The issue with cardboard packaging is not the cardboard itself but rather the glue, plastic lining, and ink that are on it [26].

Another issue this thesis addresses is electronic waste (e-waste). E-waste is simply any device with electrical components that uses an energy source to work [27]. They include home appliances, computers, mobile phones, and construction equipment. This thesis contributes in combating this issue by recycling and repurposing electronics to give them a new purpose rather than having them end up in landfills. To understand why e-waste is an issue, it is estimated that 57.4 million tonnes of e-waste was discarded in 2021 [28].

Halting the effects of global warming is critical to our well-being and existence. In the last 100 years, the earth's average surface temperature has risen by 0.9 degrees Celsius [29]. This has led to glaciers shrinking, trees flowering sooner, higher intensity heat waves, and rapid increase in coral reef diseases [30] [31].

1.1 Problem Statement

Acting now to address environmental pollution is a must in order to conserve the well-being of living and non-living organisms on our planet. Furthermore, protecting and cleaning the environment results in better living conditions for future generations to come. Through innovative techniques, what is considered as waste for some, can be upcycled or recycled into sustainable and eco-friendly products that are as effective as their polluting counterparts. One instance of these techniques is the proposed solution in this thesis. This thesis addresses common landfill anthropogenic environmental pollutants found floating on the surface of bodies of water. This is done by constructing an autonomous partially submerged aquatic robot which detects and collects these pollutants. The robot itself is completely constructed out of recyclable, recycled, upcycled, and sustainable materials and aims to spark a trend of saving the planet using the exact materials that are harming it. By constructing and testing the proposed system, this thesis aims to answer the following research question:

(1) How can this autonomous robot contribute to the global efforts of cleaning-up bodies of water? And how effective is it?
(2) How much of this robot’s construction is recyclable, recycled, upcycled, or sustainable?
(3) How flexible is this robot’s design and what are some possible different configurations? How can the robot’s design be adjusted according to a region’s common waste categories and available electronics?
(4) With respect to cost and manufacture time, how viable are eco-friendly and sustainable solutions?

1.2 Thesis Objectives

With the aforementioned in mind, this thesis presents designs and schematics of an autonomous, partially submerged, eco-friendly, and sustainable aquatic robot that can detect and collect commonly littered landfill waste. This robot will typically operate on beaches of seas, rivers, and lakes where garbage is usually washed-up. This is possible through a combination of cameras, computation devices, and actuators. A custom object detection system is trained to identify the different categories of waste and their location. The custom detector uses You Only Look Once version 3 (YOLOv3) object detection and feeds its findings into a microcontroller which then actuates and controls the driving motors. The entire system operates on electrical energy and is capable of charging its batteries using the on-board solar panel. This thesis aims to accomplish the following:

(1) Develop and train a custom object detection system, using YOLOv3, which can identify selected types of commonly littered waste through a common webcam.
(2) Design an efficient and optimized drivetrain, power source, and energy generation system for the robot and have it built using commonly found sustainable materials.
(3) Design and construct a stable partially submerged watercraft hull, from recyclable, recycled, upcycled, and sustainable materials, that is suitable for the environment and conditions it will be deployed in.
(4) Interface and optimize the robot’s different systems to interact and function together in harmony.
(5) Discuss multiple design options that may be suitable for different regions of the world and their commonly found waste. This design flexibility aspect aims to demonstrate the versatility of the proposed solution.
(6) Motivate organizations, institutes, and researchers to investigate and construct more eco-friendly and sustainable environmental-pollution clean-up solutions.

1.3 Thesis Contribution

This thesis contributes to global environmental clean-up efforts by constructing the proposed autonomous system. More specifically, this thesis contributes through accomplishing the following:

(1) Building a custom litter object detection system, with the help of YOLOv3. The constructed object detection system is cross platform further adding to its flexibility. Furthermore, the detection system provides the ability to fairly easily add or remove a waste category.

(2) Present and construct a drivetrain, including the energy source and its charging, for the aquatic robot. The drivetrain is completely constructed from recycled, recyclable, upcycled, and sustainable materials. Multiple possible configurations will be discussed according to a specific region's availability of parts.

(3) Build a stable, robust, and efficient hull, while suggesting possible alterations and configurations, that are suitable for the environment and conditions the robot will be deployed in.

(4) Demonstrate the system's flexibility and modularity. This contribution aims to show how the presented solution can be altered to fit specific needs. This includes changes object detection system and the different classes that may be added or removed, changes to the drivetrain and different suggestions for the motors' configurations, and how the construction of the hull may be done through different techniques and materials.

(5) Provide a framework which will hopefully motivate researchers, institutes, and organizations to develop eco-friendly and sustainable solutions similar to the one presented in this thesis.

1.4 Thesis Outline

The remainder of this thesis will be presented in the following order:

Chapter 2: Background and related work

Chapter 3: Requirements analysis

Chapter 4: Solution design

Chapter 5: Implementation

Chapter 6: Testing and evaluation

Chapter 7: Conclusion and future work

CHAPTER 2: BACKGROUND AND RELATED WORK

It is critical to discuss ideas related to the proposed solution in the form of some background concepts and related work. This provides and further clarifies the purpose of this robots and what knowledge gaps it tackles in the field of service robots.

2.1 Background

First, object detection. Recently, with the rise in popularity of artificial intelligence, more sophisticated, high performing, customizable techniques have become more accessible to researchers and developers [32]. Some commonly utilized object detection techniques include Faster Regions with Convolutional Neural Networks (Faster R-CNN), Single Shot Detector (SSD), and You Only Look Once (YOLO). Many studies suggested YOLO’s superior performance over other commonly used object detection techniques. This superiority comes in terms of and is not limited to the accuracy and speed of detection [33] [34].

2.1.1 YOLO [35][36][37]

YOLO is a real-time object detection system based on Darknet. Darknet is an open-source neural network framework that is compatible with both CPU and GPU. Darknet is written in both C and in Compute Unified Device Architecture (CUDA) languages.

Shown in Figure 2, YOLO works by dividing an image into equal squares of dimensions S×S. Each square detects the contents within itself forming a class probability map. On the other hand, numerous bounding boxes are drawn on the input image. Bounding boxes outline the object in an image and each bounding box has a height, width, class, and box centre. Both the class probability map and the bounding boxes techniques are used together for the final detection. One approach used in making the final detection is Intersection Over Union (IOU) which observes the overlap of boxes and determines if the detected grids make up the entire object or not. If yes, then the final detection is that box else, it expands the final detection box to fit the entire object.

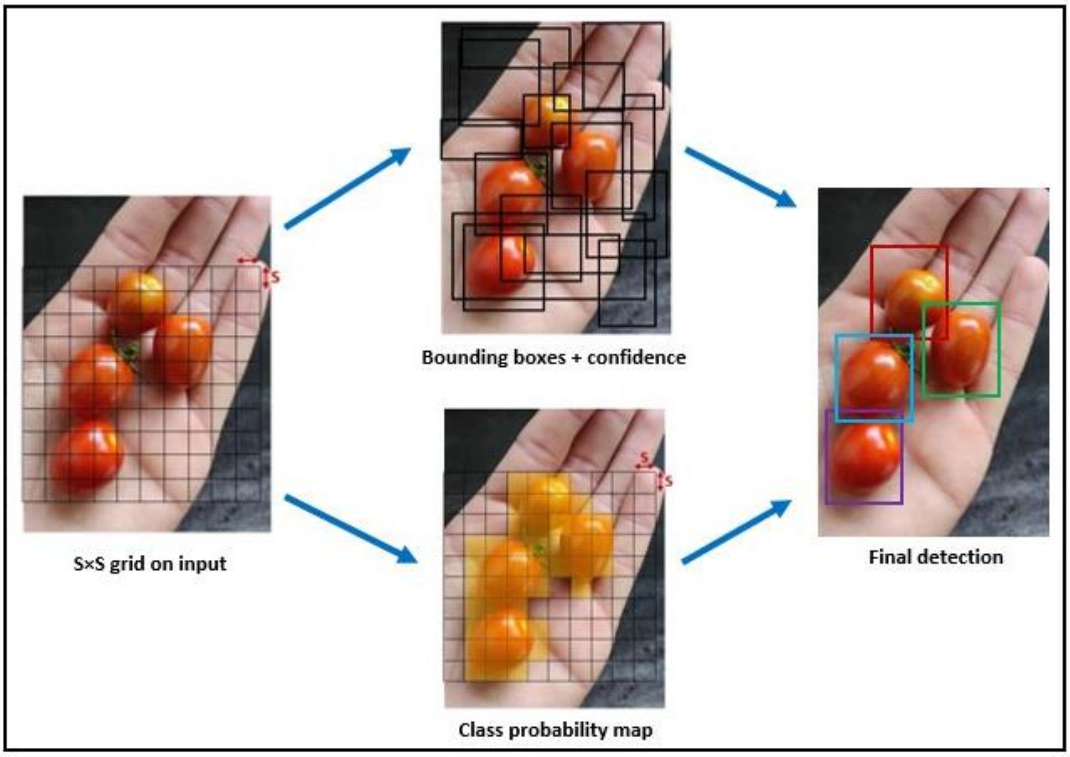

Figure 2. How YOLO works.

YOLOv3 is an improved version of YOLOv1 and YOLOv2. It is comprised of a bigger neural network but a faster one as it manages a detection speed and a mean Average Precision (mAP) of 22ms and 28.2, respectively, for an image resolution of 320×320. Due to the nature of this robot, the ease of replication for manufacturing is a main requirement. YOLOv3 has been published since 2018 and there is a plethora of online resources for system troubleshooting and modification, when compared to YOLOv4 and YOLOv5. YOLOv3 provides a balance between the ease of finding information and not being outdated.

2.1.2 Marine drivetrains

Due to the nature of this thesis, this project utilizes electric motors. In order to relay the findings of the custom object detection system to the drivetrain, a proper understanding of how marine crafts are controlled is need. More specifically, a dual motor setup will be discussed as that's what is utilized in this project. In terms of navigating the proposed craft, it either move forwards, backwards, left, or right. The following descriptions are given assuming they watercraft is viewed from behind:

(1) Forwards motion: The left hand propeller rotates clockwise while the right hand propeller rotates counter-clockwise.

(2) Left motion: Both the left and right hand propellers rotate counter clockwise.

(3) Right motion: Both the left and right hand propellers rotate clock-wise.

2.1.3 Buoyancy:

In order for the craft to float and successfully function, the density of different bodies of water and the proper buoyancy ratings of different materials need to be understood. As this robot will be employed in either fresh water or sea water, both cases need to be considered. Fresh water and sea water have an approximate density of 1000 kg/m^3 and 1036 kg/m^3 respectively [38][39]. With the aforementioned in mind, the net buoyant force for a cylindrical object is calculated as follows:

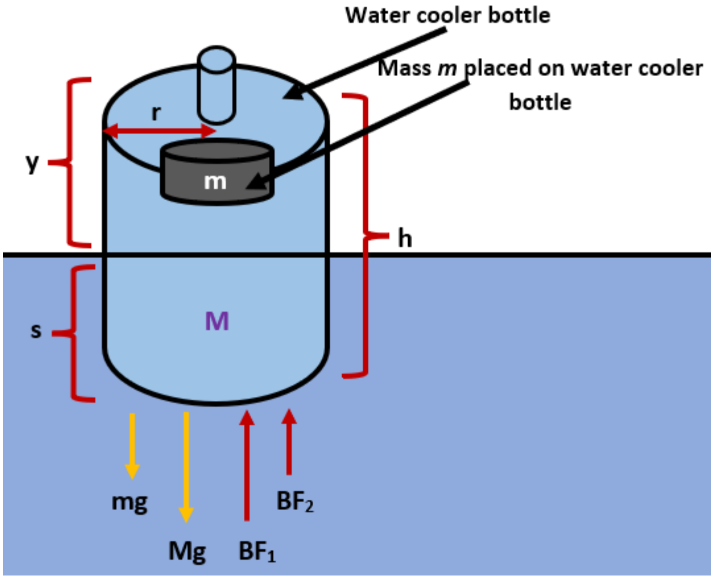

Figure 3. Maximum external mass limit calculation.

If ***M*** is the mass of the cylinder, ***m*** is an external mass that is exerted on the cylinder. ***h*** is the height of the cylinder, ***y*** is the height of the portion of the cylinder that is above the surface of the water, and ***s*** is the height of the portion of the cylinder that is below the surface of the water. ***r*** refers to the radius of the cylinder. ***BF_1*** is the buoyancy force that opposes the weight of the cylinder, ***BF2*** is the buoyancy force that opposes the weight of the external mass, and ***g*** is the acceleration due to gravity. Note that the mass ***$Mg=BF_1$*** and ***g***=9.81m/s^2.

The equation to calculate the maximum external force that can be placed on the floating cylinder is calculated as follows:

$$Weight\ of\ external\ mass = Weight\ of\ additional\ liquid\ displaced$$

$$mg = BF_2$$

$$mg = mass_{Region\ above\ the\ surface} \times g$$

Since Mass = Density × Volume, ***$mass_{\text{Region above the surface}}$*** can be rewritten as follows:

$$mg = (\rho_{liquid} \times \Delta V) \times g \qquad (1)$$

Where $\boldsymbol{\rho_{liquid}}$ is the density of water and $\boldsymbol{\Delta V}$ is the volume of the region below the surface of the water. Assuming that the floater is a cylinder, the volume of the region below the surface of the water can be written as:

$$\Delta V = \pi r^2 s \qquad (2)$$

Now by substituting equation (2) in (1):

$$mg = (\rho_{liquid} \times (\pi r^2 s)) \times g$$

The ***g*** from the left-hand side cancels with the ***g*** on the right-hand side giving us the following equation:

$$m = \rho_{liquid} \times (\pi r^2 s) \qquad (3)$$

2.1.4 Gargoor قرقور

In an effort to use sustainable material and support local businesses, this project uses a ‘Gargoor’ fishing net. Gargoor nets are handmade dome shapes nets made from galvanized steel wires and their diameter ranges from 0.50m to approximately 5.00m. The Gargoor net usually has a minimum of one trap that is large at its opening and gets narrower the more you go in. The nets are specifically designed for seawater use; therefore, they are very durable. These nets are infamous in the Arabian gulf and are strongly linked to the identity of the people in the region. A Gargoor net can be seen in Figure 4.

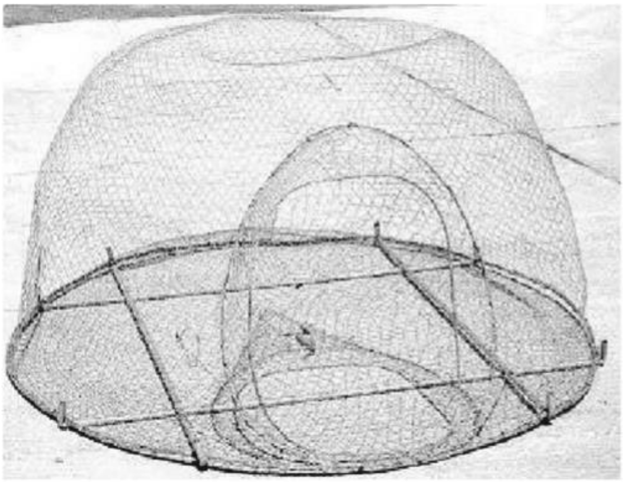

Figure 4. Gargoor fishing net [40].

2.2 Related work

Understanding and analysing previous attempts is crucial to fulfilling knowledge gaps present in any field. This section discusses work, achieved by other researchers, that is related to every component of this proposed solution. This is then followed by a comparison which will highlight the novelty of this attempt. Firstly, when discussing waste collection robots, study [41] proposes a relatively tiny partially submerged robot that has a conveyer belt shape. Their attempt weighs 10Kgs and managed to clean a 0.3m^2 area while consuming 45W of power. An observation made on their design is that no waste detection software was used but rather a mobile application that the user controls the robot from. Furthermore, with such a small area cleaned, this robot may arguably be considered inefficient and redundant. In [42], a water cleaning and surveying robot is proposed. The study's robot is made to follow a predetermined path, of size 1.0Km×0.5Km, and constantly senses the surface of the water using an ultrasonic sensor. Water temperature, humidity, and conductivity data is constantly read by the robot and sent through a Node MCU to the cloud. The waste collection mechanism utilizes a conveyer belt mechanism, similar to study [41]. The criticism of study [42] comes mainly through the choice of sensor as it is unclear how such a combination can detect pollution in a body of water. Paper [43] presents a pontoon shaped robot that cleans the surface of the water via a motor controlled robotic arm. The presented robot, which can carry up to 16Kgs of waste, is remote controlled and has no kind of waste detection system instead, human supervision over the robot is required.

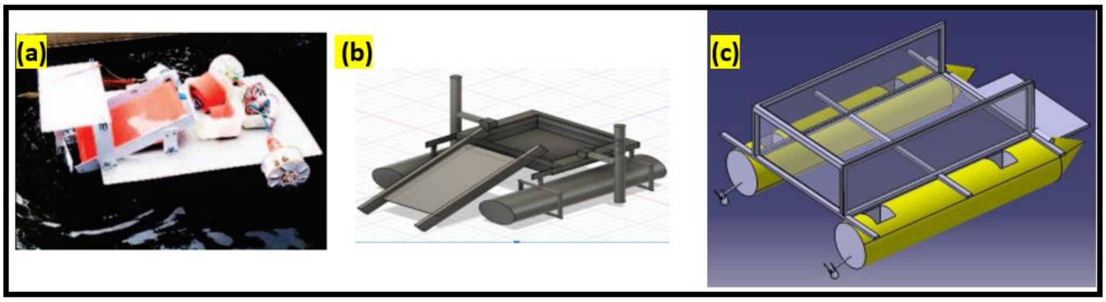

Figure 5. Displays the attempts of (a) study [41], (b) study [42], and (c) study [43].

The user controlled earthbound robot in [44] can generate its own power through the help of a 40W solar panel. The robot with its bulldozer-like tracks and shovel collects waste and stores it in an on-board box. Controlling the robot is done with the help of a remotely located operator observing the robot through its camera. Coming at 0.52×0.74×0.17 metres, the aluminium robot moves at an average speed of 0.5 m/s. Some criticism to the presented robot includes the arguably small waste storage compartment. An IoT "Aquatic Iguana" robot is presented in [45] and it consists of a live-feed camera, PH sensor, temperature sensor, and a turbidity sensor. The conveyer-like waste collection system has a 15Kg capacity and claimed to be able to collect 2Kgs of waste in 10 minutes. The remote-controlled robot's pitfalls may include its inability to generate its own power therefore, it is limited in terms of operation time. An interesting robot is presented in [46]. A submerged, torpedo-shaped robot aims to detect make chemical, biological, and physical observations. These observations include oil spills and sea floor terrain sampling. The robot in [46] is autonomous and can communicate to the base station via satellite phone, radio frequencies, or acoustic telemetry. With the ability to operate in the ocean for months, the robot can also reach depths of 0.5Kms under water. [47] claims their robot can clean oil spills and pipeline leakages. This is done by analysing the water quality and if abnormal readings appear, a distress signal is sent to the base station for action to be taken. The method in which water quality data is analysed is through a machine learning model which obtains data from the camera, LiDAR, ultrasonic sensor, PH sensor, turbidity sensor, and a temperature sensor. The different labels of their machine learning model are plastic bags, plastic bottles, Styrofoam, algae, metals, and oil spills. The model is implemented on a Raspberry Pi. The conveyer belt-style waste collection system drives the detected waste through a narrow channel and into the onboard waste bin. Study [47] did not detail which machine learning model was used to detect the waste. Furthermore, the waste collection bin may not be suitable for entrapping liquid pollutants such as oil spills.

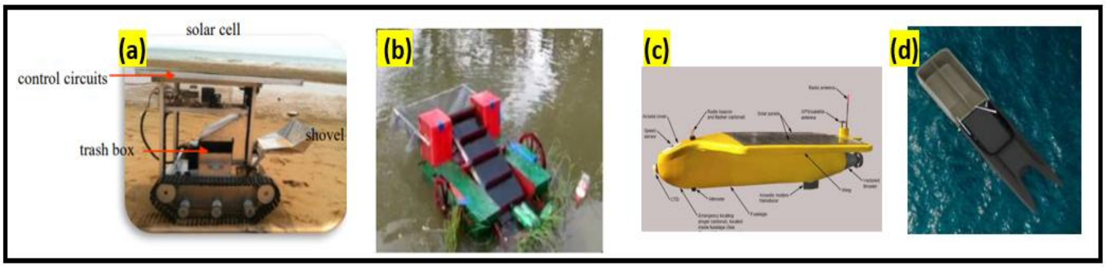

Figure 6. Presents the attempts of study (a) [44], (b) [45], (c) [46], and [47].

Study [48] aims to clean river streams by utilizing deep learning. Their proposed design uses a partially submerged craft which consists of three cameras around the robot to give an all-around view, two paddle wheels to drive the craft, and two arms which guide waste into the waste collection tub via its gate. Their robot claims to be multidirectional and moves in the direction of the delectated waste. Despite this, the study only presented the implementation of the object detection system but not the robot itself. There is no mention of the deep learning technique utilized by their proposed method.

Secondly, as for current object detection advancements, six different categories of waste were detected by [49] namely, glass, plastic, paper, trash, metal, cardboard. The study's object detector is not limited to aquatic use and utilizes a hybrid transfer learning technique for classification along with Faster-CNN to obtain the region with the detected waste. A dataset of 400 images was used and 0.842, 0.878, 0.859 were obtained for the precision, recall, and F1-score respectively. The testing criteria of this paper is well chosen but the small data set size and not training on real images may set back the algorithms ability to properly generalize. A custom animal detector is presented in [50] and it shows how footage obtained from a motion-triggered camera can be fed into a machine learning model and optimized to detect and classify different animals. Their presented model uses Faster R-CNN and aimed to optimize footage contrast and high false-positives rates. These optimizations lead to a 4.5% increase in animal detection accuracies.

Finally, considering the aforementioned related work above, many knowledge gaps exist. This thesis aims to tackle these knowledge gaps and set a new path for how a waste detection and collection robot should be designed and functions. Previous work did not discuss the environmental impact of the materials used to construct the robot itself as no mention of using recycled materials was made. This point is crucial to the sustainability and success of such a robot as when the robot is decommissioned, it will most probably end up as waste similar to that the robot itself was collecting. On the other hand, the robot proposed in this thesis only uses recycled, recyclable, upcycled, and sustainable eco-friendly materials. Furthermore, another issue that is not well emphasized in previous work is the use of clean energy generation. Most of the discussed robots employ a battery system that needs to be recharged when fully drained. This has two implications: (1) the environment cleaning robot is not using an environmentally friendly source of power and (2) the robot cannot be deployed uninterrupted for months at a time but has to return to the base station to be recharge, unlike the robot proposed in this thesis. A common and unexplained trend in related work is the concept of using paddle system to move the robot and a conveyer belt design to intake waste. The unexplained design choices raise many questions like why was this design used? Is that design the most efficient out there? This thesis aims to break the cycle of unjustified and repeated design choices by providing reasoning and practical proof. Many of the previously discussed robots are remote controlled. Despite remote controlled vehicles having their applications, common waste collection robots may not be one of them. Constant human supervision of common waste collection is a very time-consuming process since a person needs to search for waste and collect it. No time or movement critical situations are generally present in common waste collection unlike other applications such as nuclear waste and explosives management. This robot in this thesis is completely autonomous and does not require any human intervention. Another issue with previous work is the inefficient consumption of energy. For instance, previous attempts tend to utilize actuators to control the collection compartments in order to entrap waste. This thesis will provide a mechanical approach to trap was the does not require and electrical energy. Furthermore, some studies, like study [42], attached unrelated sensors to their robot and claimed they test how polluted the water is without providing a logical explanation on how that is done. Such unrelated sensors waste energy that can be useful elsewhere. The lack of design flexibility is a major concern when constructing such robots. For such a robot to be successful, it should be able to adapt to the construction materials commonly available in that specific region. The proposed robot in this thesis provides suggestions on what parts can be substituted to suit that specific deployment region. Furthermore, the majority of this robot is constructed from globally abundant waste that is free of charge. Finally, almost all previous attempts only demonstrate how their object detection system is able to successfully detect waste with no further testing criteria, unlike this thesis which aims to improve upon that.

CHAPTER 3: REQUIREMENTS ANALYSIS

3.1 Requirement’s analysis

This subsection clarifies the input and output of the system along with the processes of each functional block. Figure 7 demonstrates the main functional blocks of the system and their interactions with the actors.

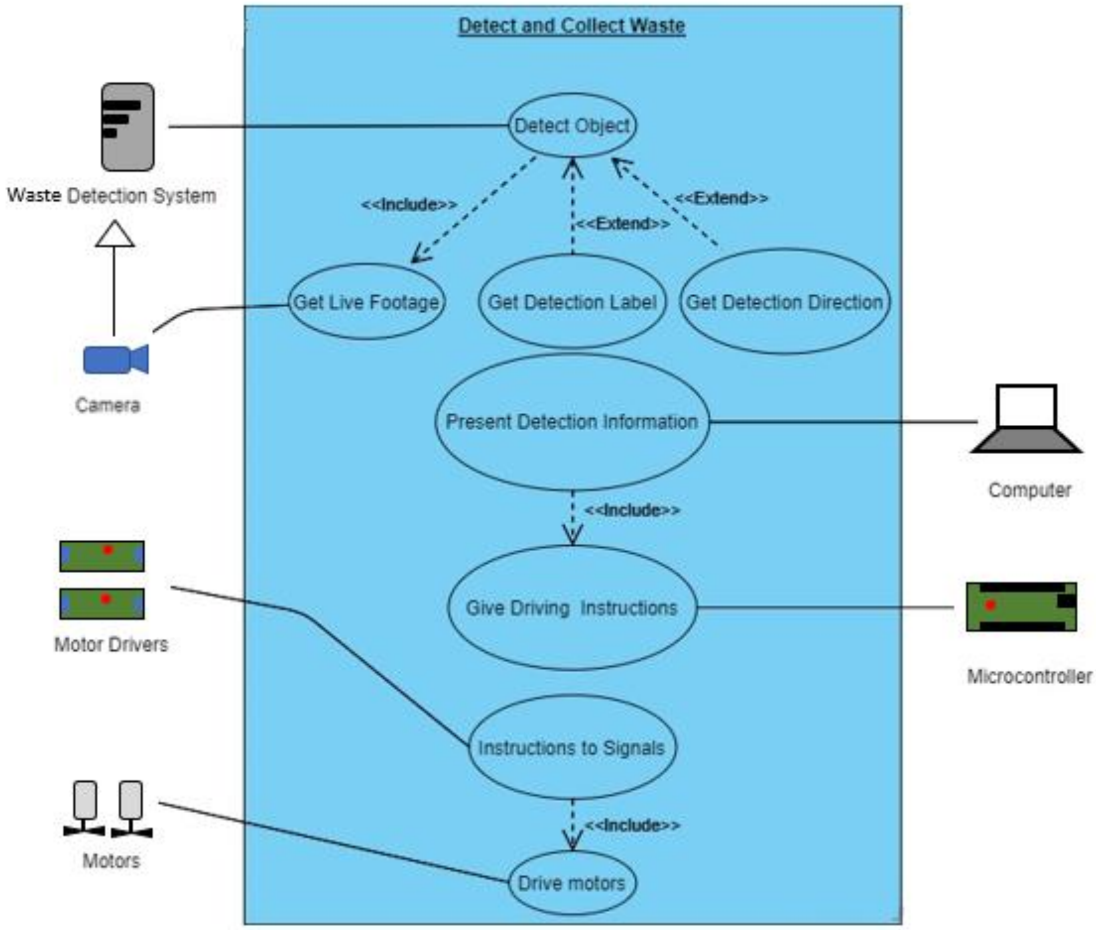

Figure 7. System use case diagram.

Live camera footage, from the webcam, is continuously fed into the waste detection system. The system checks:

(1) Has the robot not detected any waste for more than 30 seconds? If yes then the robot drives forwards for 30 seconds, resets its timer, and goes back to attempting to detect waste.

(2) If the robot has moved within the last 30 seconds or less, it checks whether any waste is detected or not. The outcome of the detection has four possible actions:

- If waste has been detected towards the left region of the live footage, drive the robot left for 3 seconds and reset the timer.
- Else if waste has been detected in the forwards region of the live footage, drive the robot straight for 3 seconds and reset the timer.
- Else if waste has been detected towards the right region of the live footage, drive the robot right for 3 seconds and reset the timer.
- Else, no waste has been detected therefore, keep incrementing the timer and continue to attempt to detect waste.

Overall, if multiple pieces of waste are detected simultaneously, the robot uses a decision narrowing technique to collect them. To elaborate, the robot will keep moving closer to the multiple detected pieces of waste until one remains in its field of vision after which it is collected.

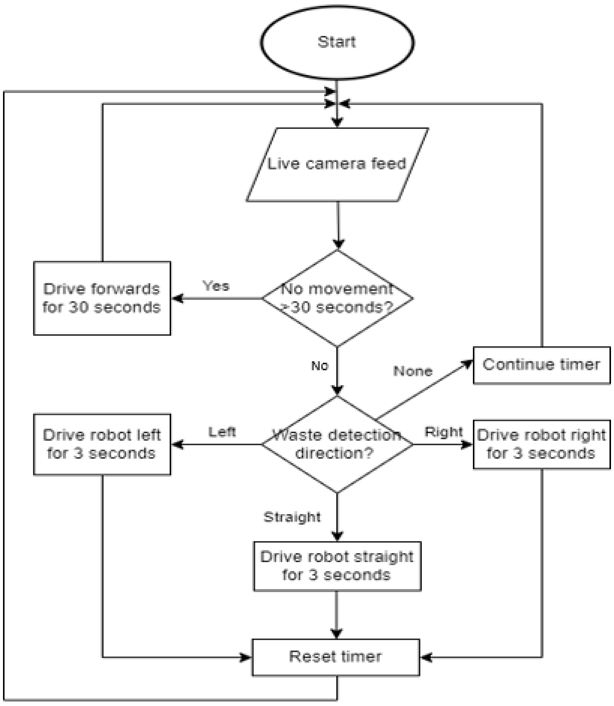

Figure 8. System flowchart

Driving the robot is possible due to a modified part of the waste detection system which allows for the export of the detected object’s label and direction of detection. The direction of detected waste is relayed to the motors through the microcontroller and motor drivers. Figure 8 further details the operation of the robots through the presented flowchart.

3.2 Design constraints

Every system has design constraints. Design constraints can be technical, shown in table 1, or practical, shown in table 2.

Table 1. Technical Design Constraints.

Name	Description
Webcam Range	The webcam has the capability of obtaining clear footage, suitable for detection, from a distance range of 0.10m to 6.00m.
Detection Accuracy	The system is expected to have a waste detection accuracy greater than 50%, at a 6.00m distance, with movement.
Battery Life	An 18Ah battery, along with the 100W solar panel, should support the system for approximately 4.00 hours.
Storage Capacity	The waste storage system, the Gargoor net, should be capable of carrying 40.0Kgs of waste. This is while taking in consideration the floaters’ buoyancy limits.
Robot’s Shape	The robot’s shape should suit areas like beaches which may have rocks and barrier. Furthermore, the robot should be able to operate in water that is only 0.50m deep.
Robot’s size and weight	The robot must be relatively small and light. The robot should not require and special tools, such as trollies, to transport to the body of water.

Table 2. Practical Design Constraints.

Type	Name	Description
Environmental	Recycling /Repurposing	The robot’s construction should be mostly made from recycled, upcycled, or repurposed materials.
Sustainability	Reliability	The autonomous robot should operate without human supervision for the most part. The robot should be checked on once a week to empty their waste compartments, ensure they are operating as expected, and to collect waste statistics.
Sustainability	Component’s Lifetime	The robot’s structure should last for years as plastic and galvanized metal are durable. Motor drive belts should be changed once every 6 months. The laptop’s lifetime depends on how much it was used before being repurposed.
Availability	Component’s Availability	Components should be very accessible. This includes old water bottles and jugs, computers and microcontrollers, cameras, and nets.
Manufacturability	Size	Size of the robot should not exceed 2.00m in length and 2.00m in width as to remain suitable for relatively confined areas.
Manufacturability	System Forms	The robot’s shape should adapt according to available waste and components. Ideally the overall robot should not have any sharp edges or corners.

Type	Name	Description
Manufacturability	Skills	Minimal construction and computer skills will be required to replicate and manufacture this robot as its systems will be made simple to implement.
Financial	Cost	Launching a campaign to ask for the community’s donations in terms of old devices and construction materials will lead to little or even negligible construction cost.

CHAPTER 4: SOLUTION DESIGN

Figure 9 presents how the webcam's live feed is taken as an input by computer, which has the waste detection system implemented on it. According to the observations made, the waste detection system then informs the Arduino microcontroller of the instructions to be executed. The Arduino microcontroller then translates the instructions into signals that the motors can carry out.

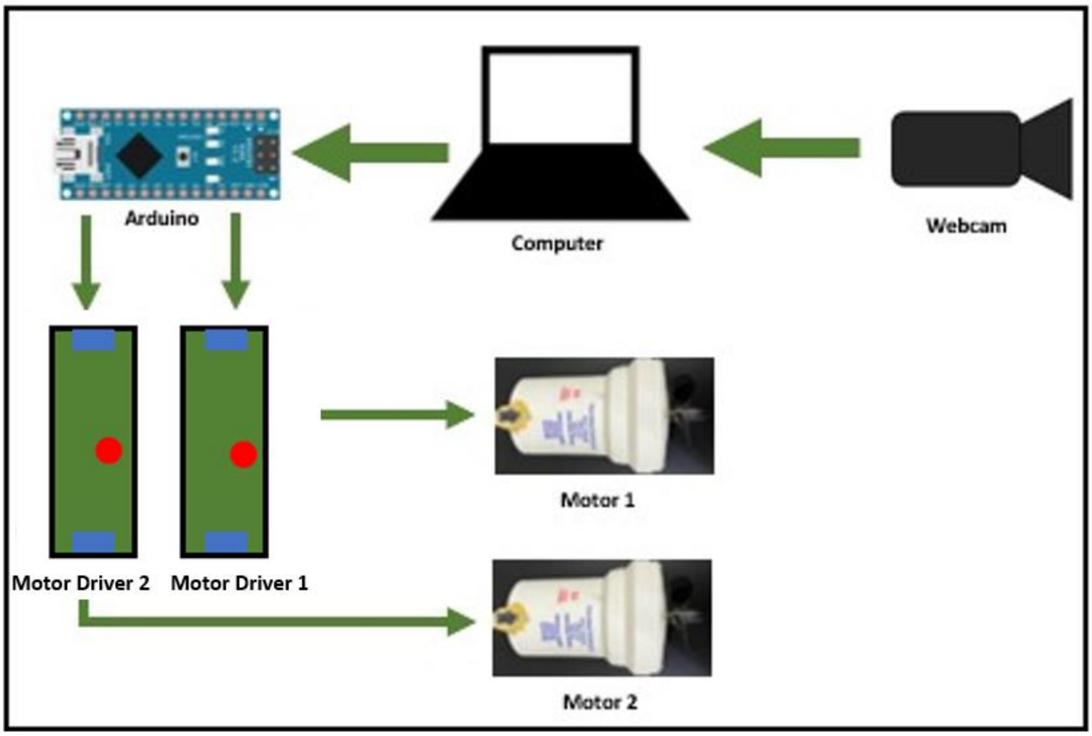

Figure 9. Proposed solution's design.

4.1 Overview

This section provides an overview of the solution and its high-level architecture. This thesis demonstrates that eco-friendly solutions to cleaning up the environment can be made with minimal cost. This project aims to further contribute to creating awareness about environmental pollution. The proposed robot is constructed from recycled materials and e-waste, and it has the purpose of detecting and collecting common waste floating on the surface of the water.

The main software components in each piece of hardware used along with their interactions with each other are discussed in this section. Figure 10, the high-level architecture, demonstrates a step-by-step sequence of events that occur when detecting and collecting waste.

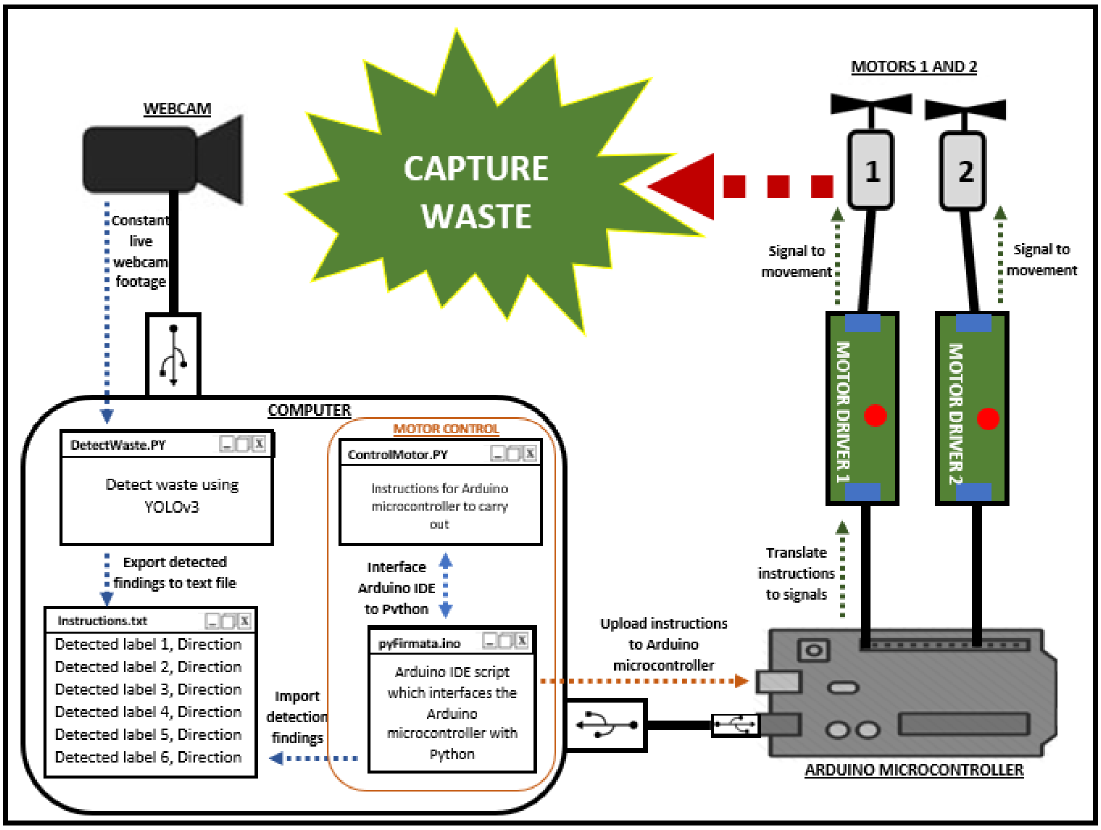

Figure 10. High level architecture.

4.2 Hardware and software used

This section describes the hardware and software components utilized in the making of this robot along with clarification on why each software was chosen.

4.2.1 Hardware used

This section presents the different hardware used in the proposed solution. One of the main objectives of this project is to allow for design flexibility and ease of parts substitution. To elaborate, this robot is not restricted to a single type of computer, construction material, Arduino microcontroller, or motor driver and motor model. With that in mind, the below sections specify part’s features, specifications, and what they can be replaced with.

a. Camera

A Phillips P506 webcam is utilized for this solution. The utilized webcam has a resolution of 1920×1080 with a capability of 30 Frames Per Second (FPS). Despite using this specific model of webcam, this project is not limited to it in fact, any webcam can be used. The proposed solution requires a webcam as they can be very cheap, they can be found in all regions around the world, and are convenient to setup.

Figure 11. Phillips P506 webcam.

b. Computer and microcontroller

In efforts to reduce e-waste, this project aims to upcycle old and slow computers by giving them a new purpose. A decommissioned Lenovo ThinkPad 440s was obtained. This ThinkPad 440s is running an i5-4200U processor at 2.60GHz with 8GB of RAM on Windows 7. With some updates and removing unnecessary programs, the laptop became capable of running the object detection system. A Windows, Apple, or Linux-based operating system computer can be used for this project due to Python and Arduino IDE being cross-platform.

An Arduino Nano was salvaged from an old project and used for this proposed solution. The Arduino Nano has a 2KB Static Random Access Memory (SPRAM) along with a 32KB flash memory. The Arduino Nano also has 14 digital pins, 6 of which are Pulse Width Modulation (PWM) pins, and 8 analog pins. The input voltage of the Nano ranges from 3.3V to 12.0V but operates at 5.0V. The Arduino is used as a way to translate instructions from the object detection system and accordingly, send command signals to the motor drivers. A total of 6 digital pins are required therefore, the Arduino Nano used here can be interchanged with most of the popular Arduino models. Using an Arduino and its IDE is a cheaper way of controlling the motors when compared to other solutions such as LabVIEW which cost significantly more.

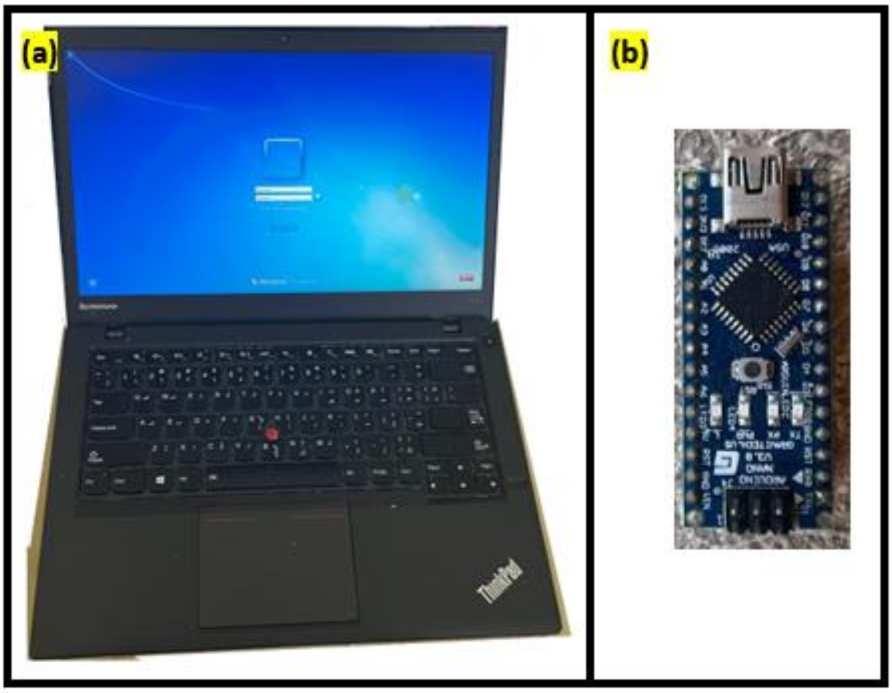

Figure 12. (a) Lenovo ThinkPad 440s used and (b) shows the Arduino Nano.

c. Motor drivers and motors

To further support the cause of reducing e-waste, two motor drives were also salvaged from an old project. The only information known about the motor drivers is that each motor driver can handle up to 32 Amperes of current. No further information was given as these motor drivers were used 11 years ago for an old project. Gray-box system problems are common in engineering. First, any inscriptions or symbols were looked for on the motor drivers and unfortunately, they did not have any. Second, and extensive web search was conducted and that resulted in a very similar but dual-channel motor driver called ‘Sabertooth motor controller 2×32’. Despite the similarity in appearance, the dip switches’ functions differed to that of the one obtained. Finally classic gray-box system techniques were applied which include trying different input combinations while observing and noting their output action. This resulted in the motor drivers giving the motors commands to rotate clockwise and counter clockwise but not stopping. In order to make the motors stop, a 10 Ampere relays were connected to each motor.

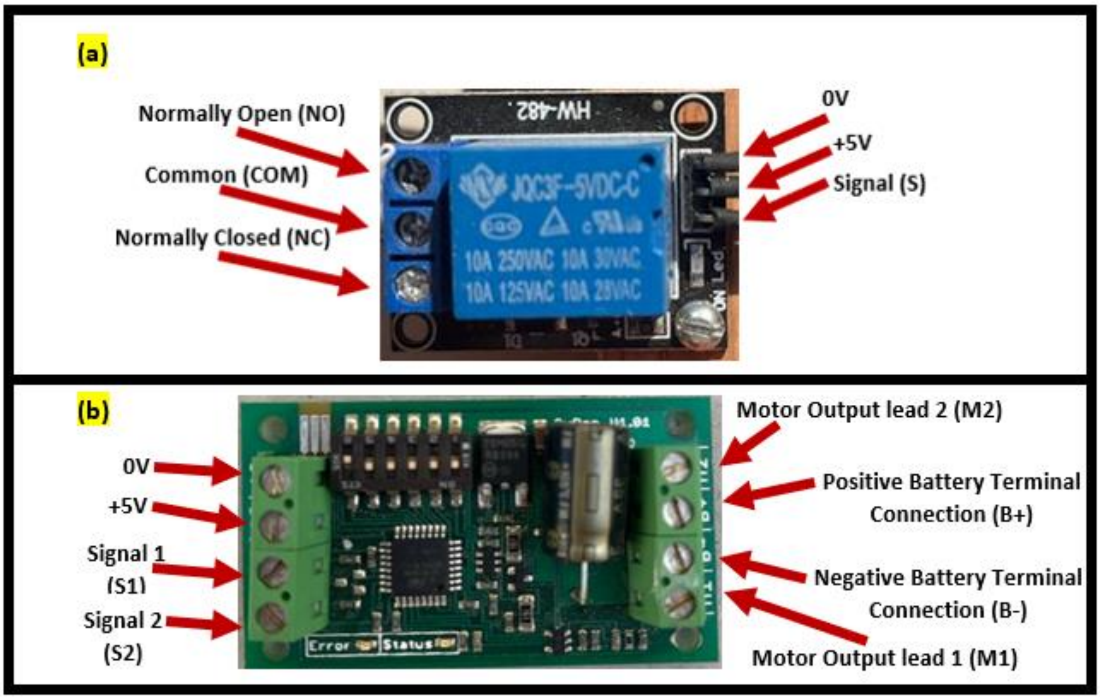

Figure 13. (a) Shows the 10A relay and (b) is the motor driver used.

Two ‘Ruler 1500’ bilge pumps were obtained and recycled from the department of computer science and engineering at Qatar university. Each motor requires 12 Volts and 4.8 Amperes to function.

Figure 14. Presents the Ruler 1500 bilge pump.

d. Power storage and generation

The only new but sustainable and eco-friendly parts purchased were the 100 Watt solar panel, 20 Ampere solar panel controller, and the 18 Ampere hour battery. Considering that the average lifespan of a solar panel is 25 years [51] and that a battery can be recycled, using electrical energy is a more sustainable and eco-friendly method of supplying the robot with energy.

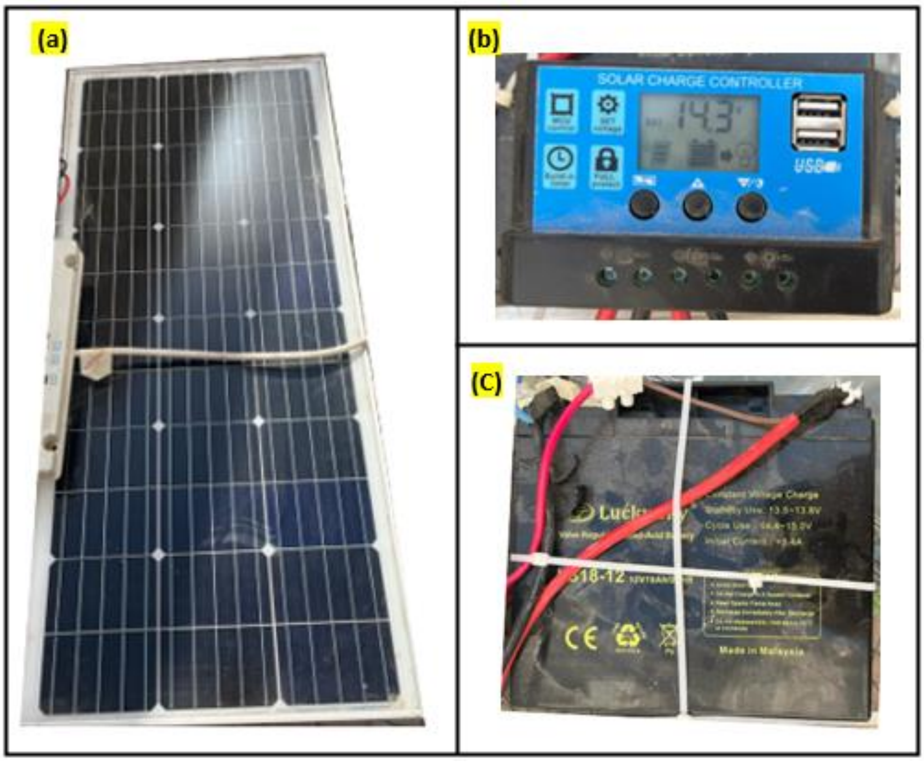

Figure 15. (a) 100W solar panel, (b) 20A solar controller, and (c) 18Ah battery.

4.2.2 Software used

Here, the different software used in the proposed solution is presented. As to fulfil one of the main objectives of this thesis, which is ease of construction and design flexibility this robot only uses free and open-source software and websites. With that in mind, the below sections further detail the software and website features used and their and specifications.

a. PNG to JPEG converter: 11zon

The first step after collecting the dataset images is to convert them to JPEG form. This is so the YOLOv3 waste detector can use them. The free and fast website ‘11zon’ [52] was used to do so.

b. Dataset labeller: LabelImg

The second step after converting the dataset images into JPEG form is to label every image manually. Labelling the images converts them into numbers that the object detector can process. The open-source ‘LabelImg’ [53] software was downloaded from GitHub and used to label the entire dataset.

c. Python

Python is a very powerful, cross platform, open-source, and free programming language with an enormous following and support. For this reason, Python [54] was selected to be used to implement the waste detection system and to control the microcontroller. The Python implementation of the waste detection system and the microcontroller control scripts were done on ‘Spyder IDE’ [55]. The Spyder IDE was downloaded using ‘Anaconda’ [56]. Anaconda allows for creating different Python environments. A Python environment is method of virtually managing dependencies and isolating projects. Both Spyder IDE and Anaconda are also free, similar to Python. Figure 16 clarifies how the Python scripts are executed using Anaconda.

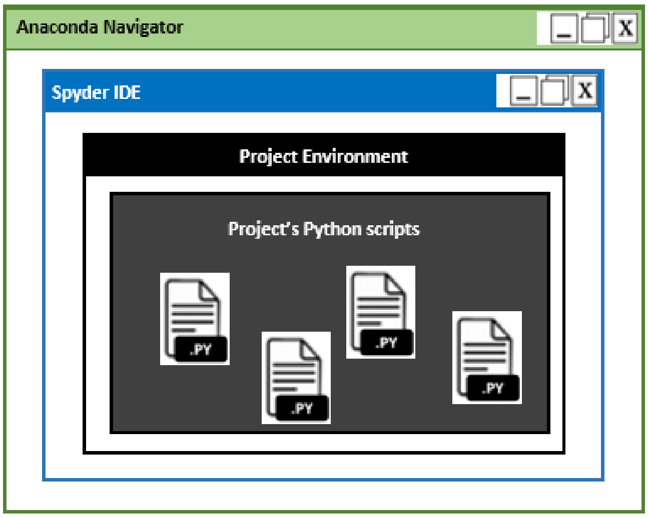

Figure 16. Python scripts implementation on Anaconda.

d. Arduino IDE

Arduino IDE [57] is the official IDE for programming an Arduino microcontroller. The Arduino IDE translates the commands given by the user into actions. Due to its robustness Python is used to program the Arduino Nano utilized in this project. In order to control the Arduino microcontroller using Python, the free pyFirmata Arduino library needs to be downloaded, installed, and run on the Arduino IDE. Only then Python can be used to communicate with the Arduino.

e. Google Colab

'Google Colab' [58] is a free service by Google which allows people to write, compile, and execute Python code online. Colab is suitable for machine learning as it allows the user to choose whether they want their program executed on a CPU or GPU. Colab provides the user with cloud storage furthermore it allows the user to select what version of Python they want to use. One of the main benefits of Colab is it gets rid of the hassle of having to download Python libraries and dependencies. For instance, the proposed waste detection system requires the installation of OpenCV, CUDA, CMake, Darknet, and some libraries. Thanks to Colab, all the aforementioned were preinstalled and ready to use immediately. Not having to install such programs and libraries saves significant local storage and time. Colab was used to train the waste detection model. After training was complete, the weights file was downloaded on the local machine and used.

4.3 Waste detection system design

4.3.1 Dataset

A dataset consisting of 820 coloured images is used in this project. The images are all in Joint Photographic Experts Group (JPEG) format and have a resolution of 1280×720. The resolution of the images is scaled down to 416×416 by the detection algorithm. The dataset consists of images of waste taken on beaches and on swimming pools. A simple Python script was written to randomly split the dataset into 70% training data and the remaining 30% to be testing data.

4.3.2 Detection algorithm design

The supervised learning technique YOLOv3 is customized to detect common waste floating on the surface of the water. This YOLOv3 waste detection model takes coloured images which are compressed to the dimensions of 416×416. Since the images are coloured, for each image, there are three channels namely, red, green, and blue. Images in the proposed model are presented in $w \times h \times c$ form where w is the width of the image (w=416), h is the height of the image (h=416), and c is the number of channels (in this case c=3). The model has 36 filters and can detect a maximum of 100 detections at a single time. Any detection with a confidence rate less than 50% will not be considered or presented. Referring to Figure 17, the utilized YOLOv3 architecture has 106 layers with layers 82, 94, and 106 being used for making detections.

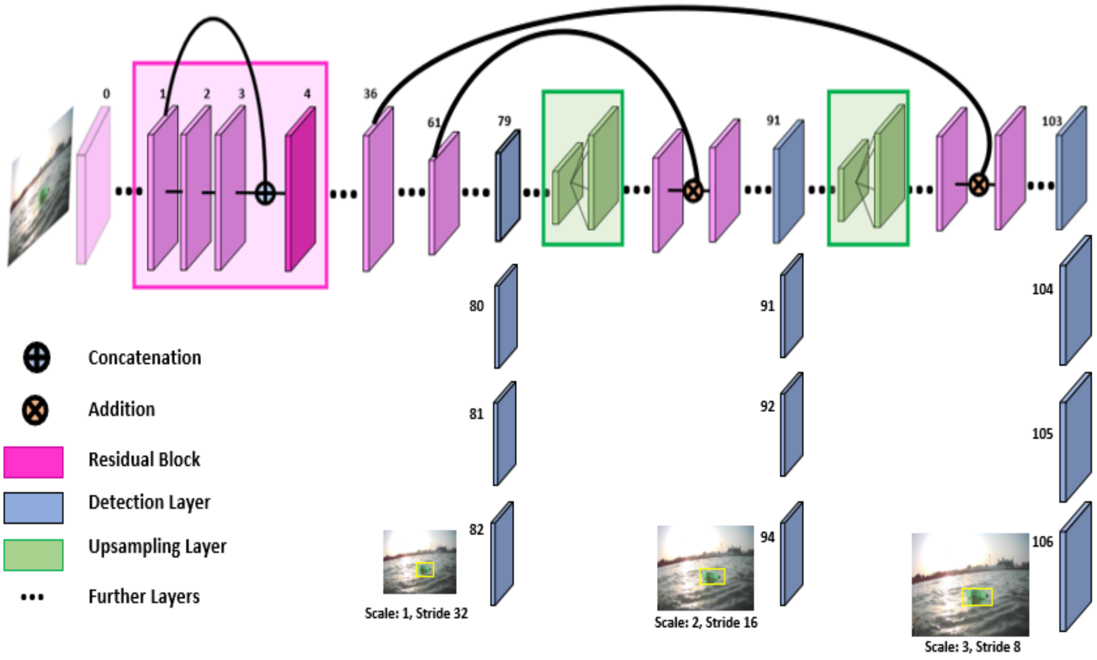

Figure 17. The utilized YOLOv3 architecture.

In terms of software design, the flowchart in Figure 18 clarifies the overall steps to be implemented.

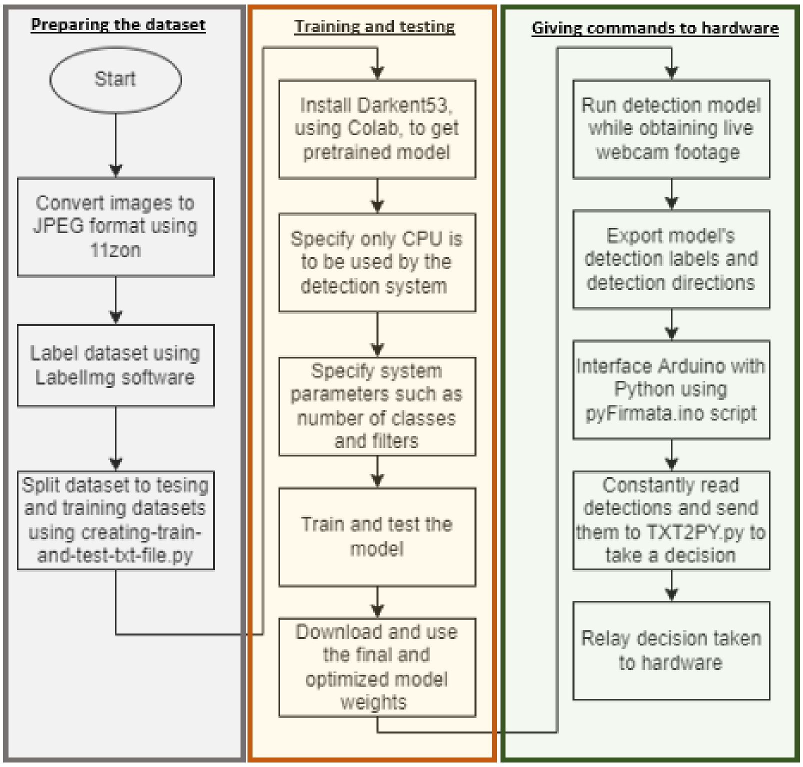

Figure 18. Software design flowchart.

CHAPTER 5: IMPLEMENTATION

5.1 Buoyancy

The partially submerged robot must be able to float for it to work. The amount of mass that each floater, in this case a cylindrical water cooler bottle, can handle must be calculated. The calculations are done for fresh water rather than seawater. This is due to fresh water being less buoyant i.e., the worst case scenario.

The two cases need to be calculated are: (1) What is maximum mass that each floater can bear when no components are attached to it? (2) What is the maximum mass of waste that each floater can bear when components are attached to the floater?

Equation (3) is used for the below calculations, knowing that $\boldsymbol{h}$=0.36m, $\boldsymbol{\rho_{liquid}}$=1000Kg/m^3, and $\boldsymbol{r}$=0.14m.

a. *Maximum bearable mass of each bottle:*

With no components attached, the submerged height is equal to the total height of the floater, $\boldsymbol{h}=\boldsymbol{y}$=0.36m.

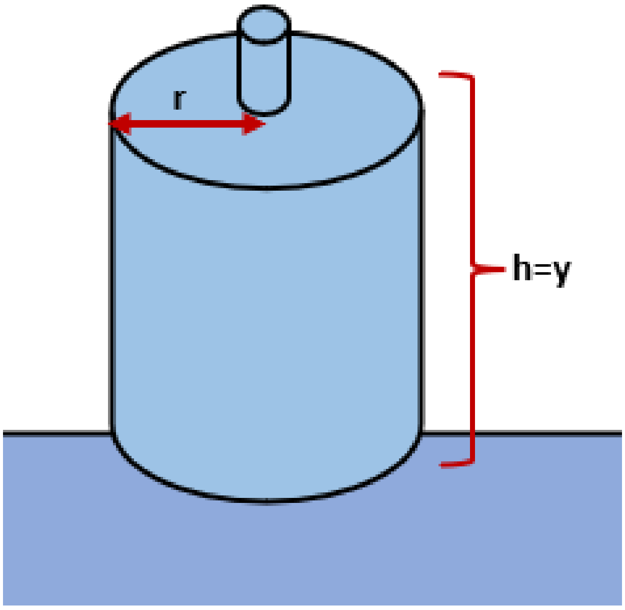

Figure 19. Mass calcualtion with no components.

$$m = \rho_{liquid} \times (\pi r^2 y)$$

$$m = 1000 \times \left(\pi(0.14)^2(0.36)\right)$$

$$\boldsymbol{m = 22.2Kg/Floater}$$

b. *Maximum bearable waste mass with components:*

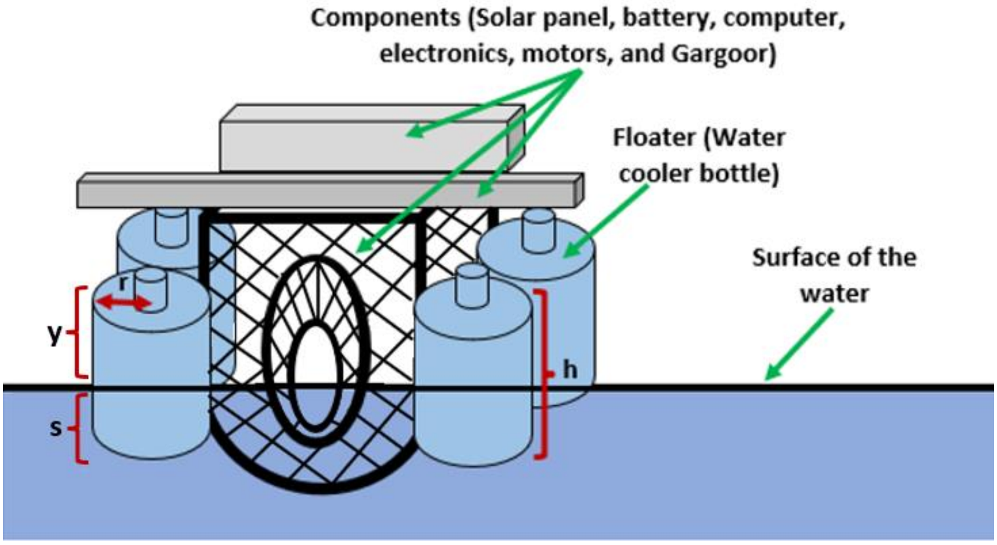

Figure 20. Maximum bearable waste mass with components.

By referring to Figure 20, The component's combined weight is 49.5Kg. With the components attached to the robot, each floater's submerged height, $\boldsymbol{s}$, is 0.16m. The maximum mass of waste, $\boldsymbol{m_{\max waste}}$, that each bottle can carry is calculated as follows:

$$m_{\max waste} = \rho_{liquid} \times (\pi r^2 s)$$

$$m_{\max waste} = 1000 \times \left(\pi(0.14)^2(0.16)\right)$$

$$\boldsymbol{m_{\max waste} = 9.85Kg\ of\ waste/Floater}$$

Knowing that 4 water cooler bottles are used, the maximum mass of waste that the entire robot can collect is:

$$Total\ m_{max\ waste} = 4 \times m_{\max waste}$$

$$Total\ m_{max\ waste} = 4 \times 9.85$$

$$\boldsymbol{Total\ m_{max\ waste} = 39.4Kg\ of\ total\ waste}$$

5.2 Construction

This section presents how the robot’s body was constructed and from what materials.

a. Motors:

Two Ruler 1500 bilge pumps were not in use anymore as they are suspected to have broken water seals but their motors functions perfectly fine. The pumps’ bottoms were taken apart and custom motor shafts along with 8mm teethed pulleys were attached. Figure 21 presents the before and after of the modifications done to the pumps.

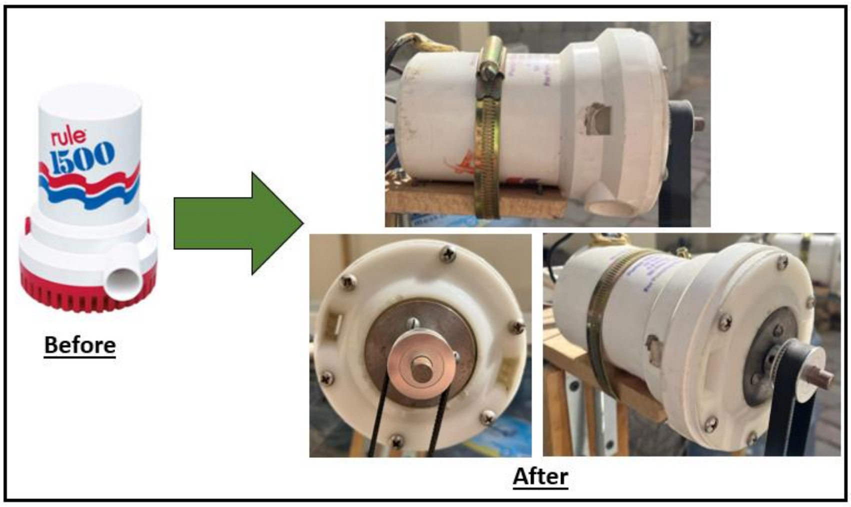

Figure 21. Before and after modify the pilge pumps.

The robot has two motors and as it is safer to keep the motors above the surface of the water, the setup in Figure 22 presents the contraption adopted. The main structure of the motor setup is salvaged pallet wood attached together with galvanized steel brackets. Both the 8mm teethed pulley and belts are 3D printer parts as they are strong, cheap, and readily available. The motor is held down tightly to the treated wooden structure using a 4-inch hose clamp and the belt is tensioned by tightening the nuts on each end of the 8mm threaded rod belt tensioner. Overall, each motor setup comes in at 55cm in height.

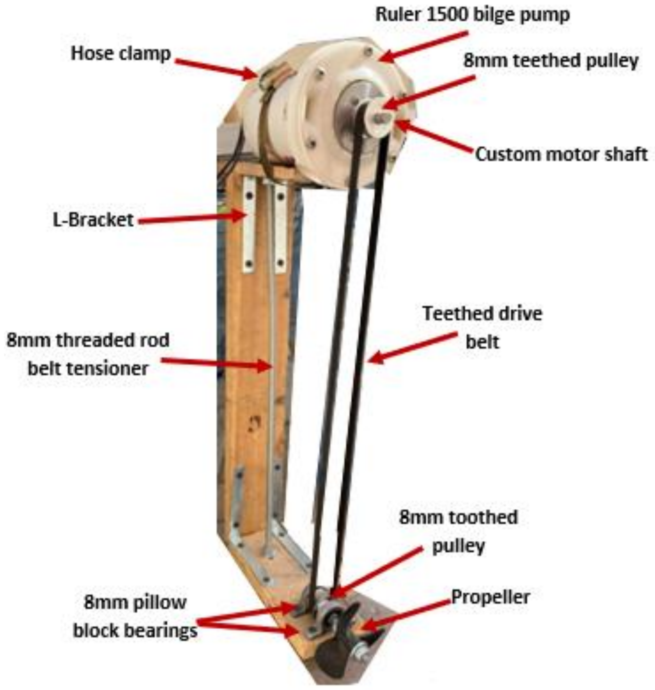

Figure 22. Adopted motor setup.

b. Floaters and Gargoor:

It is crucial that the hull of the robot is very sturdy. The floaters of the robot are four recycled 18-liter water cooler bottles. Due to the Gargoor’s dome structure, netting, and wire thickness, it provides an extremely robust structure for the floaters to be attached to. The Gargoor used in this thesis is so rigid to the point that it was tested by sitting on it (≈100kg) prior to its use and it experienced little deformation and warping. With the aforementioned considered, no extra supporting structures are needed for the Gargoor to hold its shape. Considering Figure 23, each water cooler bottle was fixed to the Gargoor at two locations. (1) A 2-inch hose clamp was tightened on the neck of each bottle. This is shown in Figure 23(a). The hose clamp also has a bundle of wires attached to it. The bundle of wires gets tied to the Gargoor’s top. This is shown in Figure 23(b). (2) For each floater, a 4-inch hose clamp was tight from the water cooler bottle’s handle to the Gargoor’s bottom. This is shown in Figure 23(c).

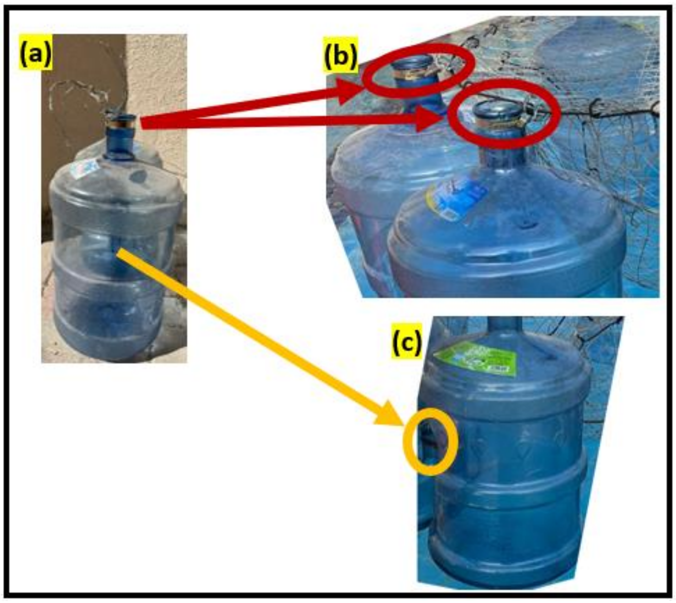

Figure 23. (a)Shows a floater and (b) shows the bottle's neck connected to the 2-inch hose clamp, which is connected to the wires that is connected to the Gargoor. (c) Presents the 4-inch hose clamp connected from the floater's handle to the Gargoor.

c. Overall structure

Other components of the robot include the solar panel, battery, computer, microcontroller, and other electronics such as switches and fuses. The solar panel is tied down to the Gargoor using wires. The battery and solar controller are tied down to the Gargoor using nylon zip ties instead of wires as to avoid the possibility of any short circuits. The battery terminals were covered with silicon as to avoid any water contacting them. To further protect the robot, it is outfitted with a 10A fuse. The computer, microcontroller, motor drivers, and the rest of the electronics are placed in a recycled plastic box shown in Figure 24(a). The plastic box has a rubber gasket which ensures no water seeps through. Any holes made in the box filled up with silicon. The plastic box is also attached to the Gargoor using wires. The motors shown in Figure 24(b) are connected using U-bolts, 4-inch hose clamps, and wires to the Gargoor. This was done to ensure that the motors do not move which may cause the robot to deviate from its intended path. After its construction, the 49.5Kg robot’s dimensions come to 1.20m×1.10m×0.55m for length × width × height, respectively.

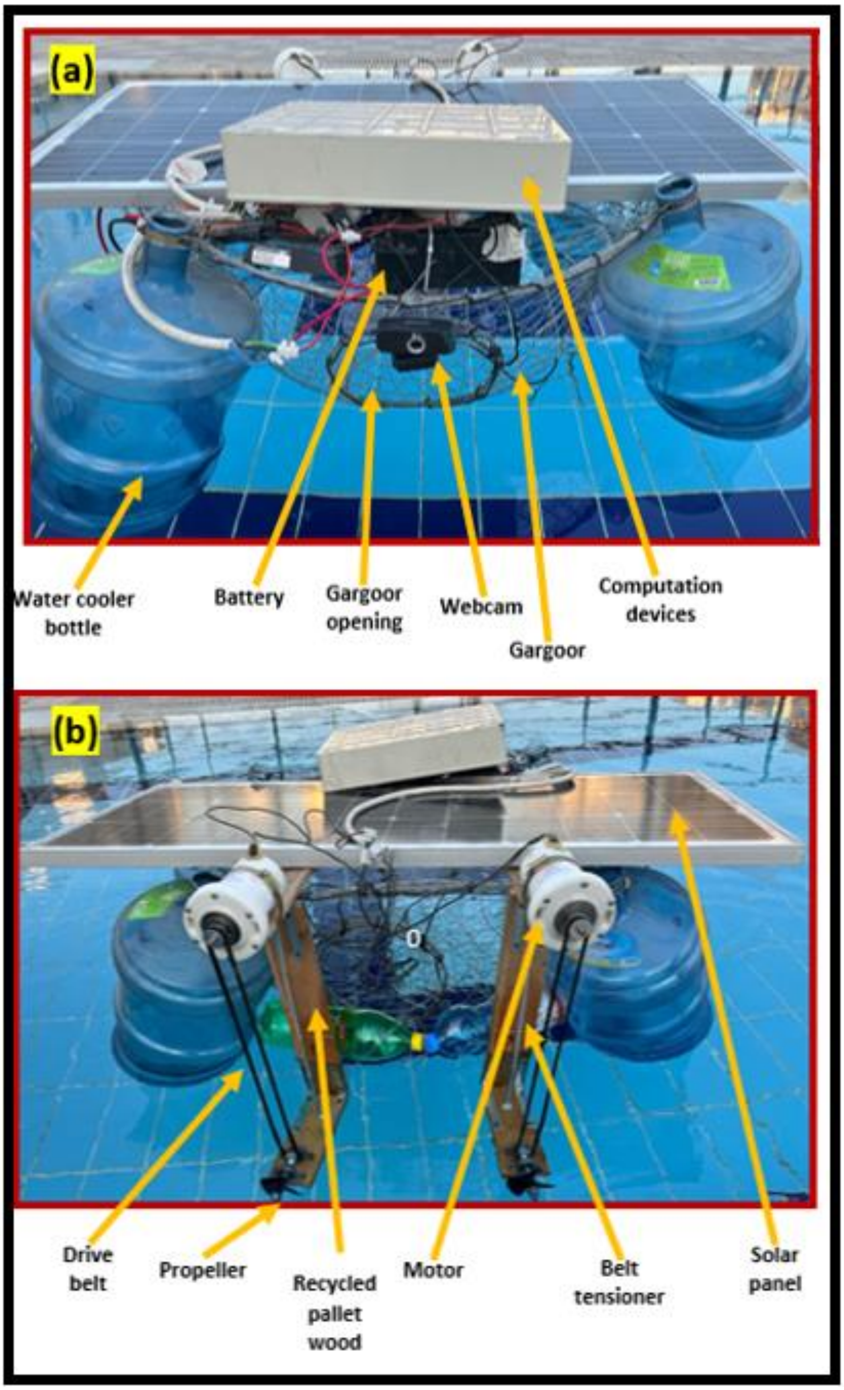

Figure 24. (a) Shows the front of the robot and (b) shows the back of the robot.

5.3 Energy management

This section discusses calculations related to the robot’s power generation and consumption. These calculations provide an idea on how long the robot can possibly operate. Knowing each motor operates of 12V at 4.8A, the calculations for the motors are as follows:

a. *Consumption:*

The following calculations show how much charge is required be motor to operate for 1 hour:

Consumption of 1 motor for 1 hour:

$$Charge\ (Q) = Current\ (I) \times Time(t)$$

$$= 4.8 \times 1$$

$$\mathrm{Q} = 4.8\ \mathrm{Ah}$$

Consumption of 2 motors for 1 hour:

$$Q_{2\ motors,1\ hour} = \mathrm{Q} \times 2$$

$$Q_{2\ motors,1\ hour} = 4.8 \times 2$$

$$\boldsymbol{Q_{2\ motors,1\ hour} = 9.6\ \mathrm{Ah}}$$

b. *Generation:*

The 100W solar panel used generates 30Ah of charge a day. Assuming the system starts off with an empty 18Ah battery, the available charge available for the two motors to use per day is calculated as follows:

$$Total\ available\ charge = Abundant\ solar\ charge + Battery\ charge$$

$$= (30 - 18) + 18$$

$$\boldsymbol{Total\ available\ charge = 30\ \mathrm{Ah}}$$

c. *Continuous operation duration:*

The time duration the motors can continuously operate for per day is calculated as follows:

$$Continuous\ overall\ running\ time = \frac{Total\ availble\ charge}{Q_{2\ motors,1\ hour}}$$

$$= \frac{30}{9.6}$$

$$\boldsymbol{Continuous\ overall\ running\ time} = \mathbf{3.13\ Hours\ per\ day\ continuously}$$

d. Realistic operation duration:

Realistically, the robot is assumed to not be constantly collecting waste. It is assumed that the robot will find waste 50% of its operation time. This means:

(1) The robot drives for 30 seconds for every 30 seconds of no waste detected (50% non-operational).

(2) The robot drives continuously to collect waste (50% operational).

With the aforementioned in mind:

$$Motors'utilization\ per\ hour = \frac{Working\ time}{total\ time} \times 100$$

$$= \frac{(Non - operational\ time + operational\ time)}{total\ time} \times 100$$

$$= \frac{15 + 30}{60} \times 100$$

$$\boldsymbol{Motors'utilization\ per\ hour} = \mathbf{75\%}$$

Since the overall moto’s utilization is 75% per hour the overall running time increases by 25%. This leads to the following new overall running time:

$$\text{New overall running time} = \text{Continuous overall running time} \times 1.25$$

$$\boldsymbol{New\ overall\ running\ time} = \mathbf{3.91\ hours}$$

5.4 Electronics’ connection

Figure 25 presents how all the electronic components of the proposed partially submerged aquatic robot are connected to one another. Table 3 further clarifies the connections made between the different electronic components shown in Figure 25. Connections between devices are done either by port or by pin.

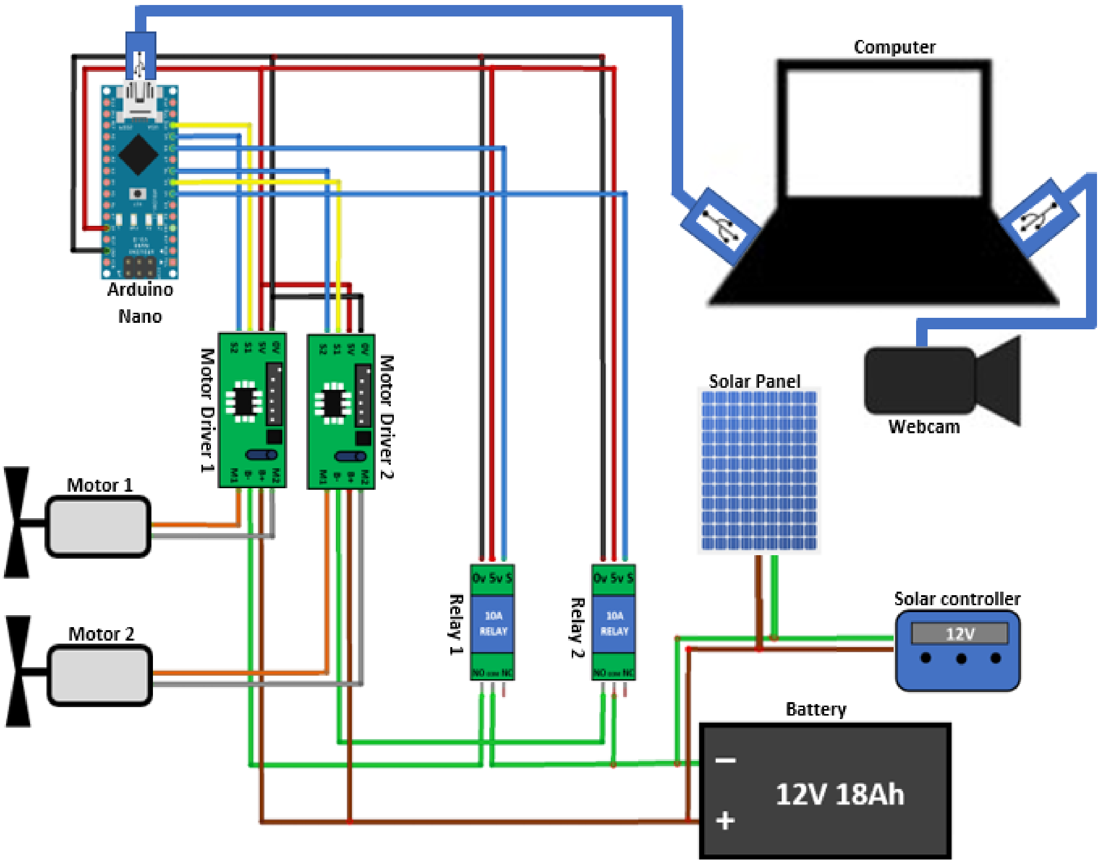

Figure 25. Connection diagram.

Table 3. Connections between devices.

Device connection to (→) another device	Connection from port or pin to (→) port or pin
Webcam → Computer	USB output → USB input port
Arduino Nano → Computer	Mini USB input port → USB input port
	Pin D9 →S2
Arduino Nano→ Motor Driver 1	Pin D10 → S1
	Pin 5V → 5V
	Pin GND → 0V
	Pin D5 → S1
Arduino Nano → Motor Driver 2	Pin D6 →S2

	Pin 5V → 5V
	Pin GND → 0V
	Pin D8 → S
Arduino Nano → Relay 1	Pin 5V → 5V
	Pin GND → 0V
	Pin D4 → S
Arduino Nano → Relay 2	Pin 5V → 5V
	Pin GND → 0V
Motor Driver 1 → Motor 1	M1 → +
	M2 → -
Motor Driver 2 → Motor 2	M1 → +
	M2 → -
Motor Driver 1 → Battery	B+ → +
	B- → -
Motor Driver 2 → Battery	B+ → +
	B- → -
Solar Panel → Solar Controller	+ → Input +
	- → Input -
Solar Controller → Battery	Output + → +
	Output - → -
Motor Driver 1 → Relay 1	B- → NO
Motor Driver 2 → Relay 2	B- → NO
Relay 1 → Battery	COM → -
Relay 2 → Battery	COM → -

5.5 Running the robot

After the robot’s completion, the robot can be started by connecting the battery and turning on the computer. A Python terminal should then be opened, and in the project’s directory, following command should be issued to load the weight into the object detection system:

```
python load_weights.py –weights ./weights/yolov3_custom.weights --
output ./weights/yolov3-custom.tf --num_classes 7
```

After loading the weights, the detection system can start working by providing the following command in the Python terminal:

```
python detect_video.py --weights weights/yolov3-custom.tf --video 0
-num_classes 7 --classes data/labels/classes.names
```

Finally, the pyFirmata script must be run on Arduino IDE followed by TXT2PY.py. These scripts interface the detection system’s findings with the Arduino, which gives the commands to the motors.

5.6 Environmental Impact

With the main objectives of this thesis in mind, the proposed solution aims to construct a waste detection and collection robot that is made from recyclable, recycled, upcycled, and sustainable materials. This reason of doing so is to increase the impact to the proposed solution on the tackled problem. To elaborate, the proposed robot does not only collect environmental pollutants, but a portion of it is also made from these pollutants it collects. Furthermore, when the robot is decommissioned, the disposal of its components should be done in an eco-friendly manner. Table 4 helps to further understand how the implementation of the proposed robot’s construction contributes to global environmental pollution clean-up. Moreover, it presents what may occur to those parts after the robot has been put out of service.

Table 4. Component's categorization.

Item	Environmental Category	Acquired As	Disposal After Decommissioning	Item purchase Price (US $)
Gargoor	Sustainable + Recyclable	New	Dispose of by metal recycling	20
Water Cooler Bottles	Recyclable	Recycled	Dispose of by plastic recycling	Free
Hose Clamps	Sustainable + Recyclable	New	Dispose of by metal recycling	7
Tying Wires	Sustainable + Recyclable	New	Dispose of by metal recycling	1.5
Pallet wood	Recyclable	Recycled	Dispose of by wood recycling	Free
Metal Brackets	Sustainable + Recyclable	New	Repurpose components or dispose of by recycling the metal	1.5
Screws and Bolts	Sustainable + Recyclable	New	Repurpose components or dispose of by recycling the metal	1

Item	Environmental Category	Acquired As	Disposal After Decommissioning	Item purchase Price (US $)
Threaded Rod	Sustainable + Recyclable	New	Repurpose components or dispose of by recycling the metal	1.5
Bearings	Sustainable + Recyclable	New	Repurpose component or dispose of by recycling the metal	3.5
Propellers	Recyclable	Recycled	Dispose of by plastic recycling	Free
Component's Box	Recyclable	Recycled	Dispose of by plastic recycling	Free
Computer	Recyclable	Recycled	Repurpose the computer, or its internal components, or dispose of by electronics' recycling.	Free
Microcontroller	Recyclable	Recycled	Repurpose the relays or dispose of by electronics' recycling	Free

Item	Environmental Category	Acquired As	Disposal After Decommissioning	Item purchase Price (US $)
Webcam	Sustainable + Recyclable	Used	Repurpose the relays or dispose of by electronics' recycling	Free
Relays	Sustainable + Recyclable	New	Repurpose the relays or dispose of by electronics' recycling	4
Motor Drivers	Recyclable	Recycled	Repurpose the relays or dispose of by electronics' recycling	Free
Motors	Upcycled	Recycled	Repurpose the relays or dispose of by electronics' recycling	Free
Solar Panel	Sustainable + Recyclable	New	Repurpose the solar panel or dispose of by recycling the metal	55

Item	Environmental Category	Acquired As	Disposal After Decommissioning	Item purchase Price (US $)
Solar Controller	Sustainable + Recyclable	New	Repurpose the solar controller or dispose of by recycling the metal and plastic	8
Battery	Sustainable + Recyclable	New	Dispose of by battery recycling	33
Electrical Wiring	Sustainable + Recyclable	Recycled	Dispose of by metal recycling	Free
TOTAL COST				136

CHAPTER 6: TESTING AND EVALUATION

The proposed robot's performance is evaluated in this section. There are multiple critical points that must be analyzed to fulfill the main objectives of this thesis. The testing criteria of the proposed robot are:

(1) Can the proposed custom waste detection system detect waste?

(2) How are the proposed waste detection system's findings affected when movement is introduced to the robot?

(3) Can the robots still detect waste in relatively low light conditions?

(4) Can the robot collect waste?

6.1 Can the proposed custom waste detection system detect waste?

With the webcam place 26cm above the surface of the water, the real-time custom waste detection system was capable of detect all of the 7 classes which are, cardboard, wrappers, metal cans, surgical face masks, plastic bags, polystyrene, and plastic bottles. The results of the detections shown in Figure 26 are a screen capture of the output of the waste detection system. Running on CPU with an approximate frame rate of 1.5 FPS, the real-time waste detection system is capable of detecting cardboard with 95.3% confidence, wrappers with 94.1%, metal cans at 93.8%, surgical facemasks with 93.2%, plastic bags at 96.2%, polystyrene with 92.6%, and plastic bottles at 93.8% confidence. The detections in Figure 26 differed in working environment as the cardboard, plastic bag, and the plastic bottle were detected on a local beach while the wrapper, metal can, surgical facemask, and polystyrene were detected in a pool. With that in mind, these results shows that the waste detection system is capable of detecting waste regardless of the experiment's setting.

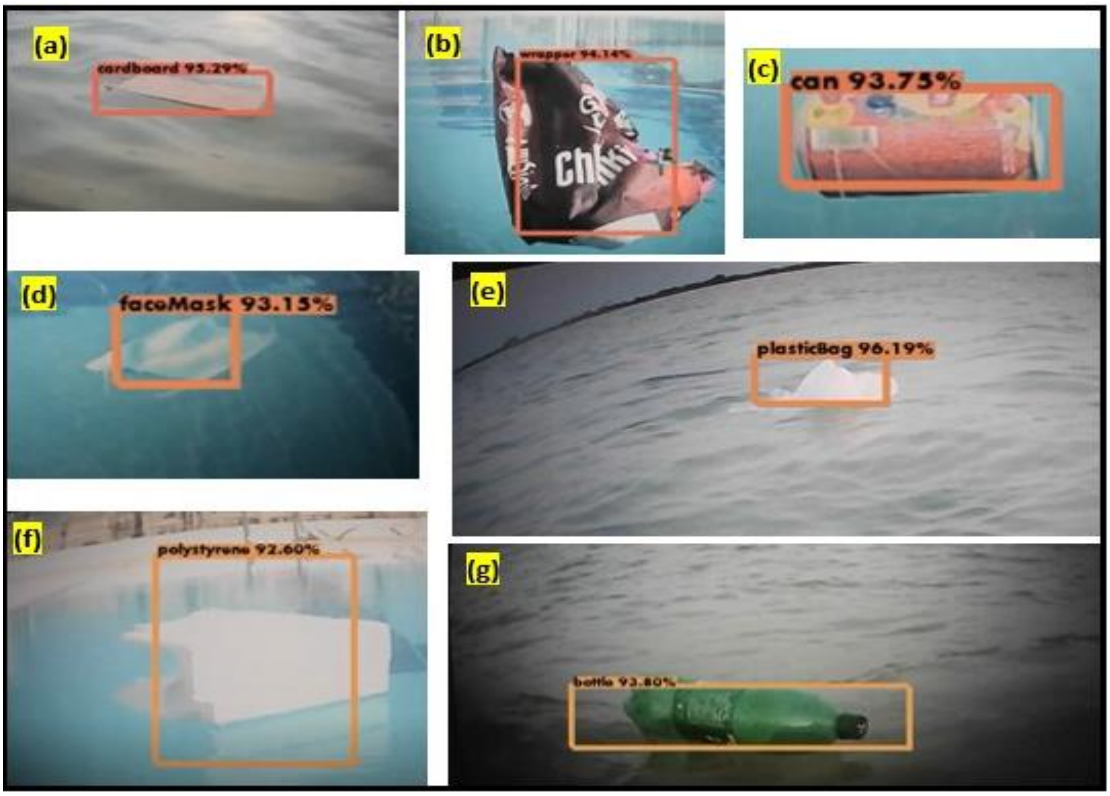

Figure 26. Shows waste detection for (a) cardboard (95.29%), (b) wrapper (94.14%), (c) can (93.75%), (d) surgical face mask (93.15%), plastic bag (96.19%), (f) polystyrene (92.60%), and (g) plastic bottle (93.80%).

6.2 How are the proposed waste detection system's findings affected when movement is introduced to the robot?

For this next experiment, movement was simulated to observe the variation in in detection confidence provided by the waste detection system. Four categories of movement were studied which are no movement, low movement, medium movement, and high movement. Movement for each category was simulated as close as possible to provide consistency and fairness. The 'Accelerometer' mobile application was downloaded on an I-Phone, through the app store, and was set to obtain readings at a rate of 20Hz. The I-Phone was attached to the webcam and readings were obtained, exported as a CSV file, and analyzed.

Shown in Figure 27 are the results for the detection system’s confidence values for each waste category. When the camera experiences no movement, carboard is the best detected category, 98.7%, while wrappers are the worst, 93.1%. When little movement is introduced to the camera, carboard and plastic bags are equally the best detected category, 94.2%, while wrappers are still the worst, 87.5%. An overall decrease in detection confidence percentages can be observed as camera movement increases to medium. The detection confidence between cardboard and plastic bags is very small at 92.1% and 91.7%, respectively. Wrappers are still the category with the lowest detection confidence percentage, 83.5%, which is significantly less than the second worst detected category, metal cans, at 87.4%. Finally, when high movement is introduced to the camera, all categories’ detection percentages are below 90.0% with the wrappers category suffering the most at 72.0%. Larger fluctuations between categories appears as they collectively stop following the overall shape they did in previous movement levels. Overall, the reason why detecting wrappers is more difficult when compared other classes might be because of the different shapes they take. Therefore, it is much harder to collect a wrappers dataset which considers their malleability and colour unlike bottles or cans which have a consistent shape. While surveying waste, despite plastic bags also being malleable and varying in shape, they do not protrude above the surface of the water and usually do not have sharp edges similar to that found in cardboard and polystyrene therefore, plastic bags can be detected well.

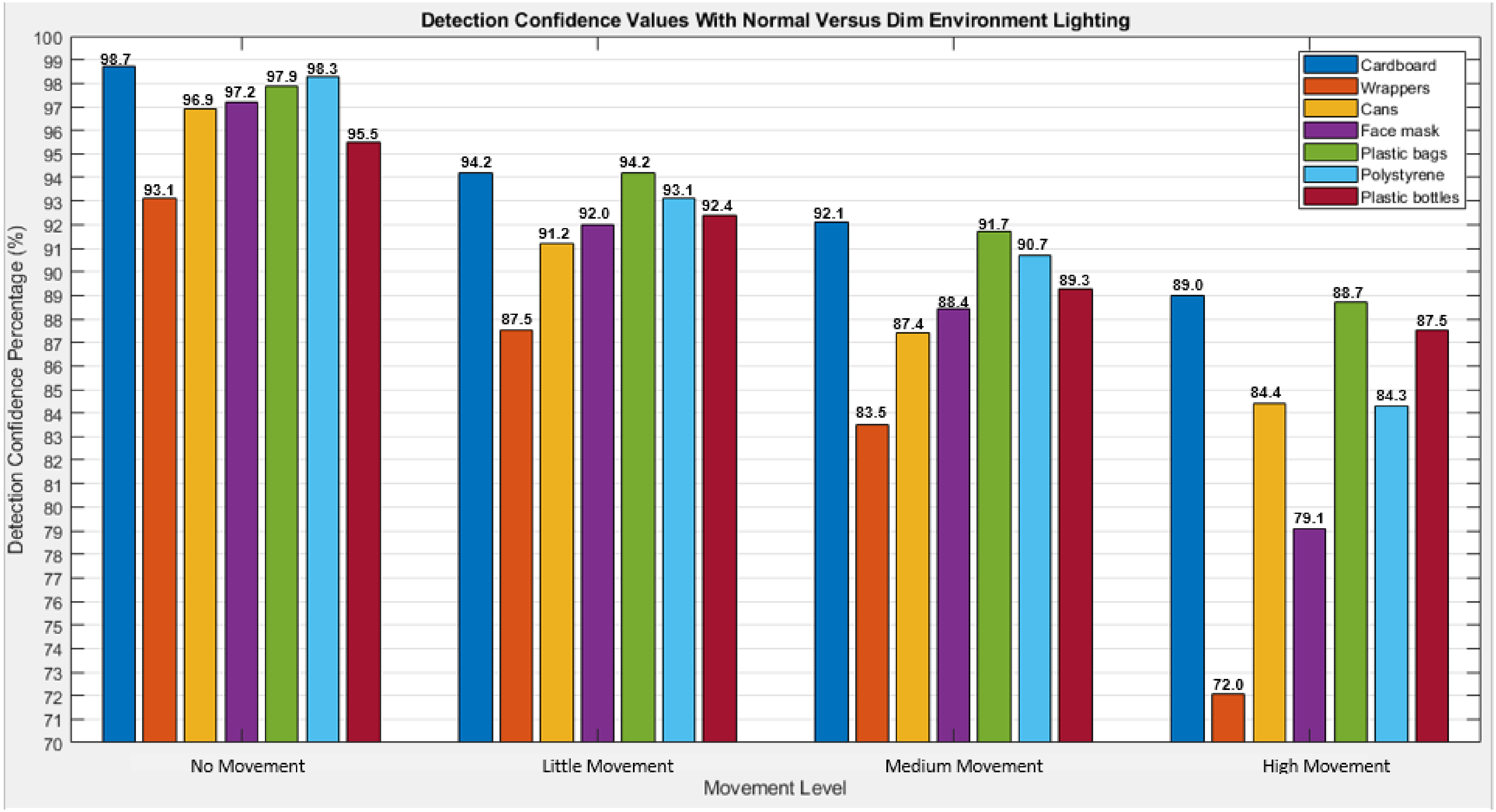

Figure 27. Movement level versus detection confidence percentage.

6.3 Can the robots still detect waste in relatively low light conditions?

This experiment's purpose is to test the custom detection system to see if it still can detect waste when the environment of operation has little light (i.e., during sunset, fog, or on very cloudy days).

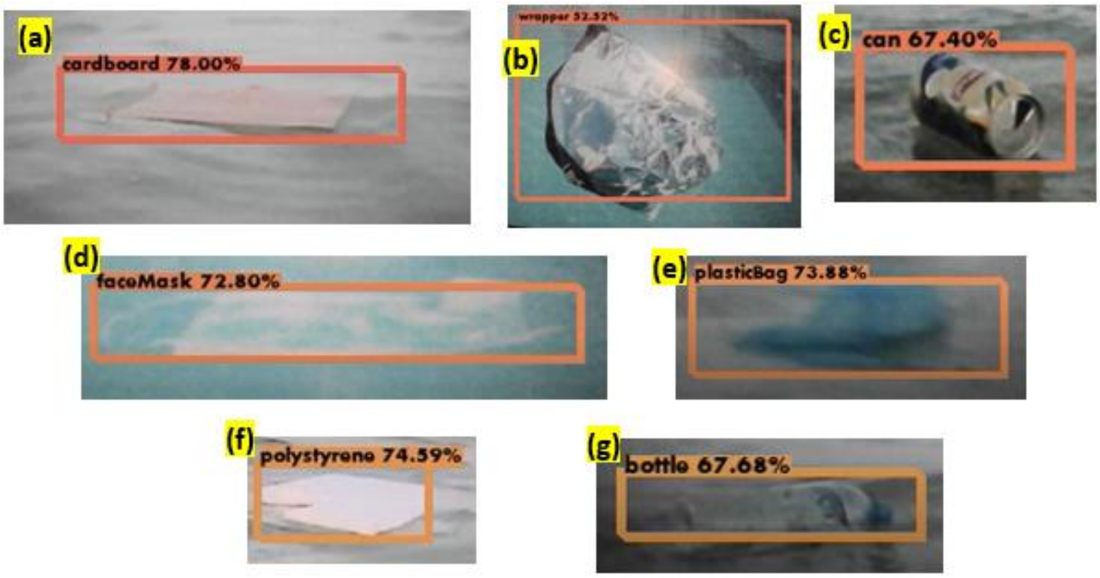

Figure 28. Presents detections of the categories in dim light. (a) cardboard (78.0%), (b) wrapper (52.5%), (c) can (67.4%), (d) surgical face mask (72.8%), plastic bag (73.9%), (f) polystyrene (74.6%), and (g) plastic bottle (67.7%).

For this experiment, the camera was fixed in place (No movement). A significant decrease in the confidence values can be seen in Figure 29. The proposed custom waste detection system's dataset consists of mainly images that were captured during the afternoon. The detections during normal and dim light, shown in Figure 29, have the same overall shape with cardboard being the best detected class while wrappers being the worst.

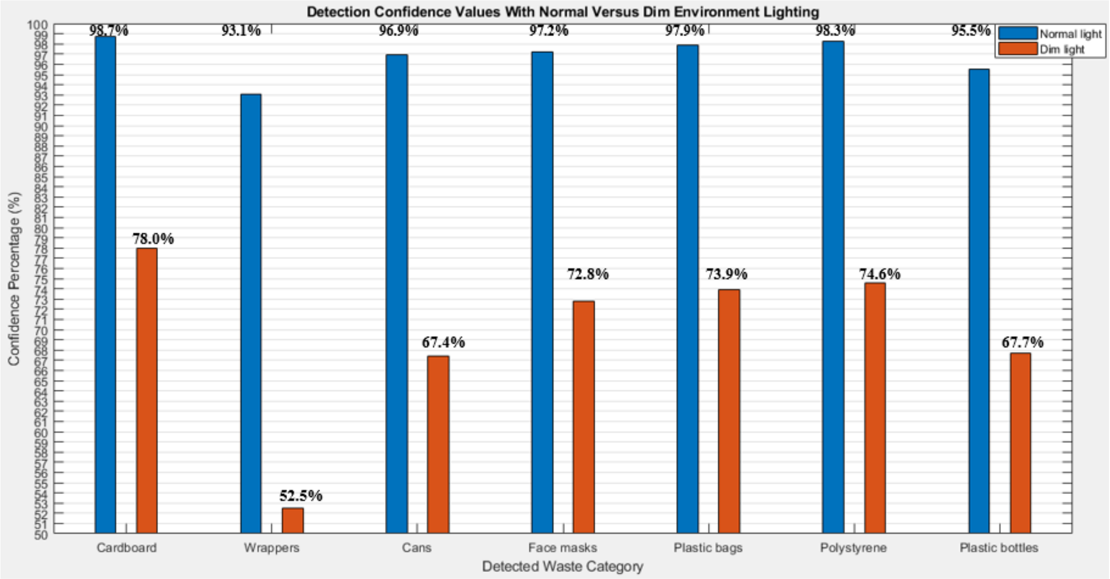

Figure 29. Detection confidence values with normal versus dim environment lighting.

Dim lighting conditions not only affect detection confidence but the object detection system's ability to correctly label its findings. For instance, shown in Figure 30 is a piece of polystyrene that was once detected as cardboard and once as a face mask. The reasoning for this error could be that when there is little light in the environment of operation, the captured live footage becomes grainy and starts to lose its colour. The loss of colour causes the camera feed to become nearly grayscale which may cause polystyrene, cardboard, and face masks to have a similar overall shape.

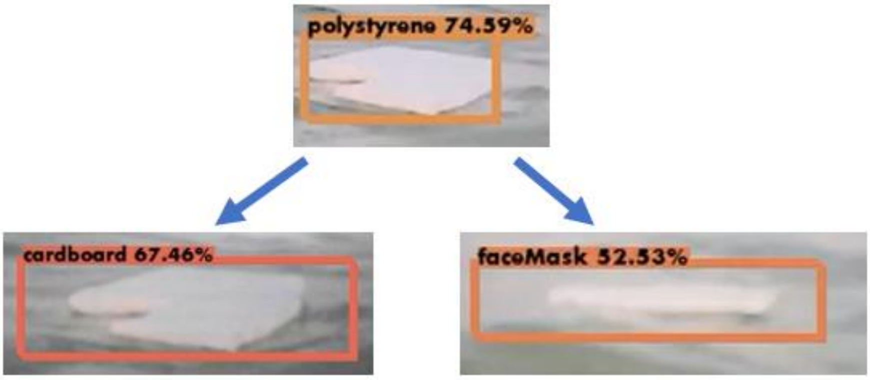

Figure 30. Polystryrene misclassified as cardboard and face mask in dim conditions.

6.4 Can the robot collect waste?

The custom waste detection system was successful in detecting the targeted waste categories. This experiment tests the robot’s ability to receive instructions and act upon them through its drivetrain. This experiment tests the robot’s motion which drives it to collect the detected waste.

With this dual motor setup, the robot achieved a speed of 0.67m/s, or 2.41Km/h, when driving straight with no waves present on the body of water. The robot was able to turn left or right, as instructed, towards the detected waste and collected it. Some changes can be made to the proposed systems as they will be discussed and detailed in the future work.

CHAPTER 7: CONCLUSION AND FUTURE WORK

The living conditions of current and future generations are dependent on how we treat our planet. One major issue negatively affecting our planet is surface water pollutants. Surface water pollutants could be introduced to bodies of water through littering, during the waste transportation process, and by these items being thrown down drains. Surface water pollutants have many negative effects on the environment such as tangling and suffocating marine creatures, destroying beneficial algae existing on the surface of the water, and the production of microplastics which are finding their way into our drinking water and food. With the aforementioned in mind, this thesis contributes to the ongoing efforts to combat the issue of surface water pollutants by proposing a partially submerged aquatic robot that detects and collects them. More specifically, this robot is capable of detecting and collect seven different categories of surface water environmental pollutants namely, metal cans, surgical face masks, plastic bags, plastic bottles, polystyrene, wrappers, and cardboard. These seven categories were selected after local beaches were surveyed. The robot itself is constructed from recycled, recyclable, upcycled, sustainable, and eco-friendly materials in an effort to further contribute to the cause. The solar powered robot has an onboard computer, that is recycled, which has a custom YOLOv3 waste detection system. The waste detection system was trained using images taken on local beaches and pools. The waste detection system was tested in terms of whether it can detect waste, how well it deals with movement and how effective is it in low light conditions. Finally, the robot was tested to see how effective it operates to collect the waste detected. The custom waste detection system showed promising results and is able to detect cardboard (95.29%), wrapper (94.14%), cans (93.75%), surgical face masks (93.15%), plastic bags (96.19%), polystyrene, and plastic bottles (93.80%). The values of the detection decrease as the movement level increased. Detection levels were affected the most when the object detect system was subject to low light conditions. In terms of the robot's ability to act upon its detections, the robot is able to move at a relatively high speed of 2.41Km/h to collect the detected waste.

Despite the promising outcomes achieved by the proof of concept presented in this thesis, there is still room for improvement. Future work includes collecting a larger dataset. Having a larger dataset will help in the detection system's ability to generalize as it will have seen more appearances and forms of that waste during training. Increasing the dataset's size includes adding more categories of waste and adding images from different operating environments to accommodate for the different regions of the world. Improving the robot's ability to work in low light conditions is another improvement. This can be done by strapping a lighting system to the robot and adding images obtained during low light conditions to the dataset. In terms of the robot's hull, further experimentation includes testing different types of floaters such as water bottles and jerrycans. Different drivetrain configurations need to be tested. This includes experimenting with a single motor setup for the drivetrain. Initial testing was conducted on a single motor setup, which resulted in a forward's driving speed of 0.4m/s, or 1.44Km/h. As for turning, a rudder style system will need to be designed, implemented, and tested. Implementation of a single motor setup will increase the robot's operation time, but it will probably decrease its ability to drive through larger waves. Finally, regarding energy generation and consumption, a larger battery is in the plans which will increase the robot's operation time.

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