End of Project Documentation

Project “Litter Bot”

College of Computer Engineering and Science

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CpE 190/191 and EEE 193A/B
Team 10
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Elevator Pitch

We are designing an autonomous scouring bot as a remedy to mitigate the man-made litter pollution and reduce the direct impacts that it has on Earth.

Executive Summary

For our senior design project, our team focused on the societal issue that is litter pollution and the harmful effects of trash being disposed of improperly for water sources, agriculture, animal life and everyday living. We initially focused on the effects of plastic litter left on beaches or in oceans, but as the course went on and with the way our design was headed, we chose to also focus our design philosophy on reducing the litter pollution in parkways, fields, and near busy streets. After agreeing on trying to help reduce the trash pollution left all over environments, team 10 started forming design ideas on what would eventually become project litter bot. When brainstorming how we would use an engineering approach to help clean up trash, we all knew that our project would be a robotics intensive device and so we chose to add crucial features such as object detection, four-wheel drive, and a robotic servo, as well as a supplemental feature of GPS boundary tracking. More elaboration of those features can be found in the design idea and test results section of the report.

After the team had a broad idea of what features and components we would use to kickstart the project litter bot, we moved on to creating a project timeline that fully outlined how we expected the work to be broken down by each team member and with work packaged specifically towards certain features and testing. However, midway through the project things got out of hand with testing causing many debugging issues, and upgrades that would set the team back and working overtime to meet the deadline, as explained in our testing results and test plan.

With a project litter bot, we had to create a risk management chart and the team came together to agree on which features needed all hands of deck to complete because things would go wrong easier for them, such as the robot arm that proved to be more complex and went through four different revisions. The design of project litter bot's deployable prototype focused heavily of being mobile and powering three microcontrollers, such as a Jetson Nano and two Raspberry Pi's, four 12V DC motors, and three to seven (micro) servos at a time, so making sure everything was wired correctly or not underpowered was a risk that would introduce itself time and time again within our testing.

By the end of the senior design course, the team had thrown in over a combined *1,786+ hours* into the entire project from beginning to end (that were officially logged in reports) and we truly feel that we managed to achieve all the features to their engineering measurable metrics that we had set from the beginning, with minor exceptions of our prototype not working as smoothly as hoped. But with a project that was solely funded by Team 10's members, we managed to get a robot that can drive on most terrain and grip onto plastic bottles and carry that litter onboard with a removable trash bin for a rough price of about $600. All of the hardware that was used for the mechanics and power can be found at the end in the appendices or in the report with explanations on why some upgrades were needed or preferred over other components. The software integration for the arm, GPS, and machine vision, such as what makes project litter bot detect certain trash and not others as well as, can be found in the deployable prototype section, testing result section, as well as the appendices.

Abstract - Litter pollution is a societal problem that has caused a disruption in the aquatic life's food chain, has stunted agricultural plant growth, and continues to contaminate water systems such as rivers, wells, lakes, oceans, etc. Our approach to mitigating pollution that is a result of litter that ends up in the waterways or in public parks comes in the form of a trash picking robot, which we have named the "Litter Bot." When released into an open area, the device uses machine vision to locate bottles and an arm that extends out and grips onto plastic bottles and then puts them onboard a removable trash bin via the base. Before project Litter Bot got to that stage, however, team 10 spent the first semester designing the driving system, GPS, object detection, and arm and then created visual charts to break down the work into packages for each team member to divide and conquer building and testing remotely, due to results of the COVID-19 pandemic. After getting individual features to work, the second part of the course encompassed integrating all pieces and making necessary hardware upgrades to all devices, such as newer motors and three variations of the arm, and due to the limitations of our programming, funding, and hardware, we believed that our device is better suited for park clean up maintenance and cleaning fields for markets such as Caltrans or city companies. The overall build cost of the Litter Bot variations was roughly $600 and included over 1786 logged hours of work.

Index terms - Autonomous, Activity, AWD,All-Wheel Drive, All-Terrain, CAD, Brushed, DC, Deployable, Feature Set, Gantt, Task, Tourism, Trash, Beach, Litter, Locomotion, Machine, Marine, Milestone, Motor, PERT, Pollution, PLA, Plastic, Project, Prototype, Robot, Risk, Servo, Sensor, Ultrasonic, Vision.

I. INTRODUCTION

A. Introduction - Societal Problem

We have a problem as a society when it comes to pollution. Litter is piled up in places like the Great Pacific Garbage Patch which was created by humans who carelessly litter onto the ground. Most people do not realize but that litter has the potential to reach our oceans and pollute our waterways. This causes the waters to be contaminated with chemicals from things like plastic bottles and the fish drink that water and they get sick. The wildlife also does not realize that this is trash so then they eat it thinking it is food and that ends up in their stomachs which is indigestible, and the result is that they die. Littering is a major problem to marine life in oceans and other bodies of water with beaches. Many people that have parties on beaches or carelessly leave trash near the oceans are contributors to things like global warming that can be a direct result from their actions. Tourism has a major impact towards litter getting into the oceans because litter gets blown away into the ocean by wind poisoning the environment in which the fish lives in.

Litter, even if it doesn't poison the fish or the environment, can also block sunlight which is vital to the ecosystems in the ocean and other bodies of water. This causes things like sea otters to have a disrupted ecosystem because they eat sea urchins that eat the coral on the coral reefs. Coral reefs thrive off of sunlight and depend on it to live but when litter is there blocking that, it can cause problems and as a result some wildlife would die off. The major impact that some people are still denying in our current year is the direct impact that pollution on our lands causes global warming. People that litter most times are ignorant to where it may end up. Litter that is thrown on the ground like plastic is not biodegradable which means it cannot be broken down by natural processes. Littering is a major contributor and incineration of things like plastic bottles would cause greenhouse gasses to rise and this would result in an overall increase in global temperature. Our world is constantly changing, and production rates are increasing on things that have potential to pollute the Earth. This is a result of the demand from consumers and then obligations by corporations to supply them.

Policies have been implemented and fines have been given to offenders, but it is very difficult to keep track of everyone who pollutes the lands. This prevention of littering is based on the integrity of people and their decision of disposing it correctly or incorrectly. The impacts of climate change have been more vastly spread and more people have become aware. Our efforts in the next couple of years will determine the lifespan of Earth as we know it. Global warming is a major problem that we are facing, and many people are ignorant to its effects and how it can tarnish the world. Awareness and enforcement are key to defeating global warming because soon enough it will be too late to save Earth and we would have wished that we have taken action before.

B. Introduction - Design Idea

Our team plans to tackle this littering problem by developing a litter picking robot to help prevent more litter from getting into the ocean. The major hardware components of the robot consist of a chassis that holds the robot components together, the wheels and the motors that drive them, the robot arm that picks the trash, the machine vision that use the cameras to guide the robot's navigation and the arm to grab the trash and the Raspberry Pi that would be controlling everything. This robot would drive itself around at places like beaches using machine vision to guide its way towards trash while avoiding other obstacles such as people and water. It would then pick this trash with a robot arm guided by machine vision and distance sensors then place it in the trash bucket on the chassis. This would complete a cycle and cause less hassle upon people like sanitation workers who have high physical labor jobs. This design idea creates an innovative engineering approach to problems that are very serious and vital to the preservation of keeping Earth healthy longer.

C. Introduction - Work Breakdown Structure

Given that we have to work online with minimal meetings due to COVID-19, we would have less of an ability to help each other with the tasks and work together. We will be using Python on a Raspberry Pi for the most part because it's easier to deal with given the circumstances. We have divided our project into several major features: Identifying Objects, Drive Train, Navigation System, Holding Objects with Robot Arm, and Power Sources.

Vadim will be the lead for Identifying Objects which would be using a camera attached to a Raspberry Pi with the OpenCV library. Since this will be the main eyes of the system, we can also use the camera to help navigate with the help of computer vision when it identifies objects as litter or not litter so that we know if the robot needs to go towards or away from the object.

In order to get around, we have the drive train which Ricardo will be the lead of since he is our only EEE major, he has more knowledge of it than the rest of us. It will be all wheel drive so that the robot has less of a chance to get stuck somewhere and would allow us to drive over unpaved terrain. The code will utilize Python 3 using a Raspberry

Pi Zero W to keep it simple and within reach.

Then we have the Navigation System which would help the robot stay in an area within a given amount of meters with the help of GPS so that it doesn't wander off and get lost. Vaukee will be leading this feature which gives us an option to have a path that the robot will take to try and clean up rather than randomly finding litter. When the navigation system sends a signal, then it will light up the robot and notify the user that the robot is of course and try to readjust itself to go back into its set boundary.

Deven will be in charge of the robot arm portion of the project. This will also be controlled with a Raspberry Pi using Python code. First he will make the arm move with simple code then move on to make it move in a more fluid manner when it goes to grab the object that has been identified as litter by OpenCV.

Ricardo will be in charge of the power supply. For testing purposes, we will start with using power supplied directly to Raspberry Pi controllers either with a usb connected to the microcontrollers or with a direct AC-to-DC power supply connection from the walls. Because our motors need 12v to operate and most raspberry pis operate at 3.3v or 5v, we will need to wait on the robotic arm and sensors that Vadim, Vaukee, and Deven are working on in order to determine how much power will be consumed per hour. Once all controllers and motors are taken into account, then we will use either Lithium-Ion batteries and create our own power bank that connects to a controller or bridge and supplies power to them all, or we may have to resort to having usb power connections to the wall or another pre-made power bank capable of high power for over 10 minutes. The solution to the power bank will likely come near the end of the project when all parts are complete and is expected to take around 25-40 hours to figure out the most ideal sources of power for the prototype.

D. Introduction - Project Timeline

Now that the work breakdown structure is set and each member from team 10 is given features to work on a test, there needs to be a way to visually track the progress that the team is making. The team was assigned to work on creating a Gantt chart, which is a visual bar chart that helps illustrate what tasks are being done during certain time frames and who they are being done by. Vaukee went ahead and took initiative to format the Gannt chart the team would refer to for the remainder of the senior design course and the team filled out in a sequential order what activities for the features they were expected to work on in a sequential and weekly manner. These activities have deadlines created by each team member and they are required to be met by the selected team member. If they are not met we have promised to mention it to the team and we can help each other out to stick to the deadlines.

The team has assignments that range from the beginning of the first semester in August all the way to the final presentation of the device in May. The Gantt chart is full of course assignments that the team works on as a whole, such as the occurring report section update assignments and outgoing team leader reports that highlight how the project is going. Aside from the team tasks, we have each team member showing their responsible tasks to complete a set feature and when they are expected to complete the tasks. These responsibilities were based off of the work breakdown structure assignment and feature set punch list from the fall semester. This will be our guide to the end of the project in May 2021. We understand that life occurs and we are very involved in our project and each member is devoted to completing the feature set they have selected.

Our project timeline shows that Vadim will be working on using OpenCV in order to get machine vision working properly throughout October. Ricardo will be designing a more suitable base to get the robot locomotion working with reduced physical obstacle interference from the end of october to mid november. Deven will use an initial arm built by him to allow him to complete the feature of grabbing small objects for the month of November. Vaukee will be implementing the GPS aspect of the project through the end of November, allowing the Litter Bot to have a boundary. The Gantt chart also shows all of our contributions to the feature set of our Litter bot.

Not only did the team create a Gantt chart to visually guide the project, but a PERT diagram was also created and uploaded to the team's Microsoft OneDrive and it was created to show the project's task dependencies as well as the project's overall milestone. A milestone, as decided by the team, includes finishing successful tests on feature sets that we each worked on that contribute to the overall completion of our project. We all have goals that we are trying to attain in the month of November and these goals will be expressed in the PERT chart that we will complete. Other milestones include course milestones such as completing the bigger report and OneDrive upload course assignments throughout the semester. These milestones will give us as a team a reference to where we are currently in the project and if we need a new pace to allow the project to succeed we can do that.

Milestones by each team member for the time being will be the following. Ricardo will develop a chassis and have the efficient amount of power to the multiple Raspberry Pi microcontrollers, the robot arm and for the bot to move along different terrains which requires more power. Deven will develop a robot arm that can move using Python code to grasp small objects and put them into a trash bin. Vaukee will give the Litter bot GPS and create a "safezone" for the bot to travel to avoid any possible hazards like water. Vadim will use machine vision to identify objects that can be used on the arm to allow the bot to become autonomous. These features that we have expressed in our feature set will be included in our prototype in December.

We have completed the first three assignments of the semester and we are currently finishing assignment four on the first of November. We have five weeks until the prototype is due and we just have 3 assignments left to complete that include the risk assessment, project technical evaluation, and the lab prototype presentation. We are almost complete with this Fall semester and then we will be using that prototype to aid us through the Spring semester. In the Spring we will be expanding on the project and creating the best possible version of our build. We will be improving our machine vision recognition, we will be using an arm that will be the best and determine if we need to improve our code and add some degrees of freedom. We will also be improving the chassis and any power implications that we think that need to be improved on. Then lastly we will improve our build to have an impeccable GPS recognition and allow our bot to be absolutely autonomous and self sufficient.

E. Introduction - Risk Assessment

The Litter Bot will have some risks when building and operating it. The risks that we have have mainly come from the power and the ability for it to catch fire. When it comes to the robot arm, the multiple servo motors and a raspberry pi which has the potential of overheating can cause the arm to catch on fire. Since the arm will be bolted to the chassis then if this arm catches on fire then it can be very crucial for the project if in fact it does catch on fire. If this were to happen then we will follow proper procedure to put the fire out and assess the damage. The other risk associated with the arm is the risk of harming the operator. Since the arm moves fast and has many joints, it has the risk of pinching fingers if someone was to move the arm. These moving parts can inflict pain to oneself and we must assess the risk when operating the arm.

On the software side of the arm, there is always a reason to malfunction and when all of the parts are put onto the bot we will run many tests as a team through virtual means and prevent these small malfunctions from happening during demo. The risks above will be accounted for in our final prototype. The team has concluded that if there was to be damage to the arm then we will purchase a new arm that is the same so that we know how to prevent these accidents from happening again.

Our navigation system relies on GPS and the potential risk for this would be the inaccurate acquisition of location data, hardware failure, and software failure. The GPS is tried and true as it has been with us for a long time and is quite robust. The only thing we are worried about in our case of hardware is water damage or ESD (electrostatic discharge). Prevention of water damage includes a decent IP rated casing. ESD will be covered in the risk assessment of our power supply system. The change in software may play a role in preventing our navigation system from working but the risk is minimal.

There is always a risk of unreliable data obtained from the GPS module but we also have information that can be obtained from the IMU. The IMU contains many modules like an accelerometer, gyroscope, and magnetometer. These components may provide some redundancy to prevent many risk factors that we probably haven’t taken account for.

Machine vision has some risk with misidentifying objects as something that was not intended. If it were to confuse one object with another it could try to pick an object too heavy or an object too valuable to be thrown away as trash. This can be mitigated by adding a large number of images for each object so that it has a bigger selection to identify objects from more properly. Also, there’s a risk of it not identifying objects fast enough if it has too many objects in the selection to identify, so we upgraded the microcontroller from Raspberry Pi 3 to 4 which has a faster processor by 100mz per core and 4 times more ram. A faster processor usually means more heat from the chip, in which case we got a hopefully sufficiently large one which has been keeping it cool enough so far.

Furthermore, there is a big risk of not completing one or more features on time. If we needed to test how some of the features worked properly we would need to test it with other features. For example, we need machine vision and the robot arm to work together where the machine vision would identify an object and the robot arm would then know to try and pick it up. Another example would be the drive train working with gps, since the gps can’t keep the robot within a designated perimeter without the drive train and the robot wouldn’t know where to go if it got lost without the gps.

The team plans to complete certain aspects of the project and then hand our parts off to the team leader and have the leader demonstrate the project. We will handoff the features to the team leader while practicing proper social distancing. We have included our risk assessment chart to create a visual for the reader and display our context into a readable diagram. These include the risks that have been mentioned based on the probability of it happening and the severity of the risk on a scale of one to five. The risks that we have are not hazardous but they have potential of happening and this is why we assess this into our project.

F. Introduction - Revised Problem Statement

Realizing our societal problem was a big hurdle in of itself as there exist many high impact and high severity issues. We ended up going with the problem of litter or waste that would eventually end up in the ocean. Our focus is to mitigate the overall contamination of our precious oceans. This phenomena is currently happening all over the world with the coastal cities contributing to much of the ocean contamination. There exists various issues that may be solved merely by mitigating ocean waste.

Our solution provides a cascading effect. For example, if we start with urban parks this will allow our parks to stay cleaner and safer for children and animals. The resulting effect of this means that less waste ends up in our rivers and if our rivers carry less waste then the ocean will not be as contaminated. Less waste in the river will also have positive effects for the life that thrives there and the same goes for the ocean being a huge mass of water that supports all life. The biggest player in polluting the ocean and thus polluting the planet is Asia. Trash in the ocean contributes to global warming as sunlight and heat cause the plastic to release powerful greenhouse gases, leading to an alarming feedback loop. As our climate changes, the planet gets hotter, the plastic breaks down into more methane and ethylene, increasing the rate of climate change, and so perpetuating the cycle. Impacting marine life will impact us as well. The food chain can be disturbed as the main source of food for certain species dwindles. The original target of litter was to have a robot near waterways or on beaches to more effectively collect litter but from what we have it would be easier to have the robot move on mostly flat surfaces like urban parks where most folks frequent.

As for our design idea, we decided we didn't need to modify the current feature set as we only need to optimize them. For example, we stated that we wanted machine vision to detect certain objects like water bottles 1.5 meters away but reducing that to 1 meter will be much more beneficial when it comes to determining the object at hand. We can get a higher accuracy reading. Vadim opted into using an Nvidia Jetson Nano for better machine vision performance.

Our current multi axis arm was just a show that we can get the arm to work properly and grab a bottle but our new arm will be able to hover the bottle over the bin to be dropped. The new arm will be able to move with much more freedom. Our 4-wheel drive is working as it should using all terrain style wheels and the GPS perimeter is also working. The only problem with the GPS perimeter is that it isn't very accurate when there is no access to clear sky meaning that if there are lots of buildings or trees the accuracy will drop. It is expected that the GPS will not be greatly affected by this problem when it's outside in a park with a decent amount of trees. This also means that our work break down will remain relatively the same as it and the timeline greatly relies on our feature set. We do expect to add on to both the work breakdown and timeline as some things are not completely certain further into the future.

G. Introduction - Device Test Plan

In prototype design, having a test plan is a surefire way of getting the correct final results. In our case, we want Project Litter Bot to be able to navigate around within a certain range of a home location and pick up litter that has been identified with computer vision. For this to succeed, we want to divide and conquer by working and testing on each feature of Litter Bot.

The all-wheel drive system is going through rigorous testing as it needs to be able to move through various terrains at a constant speed of 1km/h and the dc motors must maintain a constant load and torque. The power system is tested to keep power to all devices and the motors. Testing on the motors must allow them to operate for 30 minutes. The robot arm is being tested for repeatability in picking up objects consistently and in various positions.

The GPS boundary or geofence has to consistently tell the computer of the robot that it has gone out of bounds and must return into bounds within the accuracy of the GPS system itself. Our machine vision is put to the test by facing off against various types of objects in different conditions such as longer distance or different light levels. We expect machine vision to be able to detect objects within 1.5 meters. After all the individual testing of each feature, we plan to pair two features with each other: machine vision with the robot arm and the AWD system with the GPS boundary. The test for the first pair being machine vision and robot arm is to allow for machine vision guiding the arm in picking up litter. The next pair of AWD and GPS is ensuring that they work in conjunction with the individual tests still being involved.

H. Introduction - Market Review

The market for a maintenance type robot is very small and immature but the technology is definitely there. Currently the demand isn’t as great and the people in the world are getting careless and lazier as time goes on. People just want convenience so they throw their trash just about anywhere. It is just sad and we can’t really enforce the rule of “No littering.” There are numerous signs that say “No Littering” with language stating the fee that will incur if the offender is caught. Usually these people are never caught. This means that people of good heart or people who are paid to have to clean it up.

Our design might just make such a behaviour worse but the premise is to make the world a cleaner and pollutant free place. We believe our device will mostly benefit the employees of the government and small businesses. The government tends to spend millions of dollars on cleaning and maintaining our environment through paying employees and the tools required. Let's assume that an employee at Caltrans makes $16 dollars an hour in a typical full-time shift with a work week of 5 days a week for 8 hours a day. This means the establishment will be spending over $30,000 on one person a year. We can also assume that the simple tools for picking up litter such as a trash picker and a bucket can cost as low as $20. If Caltrans employs over 4000 maintenance employees in 2019 this means that they spent over $120,000,000 in the year not including the cost of tools and replacement tools. We can also assume that the actual hours of picking litter is more than half of that meaning that less than $60,000,000 is spent as labor. Currently the design cannot accommodate working next to moving cars near the highway but despite the fact, we can put out 20,000+ Litter Bots to match the cost. This is a one time cost versus an annual cost so companies such as Caltrans can save a lot of money and use it for other maintenance!

I. Introduction - Test Results

We have come a long way to get this far into our senior project. For this assignment, we need to test all the individual features to a measurable metric. To start off, Ricardo has passed all but one test. The first test is for a consistency in speed. The speed must be kept consistent at 1 kilometers an hour over various terrains and it will also have a load that it must carry. For this test, the robot will also be carrying about 4lbs on its back. The other test is for consistency with the RPM of the wheels and the current draw that comes with it when there is a high load. Then he will be testing the battery life of the system. The goal of this test is to make sure that the battery can sustain the system for about over 30 minutes.

For Deven's part, he is in charge of the arm and will test each servo to make sure they all work together to reach an object. He will also be testing for bugs in his programming so that the arm can be integrated into the whole system. After this is taken care of the end-effector or the gripper will be tested to make sure that a bottle or can can be grabbed from various positions.

Vaukee is in charge of the geofencing and will be testing the accuracy and precision or repeatability of the system. The accuracy is based on whether the GPS module is inside or outside. For the repeatability or precision test, the test of whether the robot will return within the radius of the geofence will be looked into.

Vadim is working on machine vision and will be testing to see if his feature will allow the robot to detect multiple objects and keep up to a 70% accuracy. After he has made sure that the accuracy is at 70% or above, he wants to make sure that the robot can be guided by his feature to a bottle or can that is on the ground. While he is doing this, the test for a signal to tell the robot arm to grab an object will be emitted. The Jetson Nano will also be tested for durability as it will be running at almost 100% throttle so that it will not run into issues later on such as crashing.

Finally, the end of this extensive report of Project Litter bot ends with the concluding statements of the two-semester long project and with multiple pages that showcase the references that were used for our studies or for our hardware and software. After the references, we have a glossary that defines in more detail one of the jargon used by our engineers throughout the report or during presentations and we finally wrap up the document with all of our appendices that have also been referred to in the report, but show in more detail the hardware components and software code that made our project come to life, as well as additional appendices defined in the table of contents.

II. SOCIETAL PROBLEM

A. Tourism and Marine Life

Littering can cause serious pollution that many people do not realize. Most people think of littering as just a little trash on the ground but what they don't think of is that the trash often ends up in lakes, rivers and the ocean. Especially when it's tourism near beaches.

The tourists didn't show up to make sure that their vacation spot is going to be clean and if they do leave a few things behind, the people working there could clean it up. Eleven beaches from Santa Marta were selected for a litter sampling as shown in Table I below.

Table I.

Sample Beaches [1]

Beach	Coordinates		TL (km)	EAE (km^2)[c]	Type of beach[d]
Cristal	11° 19.652′ N	74° 4.628′ W	0.33[a]	0.007	Remote, natural park
Neguanje	11° 18.933′ N	74° 4.846′ W	0.88[a]	0.009	Remote, natural park
Grande	11°16′17.01″ N	74°11′48.88″ W	0.19[c]	0.004	Remote
Blanca	11°13′7.52″ N	74°14′18.44″ W	0.40[c]	0.008	Remote
Concha	11°17′49.82″ N	74° 9′0.12″ W	0.93[b]	0.019	Village, natural park
Taganga	11° 15.920′ N	74° 11.468′ W	0.51[b]	0.004	Village
Camellón	11° 14.557′ N	74° 12.938′ W	0.70[b]	0.012	Urban
Los Cocos	11° 14.231′ N	74° 13.121′ W	0.27[b]	0.014	Urban
El Rodadero	11° 12.266′ N	74° 13.679′ W	0.88[b]	0.059	Urban
Cabo Tortuga	11°10′18.34″ N	74°14′4.07″ W	0.56[b]	0.022	Urban
Bello Horizonte	11° 8′41.70″ N	74°13′35.17″ W	2.71[b]	0.015	Urban

Table I lists the 11 Santa Marta beaches and their parameters used to conduct research on litter in beaches [1]

The sampling was conducted during low tourism seasons as well as high tourism seasons. The standardized numbers of the people on these beaches were between 1600 to 24,000 during low tourism seasons and 4500 to 103,000 during high tourism seasons [1]. Although the number of people during high tourism seasons was much larger than low tourism seasons, no significant difference was found. A sampling of litter was conducted as shown in Fig. 1.

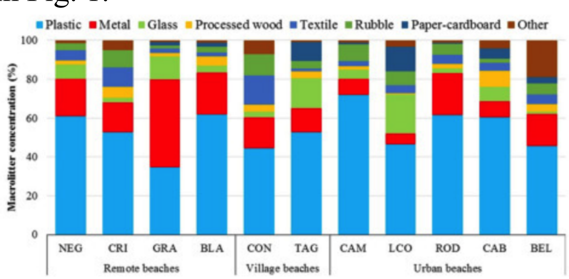

Figure 1 - Concentration of Litter Sample From Beaches [1]

With plastic being the most common litter in a concentration of items per m^{-2}. Of course this isn't all due to the tourists being lazy or hating the environment so much, though there are a few like that, there are other factors that come into play such as wind blowing away their disposables out of their reach or they get buried in sand. In areas where the commercial services are easily accessible such as hotels, stores and restaurants, often the beaches get cleaned regularly by public servants. But they often only clean bigger litter such as cups, plates, cans and such leaving the smaller litter such as cigarette butts and soda tap behind. As a result, the smaller litter is pretty much guaranteed to get into the ocean where it's likely to get mistaken for food and get eaten. That being said, cigarette butts also contain harmful chemicals that are dangerous to marine life. As a matter of fact, studies have shown that 6.5 trillion cigarettes are smoked yearly on average, and about 4.5 trillion of them are littered onto our environments [2]. This puts marine life in danger whether they eat it or not, the cigarette butts will pollute the water.

But if the beach isn't easily accessible by commercial services such as a remote beach that isn't advertised or easily found, the litter would likely be blown away by wind into the ocean or another body of water because there aren't public servants in those areas.

According to Derraik 2002 and Barnes 2005, about 2.3 billion pieces of trash were found in Southern California beach which weighed 30,500kg over the course of 72 hours [3]. If this trash didn't get cleaned up it would have ended up in the ocean polluting the environment. Of the trash found on beaches or floating in the ocean, about 60-80% of it is plastic. Sea turtles can mistake a plastic bag for jellyfish. In 2011, about 33% of catfish, in an estuary in northeastern Brazil, had plastic debris in their stomach. According to a study in the North Atlantic Ocean, the longnose lancetfish is heavily affected by plastic pollution [4]. Between 2015 and 2016, 27 specimens were captured and dissected.

They were captured far from beaches as shown in Fig. 2, so the litter will travel far to disrupt ecosystems.

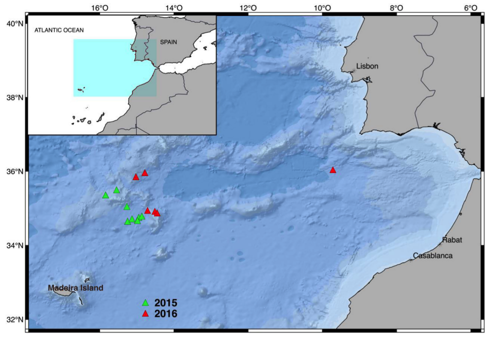

Figure 2 - Location of the Lancetfish Samples [4]

Microplastics were found in 37% of the fish with an average weight of 0.46 ± 1.14g while microplastics were found in 74% of the fish with an average of 4.7 ± 4.8 items per stomach.

Litter is a serious threat to marine life even if it doesn't contain harmful chemicals that would pollute the water or if the litter is small enough to be eaten. If there is enough litter floating around, it could block the much-needed light from the sun for the ecosystem below as demonstrated in Fig. 3.

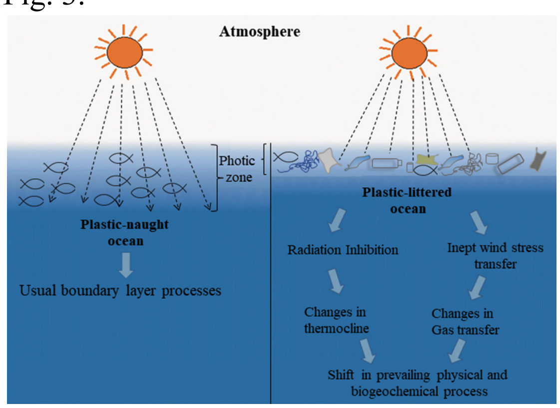

Figure 3 - Graphical Abstract of Floating Litter Effects From the Sun into the Ocean [5]

Since most of the litter is plastic, it won't degrade as fast and continue to block the sunlight while the ocean continues to collect more litter. Then while the litter decays, it pollutes the water releasing toxic chemicals and decreases the oxygen levels.

B. Climate Change

Pollution is one of the many driving forces for climate change on Earth. Some policies have been implemented by our government to try and regulate this impact of climate change. However, enforcing these policies is very challenging because there are so many people in the world. Many people in our government do not believe in climate change which also contributes to the destruction of our planet as a result. The best thing to do is to just make people aware of the effects that litter can cause to Earth and hope that these people will do the right thing.

People that litter most times are ignorant to where it may end up. Litter that is thrown on the ground like plastic is not biodegradable which means it cannot be broken down by natural processes. Therefore, this plastic ends up in waterways that can have the potential of being eaten by sea life and get stuck in their stomachs. Seals, seagulls, whales, and many other wildlife are affected by the trash being put into the ocean by humans. I know we all have seen the dissections of these creatures who have their stomachs full of plastic. This comes directly from our actions and even though we may not throw it in the water it always ends up in the ocean. Ocean currents then move these pieces of trash and in the Pacific, there is a patch called the Great Pacific Garbage Patch. The size of the patch is twice the size of Texas being over 1.6 million Km in size [6]. Fig. 4 shows the different types of trash found in the patch in a study in 2010.

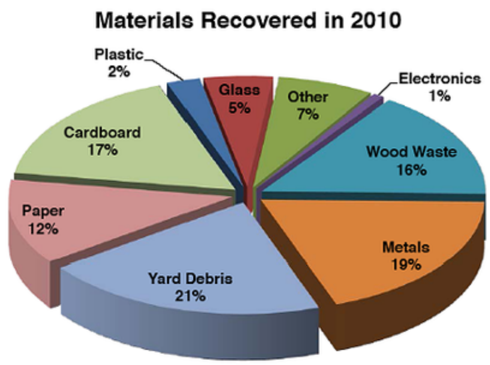

Figure 4 - The Chart Above Shows the Composition of Litter in the Great Pacific Garbage Patch Analyzed in 2010 [7]

Many policies have been implemented in our government that include fines for littering and recycle policies. However, putting climate policies sometime can be challenging especially since many are poorly understanding the effects that litter has on climate change. Ultimately there is a synergy between these policies and national development goals. Climate change mitigation in rapidly growing developing countries is receiving increased global attention, especially after the 2016 Paris Agreement [8]. The world is constantly changing and that calls for more production of things that have potential to hurt the government. On the other hand, the government is trying to regulate companies from polluting the environment but allowing them to produce products that the consumers may need. Also, the population is constantly increasing which calls for more production which pressures companies to produce more things like plastic that has a high probability of arriving at the waterways. Fig. 5 shows the plastic offenders in tonnes by country and really gives a sense to the reader about how serious the problem is in their river systems when talking about plastic pollutants ending in the ocean around the world.

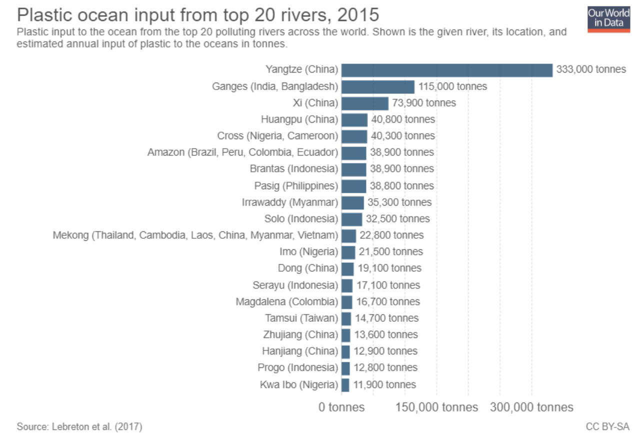

Figure 5 - Analytical Bar Graphs Showing the Plastic Offenders by Country in a 2015 Study [9]

There is a conflict of interest with people who believe that climate change is real because they do want more production of things that can harm the environment, but they want to save the oceans as well. There are always going to be believers and deniers for climate change. The left-wing candidate handles environment challenges better while the right-wing candidate proposes the more pro-industry approach to the situation [10]. So, government policies may be implemented, however the way that they are enforced around the world are dependent on their political beliefs. Politicians have modeled their campaigns to compete for the support of the voters who can be swayed by policy rather than someone who takes action on problems that the Earth faces. Climate change is happening as our summers are getting longer and our winters are getting shorter. Laws can be made, and policies can be introduced however there is not that much action, and this creates a major problem because as time goes on the Earth is exposed to more harmful effects from pollutants. Then as a result greenhouse emissions increase and cause the Earth to increase in temperature.

Climate change mitigation has increased in many parts of the world due to the increased awareness of its effects. By curbing greenhouse gas emissions these pollutants become less hazardous and overall reduce environmental pollution [8]. Many more policies have been implemented and the reliance on low-cost, carbon-intensive energy solutions, while ignoring environmental concerns has made it difficult for the country to reduce its emissions. As a result, there has been little progress made when trying to accomplish the reduction of harmful effects on the Earth.

Earth as we know it in the future will be directly affected by our actions. Climate change is not just a single issue but rather a complex issue involving multiple disciplines including economics, energy, ecology, agriculture, health, and security. There are so many different opinions on if climate change is real or not, but many people have started to try and project climate change. Generally, climate change is determined by climate models with projection of anthropogenic greenhouse gas concentrations [11]. Primarily, the climate model used to determine emission scenarios are called the integrated assessment models (IAMs). These are used by depicting a chain of causes of climate change from energy, economics and climate policy. These tools are used to help predict climate change so that us as humans can take action now instead of taking action when it is too late.

Carbon dioxide is one of the main sources of greenhouse gas and one of the contributors to climate change. Fig. 6 shows how atmospheric carbon dioxide emissions are increasing at an alarming rate over the last ten years. These rising carbon dioxide levels only create future problems as the years go on.

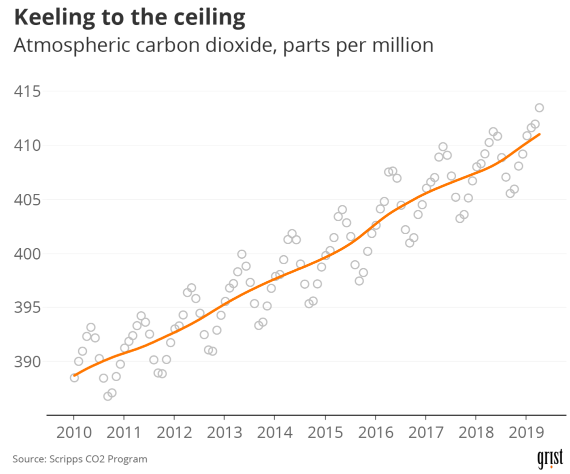

Figure 6 - Rising CO2 Emissions in the Atmosphere in the Past Decade Range From 2010-2019 [12]

We can see from the chart that there is an average of about 2 parts per million increase in carbon dioxide every year. This means that the overall temperature of the Earth will increase and things like polar ice caps will melt faster and many more polar bears will die off. I know that 2 degrees does not seem like much but if we put that into perspective over the next decade that would be 20 degrees increase to the current problematic temperatures that we already are experiencing.

Climate change affects everyone, and our actions today determine if we will have an Earth in the next couple of years. With rising global temperatures and increasing greenhouse gas emissions the predictions suggest that we determine a plan to reduce emissions and stop the constant increase in temperature. Littering can be controlled by humans however ignorance about climate change is a key factor in the poor actions among our society. This is a societal problem that we all must face and being that it affects everyone living, it would be insane that we all do not take action.

C. Waste Overwhelming Parks

One big factor that was overlooked previously was just how much trash there is amongst urban parks. Litter pollution is not just affecting marine life and climate change indirectly, it is also affecting the safety of families and critters that visit parks worldwide. A study was done in New Orleans where more than thirty recreational parks were being visited in order to observe litter and trash thrown around and the results proved that almost half the parks had items such as cups, food wrappers, glass bottles, and even condoms lying everywhere [13]. Although there are not many documents that have been released publicly that highlight how polluted with trash the nations or states' parks are, it is crucial to realize that this is just one state's results. With that in mind, there are most certainly hundreds of parks worldwide that have litter cluttered all around them, which detriment the natural wildlife living there or affect kids who are young and touch everything they see on the fields or near the park paths. Ideally, alitter bot could be used to help reduce the trash that gets swept into the parks and have it be placed next to actual trash containers in order to reduce litter getting swept into water sources near parks and contaminating the animal life. Also, cleaner parks are more attractive and tend to be safer to utilize for recreational purposes for those who seek a safer environment.

D. Filth and Costs Amongst Freeway Litter

As the first half of the senior design course was coming to a close, team members started to notice just how much more the freeways have become polluted with trash. Freeways are the best form of commuting from town to town and with large amounts of traffic driving on them all day, everyday of the week, there are some bad apples or "litterbugs" who lower their windows and throw away their trash onto the side of the roads. Eventually, there is a pileup of trash in between both sides of the freeways that have been moved by the natural winds or from the wind force created by cars driving at high speeds near the side of the road.

The problem with trash accumulating on the freeway is that it becomes dangerous to drive around due to it creating roadblocks, popping tires, or fueling the flames of fires started by man or lightning. These are just a few examples of how we now better understand more risks associated with the societal problem of litter pollution contaminating the world we drive in. According to the California Department of Transportation and California Highway Patrol, "Caltrans collected 287,000 cubic yards of litter in 2019 alone—enough to fill 18,000 garbage trucks...35 percent resulted from efforts by the department's community volunteer programs, saving California millions of dollars and untold associated environmental costs" [14]. To reiterate, in California alone there is tons of trash littered on the highways and freeways and it costs taxpayers millions of dollars to have it cleaned up by the state. With our prototype device, we are essentially reducing the long-term costs of labor and cleaning up done by the cities, counties, states, etc. and we are also reducing the risk of workers going out and having their lives taken from distracted drivers or hazardous waste.

Now with the COVID-19 pandemic extending its welcome into this next semester, we have also learned that more masks and gloves are being disposed of either by accidentally dropping them or intentionally in parking lots and roadsides. Although we were more focused on picking up plastics and aluminum, this semester we can also implement having our litter bot dispose of masks and small contagious material (that is lightweight too). North Carolina has also reported that due to the pandemic closing many jobs and having small windows of shops reopening, budget cuts really hurt roadside litter cleanup services and NCDOT had to spend "$21,665,454 removing litter from 80,000 miles of state routes, according to state data" [15]. Again, trash ending up in parks and highways is a big risk to drivers damaging their cars or swerving into other cars due to obstructions, as well as igniting fires that can be caused due to cigarette butts being thrown out when lit so it is essential that trash is cleaned up from busy areas with heavy traffic. The litter bot can be used by the counties or states of any country to help cleanup open areas polluted by litter, as long as those areas are free of activity at the time of cleaning.

III. DESIGN IDEA

A. Autonomous Design Overview

For the Fall of 2020, we are seeking to deal with the societal problem that is litter polluting the world. We want to reduce litter as much as possible, but the right way by having it collected and then disposed of professionally, so it is not endangering the aquatic system or worsening the air pollution. Therefore, we have proposed to invent a machine that can go around a set and defined perimeter in order to pick up and collect trash with as minimal human interaction as possible.

The team is planning on building an autonomous robot prototype for the first semester of our senior design class. The goal for this project will ideally be for the robot to be able to scan ahead within five meters through the use of machine vision encoded microcontrollers and cameras that will be mounted onto the device. Machine vision will be the driving force for this robotic project, as well as the motors and wheels, and will be what makes this project so unique.

What is machine vision and how will it operate in terms of reducing the litter by the shores, of the streets, or in grasslands? Machine vision is the capability of a computer to perceive the environment and is used for a variety of assets, such as material inspection, object recognition, pattern recognition, electronic component analysis, along with the recognition of signatures, optical characters, and currency [16]. We will be implementing cameras and microcontrollers with machine vision in order to command our autonomous robot to operate freely on its own and collect trash that is identified within its database. Such trash will include ordinary plastic water bottles, aluminum cans, wrappers, and excess trash that is small in size but littered among the world.

Once the machine vision is implemented into the device, we will be using a robotic pivoting arm that can collect the trash when it is within reaching distance of the machine; specifics are in a further section. This robotic arm will be attached to the chassis of the machine and move with multiple degrees of freedom to coordinate how far, low, and centered the trash to be collected is. For the prototype design, we are focused on using a "claw" design for the end of the arm, that way it can pick up trash with more leeway and better grip so it can then pivot into the trash bin attached behind the chassis. The arm in the second semester will have more degrees of freedom and allow the claw to turn and grab items more efficiently.

Another unique feature about our device will be the use of an all-wheel drive function, supported by servo motors and rubber tires with off-road treading. Our autonomous machine will be put to the test and will be set to work around unpaved areas that may have accumulated trash through rain and winds blowing them in an area. We will have our collector robot drive over sand, gravel, small rocks, leaves and still have it collect trash in bumpy and uneven terrain, which the average robot has a hard time traversing due to how previous cleaning bots have smaller and smoother wheels.

Our current estimated cost projections run at about five hundred dollars not including tax and shipping. Vaukee has access to a 3D printer, so we might be able to save some money by printing parts. We also might have other options on retail sites such as eBay, which could get us a better component and save us money. Some parts we might be able to get away with cheaper quality such as the frame, since it only holds things together and it isn't a heavy-duty robot. But we might have to spend a bit more for a higher quality microcontroller such as Raspberry Pi 4 for its processing power and possibly higher quality cameras if the prototype has a hard time detecting objects.

B. Fall 2020 Punch List

Table II.

Fall 2020 Semester Feature Set List [17]

Feature	Measurable Metric
Identify objects such as plastic bottles, and aluminum cans	Computer Vision will determine if the identified object is a plastic cup or not with a 70% accuracy rating within 1.5 meters of the robot's line of sight
Device can hold small objects with a gripper arm that has at least 3 degrees of motion, meaning at least 3 pivot points.	Will hold small objects that can fit within a .3 square meter area and .15 meter height.Trials will be focused on grabbing the trash within a distance of 6-10 inches from the robot and have enough freedom to reach its trash bin and not tip over with a high success rate. This also requires that object identification works first.
Perimeter check / GPS geofence.	Will use gps to keep track of how far away it is from a home location and go back if its further than 'x' radius. The value x can be any such value depending on the location of deployment.
Machine locomotion will operate on wet mud, sand, grass and drive slowly on dry, flat surfaces.	Testing the robot's driving capabilities on very muddy ground and near wetland to have the robot be able to perform through the after-effects of weather or nature at 1km/h speed or better.
Operate without being plugged in	A battery pack will ensure the robot's

for a limited time.	operation for at least 30 minutes.

TABLE II IDENTIFIES THE FEATURES WE HAD PLANNED FOR OUR PROTOTYPE IN FALL AND HOW WE WILL MEASURE THOSE FEATURES.

C. Hardware

1) Fall 2020 Hardware (Lab Prototype)

- 1x Raspberry Pi
- 1x Jetson Nano
- 1x Controller for Motors
- 4x Stepper/Servo Motors
- 1x Body/Frame
- 4x Off-Road Tires
- 1x Camera
- 3x Buttons
- 3x Indicator LEDs
- 1x Robot Arm with Grabber
- 4x Proximity Sensors
- 1x Trash Basket
- 4x Water Sensors
- 4x Infrared Sensors
- 1x Battery Pack

2) Spring 2021 Hardware (Deployable Prototype)

TABLE III.

SPRING 2021 PROTOTYPE HARDWARE LIST [18]

Part(s)	Amount
Berry GPS-IMU V3	1
Waterproof Active GPS Antenna	1
Raspberry Pi Zero W	2
Nvidia Jetson Nano	1
8MP 160deg. FOV Camera	1
MG995 Servo (Big)	2
MG90s Servo (Small)	3
12V 100RPM DC Motors	4
2.56" Wheels + Brackets	4 (ea.)
L298N Motor Controller	1
6000mAh 12V/3A Battery Pack	1
10000mAh 5V/3A Power Bank	1
Distance Sonar Sensor	2
Storage Basket	1
Adafruit Servo Controller Hat	1
Camera Ribbon Cable	1
Lexan (Polycarbonate Base)	0.8
Noctua Fan for Jetson	1

TABLE III SHOWS THE FINAL HARDWARE ELEMENTS WE USED FOR OUR END OF THE SEMESTER DEPLOYABLE PROTOTYPE.

D. Software

TensorFlow Lite (Latest Version)
Visual Studio Code (Latest Version)
Fusion 360 (Latest Version)
OpenCV (Latest Version)

E. Individual Focus.

Vaukee will be focused on leading the team in the first quarter of the project while having input on aspects of the design. He will mainly focus on the machine vision aspect of the project after he has completed his term as team leader.

Ricardo is the electrical engineer asset to the group, and he will concentrate mostly on the circuitry of the machine. He will find ways to make sure all the components are receiving enough power and help avoid the risk of frying any microcontrollers as well as making sure they are not underpowered. It goes without saying that Ricardo will also contribute heavily on soldering and building the team's project.

Vadim will be working on making sure that the microcontroller, sensors, cameras and other components are communicating properly with each other as well as reporting the data for maintenance. He will also be making the maintenance portal accessible from a terminal.

Deven is a computer engineer and will be contributing to both hardware and software aspects of the design. I will collaborate with the team to debug any errors in code and will play a role in creating the features necessary in our design idea. I also have experience with operating machines in a previous project where we made an autonomous RC car.

F. Estimate Time of Completion.

The team is estimated to spend fifty hours, at the bare minimum, just on making sure the object detection sensors will be working properly for testing near water hazards. That should take up most of the time, other than the weekend or two it will take to get the motor controls running, which are estimated to be around twenty-four hours.

The machine vision aspect of the project is expected to take more than 50 hours to complete as there exist many features to machine vision. We have obstacle avoidance and detection. With a camera, it is also possible to calculate distance without the use of sensors.

Motor control is quite simple as an h-bridge will be used for forward or reverse movement and PWM (pulse width modulation) can be used for controlling the speed of the robot. One can expect the completion time to be less than 5 hours.

The motion of the trash picking arm may take more than 20 hours. Depending on the degrees of freedom that the arms of the bot may have, we will have to relearn some matrices to find out the final location of the "hand" of the robot and implement it so that the robot will always be able to grab an object.

A maintenance portal will take 30 or more hours to complete as we will have to learn how to make a GUI and assign buttons for information that we need.

G. Measurable Metrics.

- Testable sample of TensorFlow Lite (object detection) for few items
- Robot Arm motion
- Motor Control drives
- Maintenance portal displaying sensor information as well as basic controls
- Servo motors with gears tilting the trash container

H. Team Member Skill Set.

Vaukee will have access to a 3D printer at home and is also competent in the design of parts with the use of Fusion 360. Printing the majority of parts would be ideal as it would reduce the entire cost of the entire project. He also has automotive experience that can be translated into this project as automotive physics can be used in a similar fashion for locomotion. Also having done a huge automotive project, he has various tools under his belt when it comes to assembly and troubleshooting.

Vadim has experience connecting multiple microcontrollers together and having sensors on separate microcontrollers work together as needed as well as providing a way to view live sensor data via a terminal or webpage.

Ricardo has taken previous academic courses that encompass the use of programming microcontrollers and creating circuits using basic logic and coding. As an electrical engineer, he has the resources to solder and help construct and combine different elements into a working device.

Deven is an asset to this project because he has had experience with autonomous cars. He also knows about microcontrollers and circuit building as well as implementing aspects of the robot that we will need to implement.

I. Revised Feature Set Punch List for Spring 2021 Deployable Prototype

TABLE IV.

SPRING 2021 SEMESTER REVISED FEATURE SET LIST [19]

Feature	Measurable Metric	Lead
Identify objects such as plastic bottles, and aluminum cans.	Computer Vision will determine if the identified object is a plastic bottle or not with a 70% accuracy rating within 1.5 meters of the robot's line of sight	Vadim Babiy
Device can hold small objects with a gripper arm that has at least 3 degrees of motion, meaning at least 3 pivot points.	Will hold small objects that can fit within a .3 square meter area and .15-meter height. Trials will be focused on grabbing the trash within a distance of 6-10 inches from the robot and have enough freedom to reach its trash bin and not tip over with a < 80+% success rate. This also requires that object identification works first.	Deven Robin-son & Vadim Babiy
Perimeter check / GPS geofence.	Will use GPS to keep track of how far away it is from a home location and go back if it is further than '*X*' radius. The value *X* can be any such value depending on the location of deployment.	Vauke-e Lee
Machine locomotion will operate on mud, sand, grass and drive slowly on dry, flat surfaces.	Testing the robot's driving capabilities on muddy, patchy, flat, and/or uneven ground to have the robot be able to perform through the average effects of weather or nature at up to 1 km/hr speed.	Ricar-do Navar-rete Jr.
Operate without being plugged in for a limited time.	A battery pack system will ensure the robot's overall components operate for at least 30 minutes of constant deployment.	Ricar-do Navar-rete Jr.

IV. FUNDING

For this project, there was no source of outside funding or funding from any sponsors. Team 10 was fully responsible for buying all elements of our project from our own saved up money. After the first semester, we expect that upgrading and integrating all of our features together will still have us stay within our $300-$450 limit that we initially hoped for since the beginning of the project.

After testing the lab prototype in the fall semester, it was obvious that we needed better servos, motors, and new sensors, and we have still been funding the project ourselves. Unfortunately, due to last minute integration, things started getting sloppy and there was a lot of replacing between parts that occurred, and that led to the team buying more batteries or electrical components. By the end of senior design, we had combined that the overall cost of parts we used together was well over $750, including parts from the spring semester and parts we already had from previous courses.

However, if we include only the necessary parts to create our Litter Bot project, then all parts combined into our deployable prototype came around to be $460, as shown in table IV below. Ultimately, we also included a second table, table V, to show the overall cost of the deployable prototype with miscellaneous components we bought to fit everything together.

Table V.

Cost of Spring 2021 Deployable Litter Bot Components [20]

Part(s)	Cost (per)	Amount
Berry GPS-IMU V3	$53.50	1
Waterproof Active GPS Antenna	$11.50	1
Raspberry Pi Zero W	$23.99	2
Nvidia Jetson Nano	$58.99	1
8MP 160fov Camera	$28.99	1
MG995 Servo (Big)	$5.75	2
MG90s Servo (Small)	$3.33	3
12V 100rpm DC Motors	$15.99	4
All-Terrain Wheels + Motor Brackets	$7.49	4 (ea.)
L298N H-Bridge Motor Controller	$4.99	1
Batteries / Power Supplies (12V, 5V, 5V)	$27.59	3
Distance Sonar Sensor	$3.99	2
Storage Basket	$5.99	1
Adafruit Servo Hat	$6.99	1
Camera Ribbon Cable	$2.99	1
Total Cost of All Integral Parts		**$459.27**

Table V. features the cost of the essential components needed to manufacture the project litter bot.

Table VI.

Overall Cost of Deployable Litter Bot From Scratch [20]

Additional MISC.	Cost (per)	Amount
PLA Filament (1KG Rolls)	$22.00	3
PETG Filament (1KG Rolls)	$22.00	0.3
M3 Bolts and Nuts	$24.00	0.1
M4 Bolts and Nuts	$25.99	0.08
Velcro	$14.20	0.2
Heat Shrink Tubing	$10.00	0.01
Extra Wires	$16.30	0.05
Proto Boards	$13.99	0.02
Total Cost of MISC Parts		$81.11
Final Cost of "Final" Design :		**$540.39**

Table VI. Shows the overall cost of the spring semester prototype with all components from scratch added.

V. PROJECT MILESTONES

This litter bot project is allotted two semesters of time for the team to work on, and with a year long course there are bound to be milestones achieved in both the first and second semesters. As a team, we have decided that milestones for this course include finishing successful tests on feature sets that we each worked on as well as completing the bigger course assignments throughout the semester. Below is a table that shows our already completed milestones by the submission of our fourth fall semester assignment, and all remaining course assignments (highlighted in yellow numbers) that we are projected to finish as a team with their respected dates all the way until the end of the spring semester. Of course, ***this table is tentative and will be updated throughout the course*** as we test and improve our prototype, achieving new breakthroughs that allow us to interconnect our project together from different features and tasks.

TABLE VII.

MILESTONES OF TEAM 10'S PROJECT TASKS AND TEAM COURSE ASSIGNMENTS [21]

2020 FALL Semester Milestones	Date of Achievement
1- Societal Problem - Litter	09/28/2020
2- Design Idea – Litter Bot	10/05/2020
3- Finalize Feature Set of the project	10/07/2020
Machine vision detects faces using RPi-camera	10/23/2020
4WD system fully operational	10/25/2020
Created Tentative Work Breakdown Structure for the Project and Members	10/26/2020
GPS set up with a fix for location data waiting to be parsed into usable information	10/27/2020
Upgraded to Raspberry Pi 4 for better video frame rate of identifying objects	10/29/2020
4- Project Timeline	11/02/2020
5- Risk Assessment	11/09/2020
AWD system is fully mobile powered and can drive outside (with access to Wi-fi hotspot).	11/23/2020
AWD system operates outside of cement and grass and can drive with plastic trash onboard.	12/04/2020
6- Project Technical Review and Project Lab Prototype Poster	12/07/2020
7- Lab Prototype Presentation	12/11/2020
2021 SPRING Semester Milestones	**Date of Completion**
4 Motors proved to drive over 1km/hr with over 10lbs of weight.	01/12/2021
1- Revised Problem Statement Report and Presentation	02/01/2021
2- Litter Bot Test Plan	02/08/2021
New base is constructed with Lexan and 3d Printed pieces + mobile motor control system is assembled and operational for testing cases and collaboration.	02/13/21 - 02/14/21
3- Marketability Review of Litter Bot Report and Presentation	03/01/2021)

4- Features Report and Presentation	03/08/2021
New PLA arm with metal servos hooked up with Driving Train and Machine Vision together!	03/29/21
5- Testing Results Review and Presentation	04/05/2021
Camera detection has ditched OpenCV and drastically reduced video lag issues, thus being more reliable with driving.	04/09/21
New, heavier 12V DC motors replaced previous lab motors for better Torque at slower speeds for better object detection + Distance Sensor in front of device for more reliable stops.	04/15/21
2nd variation of Arm with big servo at the bottom allows for less stress on placing bottles in trash.	04/22/21
3rd and Final PLA arm uses 2 big servos and 2 micro servos + new sensor on gripper to more fluidly grab bottles within 8-12 inches in front of device!	04/25/21
7- Deployable Litter Bot Prototype Technical Review	04/26/2021
8- Finalizing the End of Project Report Document + Project Poster for Website	05/03/2021
9- Senior Design Showcasing Team 10's Litter Bot with a 5 minute Project Summary Video	05/010/2021

TABLE VII. SHOWS THE TEAM'S ACHIEVEMENTS OF THE PROJECT AND REPORTS THROUGHOUT THE ENTIRE 9 MONTHS OF SENIOR DESIGN.

As seen above, the team is constantly working on the litter bot project and developing new milestones, all at different rates due to how flexible we are trying to be during the pandemic's university closure. A big milestone for our physical project itself was when Ricardo got the four DC motors to start working properly in every direction, such as frontwards, backwards, turning left, turning right, and pivoting in place in a 360 motion. Now that the robot's locomotion was wired properly and working, we had faith the robot would be able to move around terrain easily. Another milestone (so far) for the project was when Vadim got the raspberry pi camera and microcontroller to start detecting objects. This is arguably the most important feature to getting our autonomous robot to think freely and for itself when the time comes for it to identify and pick up trash. Since Vadim has got the camera to identify faces, he is working to upgrade the processing power by replacing the Raspberry Pi controller with a newer and more powerful one for better object identification!

We have developed a PERT diagram as well to help visually guide us and show how the project has gone throughout the course. Parts of our PERT diagram can be found at the end of our report, in the appendix section, Appendix-H. There you can see the tasks that the team is going through to get the project done as well as the course assignments throughout the semester as well as tasks and assignments we are projected to complete for next semester as well. The full PERT diagram is uploaded to the team's shared OneDrive account and may be added to the report in the future, once the final report editing session occurs in April of 2021.

VI. WORK BREAKDOWN STRUCTURE

Our project has been stated by some experienced engineers as being a very ”aggressive” project that will require many more hours than we have originally anticipated going into it. However, with the pandemic that has occurred in the year 2020 that has universities shut down any physical meetings, we are not discouraged as engineers and plan to break our project apart into different tasks for different members in order to compile all our work together by mid-november to end of november. We have broken down how we will work on this project based on our Fall Semester 2020 Punch list. Each of our tasks can be broken down into two sections - hardware and software. Each team member will be working remotely from home in their offices or in garages when testing machine parts or soldering hazardous materials together. With each team member working independently and at their own designated times during the week, we have allowed more flexibility for each member to get their features done when they can and have them tested in their appropriate environments. Once members have certain tasks and features completed, we will schedule meeting up and exchanging components in order to progress to building the prototype for the fall semester.

In regards to hardware, Ricardo is focused on the physical build of the design. He will also be focused on finding a solution to having the autonomous prototype have a mobile power supply that is capable of powering on all motors and microcontrollers together without burning anything and making sure the device can run for at least 10 minutes of its own battery supply by the final product in Spring of 2020. For the fall semester, Ricardo is projected to work on solving the power supply issue with at least 30 hours of looking into all options and establishing connections. There is a good chance it can take longer to have figured out after researching and working with hazardous batteries. Ricardo will also work on building the base of the machine with the tires and motors that provide enough strength to the device to be able to meet the requirement stated in the fall semester feature set list. He is projected to spend about 10-15 hours constructing a base that can support all the devices and trash bins that the robot will be using to collect trash for the fall semester prototype. Then another 10 hours will be spent on building code for the base to make sure that the robot's locomotion can move in all directions for when the cameras and sensors are mounted and combined.

The software aspect of the project is where Vadim, Deven, and Vaukee will take most of the lead. Each of them will be working on separate tasks from our feature set list as well. Vadim will focus on learning machine vision in order to have our robot have “eyes of its own” and become autonomous once the project is nearly finished. He is looking to work on the machine vision aspect for at least 50 hours in order for our robot to identify objects and obstacles as intended. Deven will be focused on controlling the servos and pivots of the robotic arm that we will use for our fall semester prototype. He is expecting to work on getting the robot arm to be able to reach out and grab objects and then pivot them in all directions within about 60 hours of working on code and testing the arm. Vaukee will be focused on coding a route/perimeter feature onto a raspberry pi in order to have our machine have a GPS capability and have it not steer out of a designated cleaning area. He estimates it will take 40 hours to implement this feature. Finally, all of our features and members who will be leading those features can be further explained in the following sections.

A. Identify Objects with Machine Vision

In order for us to distinguish what is litter and what is not, we need the help of AI to identify the objects before attempting to pick it up and throw it in the trash. We decided to use a Raspberry Pi with an attached camera and a computer vision library such as OpenCV. The plan is to teach this program to recognize the different kinds of litter such as plastic cups and water bottles. We can achieve this by showing the program a lot of pictures of an object so that it could memorize it for the future. But trash isn't the only thing we need it to recognize, since there might also be people and their belongings nearby. If the robot identifies a person or pet it will try to keep its distance so that it doesn't cause trouble for anybody.

This feature can be tested by putting an object in front of the camera and having the program identify it by drawing a box around the object on the screen with an optional title. The object can also have coordinates displayed for us which could help us figure out distances or degrees if we plan to go towards or away from the object.

We plan to use Python 3 for the most part of our programming which makes it easier for us to collaborate given that we have to do this mostly online due to COVID-19. The estimated time to complete this feature is about 50 hours, but given that research will still be required and the time to calibrate the system to make sure it works properly, this number is probably off by a lot.

B. Four-Wheel Drive Implementation

For our senior design project, the team wants to be able to have the robot have an all wheel drive system integrated so we can move our machine to most surfaces, regardless of the floor condition. Ricardo will take the lead for implementing the all wheel drive system into the robots base design. The plan for the Fall semester is to have four DC motors that have a high torque value so they can move a heavy load once the machine has all parts weighed on top, plus the garbage it will be carrying. Of course, high torque motors come at the cost of the machine not being able to move as quickly as a hobbyist RC car, but for our project we do not need to get from place to place with speeds greater than 1km/h-2km/h. If improvement is needed, we can always improve the spring semester design.

Given the speed range we are aiming for, I, Ricardo, have found that using wheels that have a diameter of 2.56", and wanting a velocity of around 1.25km/h, I calculated that we need motors that produce 180-200rpm. I was in touch with a robotics professor at Sacramento State and we were able to use the formula of **V=R*w** in order to determine what motors the project would need, and ordered motors accordingly. We are using motors that output 220RPM for this semester since they were the best available at the time and they can also provide a faster machine on the ground if need be.

Figure 7 - Wheel and motor elements for fall 2020 prototype design [22]

For testing purposes, I will build a base out of wood at first in order to mount all the motors and connect them to the tires using hex-coupling adapters that are required in order to not have the shaft of the motor slip from the wheels. Once all four motors are mounted, I will connect them to a dual H-bridge motor controller. To be efficient, I will connect two motors to one set of outputs of the H-bridge and the other two sets of motors on the other outputs of the H-bridge since we are using a dual H-bridge.

I believe the process to build the base, mount the motors, wire everything properly, and then code the system to a raspberry pi zero w microcontroller will take about 15-20 hours worth of work, assuming some roadblocks and programming issues are in the process. Once the wheels are ready to work with a microcontroller and a 12v power supply, I will test the base around the outside of my house to make sure the motors and wheels have enough strength and grip to traverse wet mud, trample cement bumps, go over small tree branches, traverse over a rocky and graveled area, and finally work on a smooth cement surface. If everything is successful and all four motors work properly at 12v with hours of coding and constructing, then we can move onto mounting other microcontrollers and the robotic arm onto a more stable base.

Creating a more stable base will lead to potentially five more hours of work, or it could be reduced to researching a 3D printable base, courtesy of team member Vaukee and his resources. Overall, I believe that getting a suitable base for our device and finding a way to get all motors to program properly with a power source of 12v will take around 25 hours to have figured out.

C. Robotic Arm to Collect Small Objects

Deven will be heading the operation in the robot arm implementation. Before we implement the robot arm to the chassis we must code and implement individual features that can operate separate from the robot. I will start by setting up a raspberry pi 3b to be used as the microcontroller for the robot. I will start by getting the servo motors to rotate from 0 to 90 to 180 to 360 degrees to allow me to get a grasp on the functions of the servo motors. This will take about two or so hours to implement and carry out as a function of the servos. I will be using four micro Servo 9g motors on the physical arm to allow the functions of the arm to grasp small objects. I will be using the Raspberry Pi to code in Python and allow this to be able to function the motion of the arm.

I will start with a basic wooden arm controlled by servo motors for small objects and try to get the arm to move up and down along with allowing the claw to close and open. I believe that this will take about ten hours to implement. Once that is complete I will clean up the code and implement this with the arm that will be used on the robot that allows for computer vision to be used to pick up all types of objects. I will be collaborating with Vadim since he is the head of computer vision and we can consolidate our code so that it is optimized for max efficiency. These tasks will take some about 15 hours or more to implement and I believe that my total portion of the project will take about 40 hours to implement along with the collaboration of my teammates.

D. Navigation System / Perimeter Check

For our robot to be capable of getting from point A to point B, it needs to know where it is going and where it can't go. We need it to stay in a specific location so that it won't be easily lost. This portion of the project is crucial because the physical location information that we need can aid the robot in making certain decisions. The hardware that we will be focusing on are the GPS (Global Positioning System) and an

IMU (Inertial Measurement Unit). Within our inertial measurement unit, we have an accelerometer, gyroscope, magnetometer, and barometric/altitude sensor. The project won't be making use of barometric/altitude information. Vaukee will be the head of this portion of the design. In Appendix G. of this document, it includes Vaukee's time and effort that has been put into this part of the project. We expect to have a total time of roughly 50 to 70 hours invested in research, testing, and implementation.

1) Research

The first step to just about everything is to gather information. Research must be done for the GPS and the components in the IMU. This research will be an ongoing part of the effort required to complete this project and make it successful. It will take around 2 hours to look into each component that makes up the IMU minus the barometric sensor. This means there are 2 hours for the accelerometer, 2 hours for the gyroscope, and 2 hours for the magnetometer. The total time that it will take to research the IMU will be roughly 6 hours if we add up each component. Ofcourse, the time for research is always adding up as new things are learned along the way as there is a lot of information that is missed. The GPS also takes roughly 4 hours to have a decent understanding of how it works and how it is implemented on the Raspberry Pi.

2) Parts Testing

Next on the list after research will be the testing of each individual part. We need to make sure that each part is working and not defective in any way. Doing this will save time for future headaches and reduce the overall time in component implementation as the defective part will not have to be replaced. Waiting for a replacement part will not be a part of the equation.

The time it is required to test the GPS is roughly 5 to 8 hours. It takes about 10 minutes to solder the Berry GPS-IMU V3 if the conditions are nearly perfect in which there is a solder station in the ready for use and having the proper tools. This actually took roughly 1 hour as fixing the header pins for a near perfect alignment took the longest and a few tools were missing. Only having a desoldering pump for solder removal is not very good. The soldering iron needs an extra wide solder tip to aid in aligning the pins. In hindsight, having the RPi used as a third hand would have expedited the process. After this initial hardware setup is the initial software setup. It took about 5 to 12 hours for this phase to complete. This is mostly installing a new version of Python to the Raspberry Pi and a new OS version. There are certain tools that require installation as well. There are a wide variety of tools to test the GPS hat. The tools used to test the Berry GPS hat were Minicom, Screen, gpsd, gpsmon, cgps, gpsprof, and uCenter. All these were used for redundancy. Setting up all the tools took roughly 6 hours. Waiting for the new GPS hat to get a fix on its current location actually took longer than the average 10 minutes that were mentioned. Luckily there was a command to reset the device and this expedited the process as being stuck trying to troubleshoot the process would have taken longer. The idea to even restart the device did not come to mind earlier.

Having a unit that has various components in it is nice as you don't have to buy each component by themselves. Our IMU has 10 degrees of freedom. The 10 degrees account for the accelerometer, gyroscope, magnetometer, and barometric sensor. The time required to test if each component will work should be around 1 to

2 hours for each sensor for a total of 3 to 6 hours.

For a successful test of the accelerometer, we will need it to have a valid g-force or G reading. For this test, holding the Raspberry Pi and Berry GPS-IMU unit together with a smartphone and moving them together will be a great test. This will ensure that the accelerometer is accurate and precise as smartphones should have very good accelerometers.

Testing the gyroscope will require a visual representation of the RPi and Berry GPS-IMU orientation since the gyroscope measures the rate of rotation around an axis. For example, a plane will have pitch, roll and yaw. The same principles apply to a land roaming bot. This will be a great asset in vehicle stability and we can define where the "head" of the vehicle is as well.

Testing the magnetometer is very simple as we also need a visual representation of it on screen. The magnetometer is basically a compass and we just have to make sure it has north pointing north.

E. Power Supply

For the fall 2020 semester, we will be using multiple microcontrollers that operate at 5v each and four dc motors that require 12v of power in order to have enough torque to meet the requirement of our project. Throughout the semester, Ricardo will be working on ways to test each feature with a direct supply via a USB connection or by getting power from an electrical outlet using an AC-to-DC converter. Ideally, we are looking at around 40 hours to figure out how much power all mechanical parts of the project will require and then building a power bank off of it. A few hours will be conducted into researching DC to DC converters, possibly 5 hours looking into Lithium Ion battery packs and the benefits and dangers of creating one for our robot or purchasing a premade pack. Ni-Mh batteries will also be taken into account and may also have about 5 or more hours of research into if they can supply enough power to the machine's components for more than 10 minutes. Again, the team won't know for sure until further developments into the semester how much power will be needed, but we can assure that we are using direct power to outlets and computers for testing purposes and possibly even the prototype build if no mobile source of power is constructed and implemented by the senior showcase in december. We can always improve on the power supply for the Spring 2021 build.

F. Hours to Complete Project Litter Bot

By the end of senior design, the team went back to look at previous reports in the first half of senior design, and then we added those hours to the ones from this semester. As of this section of the report, there are no more assignments to be turned in other than the end of project document edited down, as well as some project posters. Below are the hours that were officially logged by the team members in the activity reports dating from the fall semester in August up until the end of the second semester in April.

ONLY based on Activity Reports (September 2020 - April 2021)

FALL 2020

WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13
Vadim	...	....	...	10	12	23	15	6.5	23.5	16.5	12.5	18.5	10.5
Vaukee	...	....	...	10	16.1	20.75	8.5	15	23	17	11	10	6
Deven	...	....	...	9	10	11	8	10	9	10	14.5	9.5	9
Ricardo	...	....	...	11	20	18	10	20	20	17.5	16	11.5	18

TOTAL HOURS (Fall)	
148	Vadim
137.35	Vaukee
100	Deven
162	Ricardo
547.35	**TEAM**

WINTER BREAK

SPRING 2021

WEEK	1	2	3	4	5	6	7	8	Sp. Brk.	10	11	12	13
Vadim	62	23	14	18	14	11	12	13	....	44	51	40	49
Vaukee	77.2	12	13	15	13	15.5	26.5	16.5	....	60.7	42	16	31
Deven	53.5	17	13	14	10	16	16	19	....	31	25.5	15	19.5
Ricardo	55.5	22.5	18	20	11	18.5	21	12.5	....	37	33.5	25.5	25.5

TOTAL HOURS (Spring)	
351	Vadim
338.4	Vaukee
249.5	Deven
300.5	Ricardo
1239.4	**TEAM**

FIGURE 8 - TOTAL HOURS ACCUMULATED BY TEAM 10 [23]

As seen in figure 8, the team more than doubled their hours in the second semester. The first semester was productive, but it did not include any integration and that was what ultimately caused the team to work "overtime" the second semester and it proved to us just how essential combining pieces early on for testing really was. A better view of the hours spent by each team member and the team can be found in Appendix G, under figure G2.

VII. RISK ASSESSMENT

As engineers, there are guaranteed to be risks in every project, some of which can be identified beforehand and some that come unexpectedly. For the team's senior design project, it is no different and therefore we are assessing the risks that are encompassed by our project that we can think of. Ever since the beginning of the semester, we have had to deal with the worldwide pandemic that is COVID-19 and its effects of closing school campuses and cancelling in-person lectures and gatherings. Sacramento State University's very own president, Robert S. Nelson, has already confirmed (through students emails) that the spring semester will stay virtual and once again severely limit the class to be taught remotely and not in person. This pandemic was an unexpected risk, but as engineers going into the course once the closures were already set, we knew we would have to mitigate around COVID-19's effects by working more efficient and of different features of the project and then finally combining them together one by one, or at least that is the plan.

The risk evaluation, or assessment, of our project is based on trying to locate any potential sources of failure, whether they be through our hardware or software failing, and possibly even through human failure from getting severely ill and not being able to work for a few days. When building our project during the fall and spring semesters, our team has been optimistic about creating our Litter Bot, but now we have purposely had to be as pessimistic as we can to ask ourselves: *what can go wrong with our project?* And *will it go wrong?* With this mindset, we went through all the features of our robot that have been mentioned in our feature set list from our design idea section of the report, "Section III."

From our design and feature set, we have agreed that the most crucial components and implementations for our project to work as intended are the robotic arm, a sturdy chassis with four motors, the camera with machine mision, the GPS navigation system, and the power supply/bank. It is critical that all of these features work with as little problems as possible for our machine to work. But of course, things are never that easy and there are risks associated with each one of these features, but our team will do our best to integrate as many mitigation plans as it takes to reduce the risks from the fall semester prototype to the final design at the end of the spring semester.

Below is a "risk assessment chart" that visually shows our risks' likelihood vs criticality. The left hand side represents how probable it would be for uncertainties to arise in our feature, whereas the bottom axis emphasizes the severity of each feature towards the project working successfully. We based this chart off of the risk assessment formula where ***Risk = Likelihood*Impact***, which is what led to the placement of our features on the chart. For instance, we think during the fall semester we may run into our sensors not identifying objects. It can pick up about ~25% of the time, which is a big impact on the purpose of our robot, considering it is built to identify and pick up trash.

We will go into further details about risks associated with our features and the risks they carry, as well as their consequences if they occur and how we will have mitigation plans for any risks we can see coming in the foreseeable future.

TABLE VIII.

RISK ASSESSMENT OF THE LITTER BOT'S FEATURES AND DESIGN [24]

Probability	**5** 80 - 100%					
	4 60 - 79%				Robot Arm	
	3 40 - 59%			GPS/ Naviga-tion		
	2 20 - 39%				Power/ Battery Pack	Object Identif ication
	1 00 - 19%		4WD chassis			
		1	**2**	**3**	**4**	**5**
	Impact on project (from Low - Severe)					

TABLE VIII. SHOWS THE RISK MATRIX OF THE FEATURES ASSOCIATED WITH THE PROJECT.

A. Robot Arm Risks and Mitigations

When it comes to the robot arm there are some risks associated with the functions of the arm. The arm is controlled by multiple servo motors and a raspberry pi which has the potential of overheating which can cause the arm to catch on fire. Dealing with electronics there is always the risk of fire because it requires electricity to operate. Since the arm will be bolted to the chassis then if this arm catches on fire then it can be very crucial for the project if in fact it does catch on fire. The other risk associated with the arm is the risk of harming the operator. Since the arm moves fast and has many joints, it has the risk of pinching fingers if someone was to move the arm. This can cause a lack of proper blood flow to the finger and if the arm gets jammed then it can possibly cause the potential to have the finger amputated. This is extreme however, this can be a possibility and a risk that we must account for when making our project. The software can also malfunction and cause the arm to grab things that may not be trash and can cause harm to the robot. Things like water bottles that are still full that can harm the electrical of the Raspberry Pi and gasoline that can ignite. There are any other aspects of our project that can have some risks but as far as the arm goes these are the risks that we have to assess. The risks above will be accounted for in our final prototype and we will carefully assess the amount of power that we will be using and being aware while the arm is in motion to prevent any injuries to ourselves. If the arm was indeed to be destroyed then we still have the code and the functions of the arm so we will then purchase a new arm and consider what happened to the previous arm and we will be more careful for the next time.

B. Machine Vision Identification Risks

Machine vision is one of the most important parts of this project, since the robot needs to see where to go and what to collect as trash. One of the risks is if it misidentifies an object thinking it's trash such as someone's keys but it would be less likely if we trained it with more images. Also, such a risk can be mitigated if we have the robot keep its distance away from objects that would identify as people. Another risk would be if the robot identifies an object that would qualify as trash but is not trash necessarily such as a bottle that still has liquid in it so it could still be something that wasn't thrown away; this could also give the robot arm a difficult time picking up a heavier object, but we could also mitigate this risk by having the object identified as trash be re-identified as the robot gets closer to it then maybe it could figure out if that is an object to be collected. Machine vision means the Raspberry Pi processor working hard all the time which means it creates heat. If the processor overheats it's possible that it could cause the performance of the robot to diminish or even cause permanent physical damage. We've already upgraded the Raspberry Pi from 3 to 4 to increase the performance and added a heatsink so that it doesn't overheat. So that risk has been mitigated some and hopefully the robot will last as a result.

C. Autonomous Navigation / GPS Implementation

Navigation is a crucial part of any project that involves locomotion through various means whether it is land, sea or air. Our project focuses on land locomotion with an all-wheel drive system. The goal for a successful navigation system would include accurate location and destination information acquirement. These two may be the more important information of a point A (initial) and point B (final) locations but more information is required if we want a higher success in getting from one point to another. The severe damage of this system would cost about $100 to replace. To prevent damage, the best we can do is to have a waterproof casing in the case of water damage and in the case of damage from the power supply that will be mentioned later.

The GPS (Global Positioning System) takes care of current location information estimation. With this, the robot will know its current location at specific intervals dependent on the data acquisition rate. GPS relies on four satellites to pinpoint the current location of the device. There exist 24+ satellites orbiting around the planet at all times. Only 4 satellites are required to obtain a location. From the information that will be received, they will be latitude, longitude, height, and time. The precision of location data tends to be accurate up to 20 meters. The accuracy of GPS decreases the closer it is to infrastructure. This includes people, trees, buildings, and various "large" objects. A way to mitigate this is to have a better way to receive satellite signals such as a bigger antenna. Avoiding buildings or objects is also another way to achieve higher signal reception and accuracy. The probability that these satellites will turn unoperational is quite low as these satellites have been in operation for a very long time. Avoiding or mitigating the loss of useful data from a satellite going down is impossible but GPS relies on many satellites so if we don't have one satellite another satellite will give us our information. This system is quite robust and its reliability in terms of just working is top notch. The only thing we have to worry about in this project is our device not working.

Destination information is a dependent variable that must be defined. To have a destination, we the system designer must manually define them or have an algorithm that takes care of that. It is much easier to make a pathing algorithm compared to manually defining multiple points as it will be painstakingly long to plan out paths. This method of manually assigning destinations may have a lower risk but the time to make a new path for every new location is not something that an engineer wants to do all the time. Making a pathing algorithm is a much more useful idea as paths will automatically be defined based on location. The desired result is that we want the robot to cover 100% of a location but the algorithm may not be able to do that. The uneven ground may also add to changing the path. We also need another source of information to help decide on where the robot should not be for example near or even in water. These preventative measures will be covered in machine vision.

The navigation system also makes use of a device called an IMU (Inertial Measurement Unit). This unit consists of multiple parts with each part being called an accelerometer, gyroscope, magnetometer, and barometer. This device is quite crucial and probably overlooked by novices in robotics. The chance this device will fail or be destroyed is quite low and replacing it is fairly low cost. When receiving a certain good, it must be tested for functionality. The testing of a complete functionality of a device will remove headaches in the future. The IMU will be a great device that can prevent or mitigate various hazards.

In the IMU, we have what is called an accelerometer. This device measures acceleration, which is the rate of change in the velocity of an object which is measured in meters per second squared (m/s^2) or in G-forces (g). This is a very useful device as it can detect motion in locomotion or impact. For example, if the robot is stationary for way too long, we will know that something is wrong and we can have a person check out what the problem is. This can prevent major damage to the robot or device. Detecting impact from objects, people or animals is also possible and will allow the robot to stop and make new decisions based on what just happened.

The gyroscope is another device found in the IMU. This device and the accelerometer compliments each other very well. The gyroscope is a great tool for measuring the orientation of an object in 3D space.. Gyroscopes determine angular velocity (ω) which is typically measured in radians/second and this provides orientation information (if an initial orientation is provided or a value can be assumed) across three axes: pitch, roll and yaw. With this information, we can detect whether the robot will be in a position where it will fall and correct itself so that it won't tip over and fall. This will also aid in the heading of the robot with conjunction of a magnetometer.

The magnetometer is basically a compass. This is useful as we can use it to determine where the robot can go as in where it's heading in respect to North. It is another tool with redundancy to to decrease the rate of failure in the case of navigation.

D. Power Bank Uncertainties

The power bank is a critical component of the project because it will ultimately be what allows our project to start in the first place. We believe that the probability of risks occurring with our power supply will be low to medium (irregular uncertainties). This is because one risk the power supply can have is that it will be too low to power all electrical devices encompassed into our design. We are using four 12v DC motors for the driving system, as well as a few microcontrollers that only need 5v to operate and some other servos and cameras. If our power supply is too low, it will severely impact our project and may not even allow it to operate! But the opposite is true and if our power bank has a high nominal voltage value and holds a big charge, we may finally have the amps needed to spin our motors, but we run the risk of frying our microcontrollers and motor controllers. In order to avoid underpowering or frying our project, one way to go about the project is to have separate portable power banks that can power different components such as the microcontrollers, and then one for the dc motors and robot arm servos. However, this would not be ideal for a spring semester build.

Yet another risk that the power bank can run into is having it overheat from all the devices that are drawing power from it. The initial plan has been to use a rechargeable lithium-ion battery pack, but if we are not careful they are very hazardous and can explode if they overheat. Of course, to mitigate this, we would only charge the batteries up to ~85% capacity and make sure we have slightly more amps to supply to our components, in order to make sure that we are not juicing our power supply too hard and thus causing it to overheat. If overheating is still an issue, another mitigation would be to just invest in a pre-built Ni-mH battery pack for an RC car that may not hold as much charge, but is more suitable for driving motors and controllers at the same time. However, we expect the likelihood of our battery overheating is low since we will not be running our project for long periods of time in this course.

E. Chassis and 4WDrive system

Lastly, our robot's chassis will be, what we believe, to be the last critical feature with risks that can jeopardize the project. Initially for the fall semester prototype, we had Ricardo build a flat chassis to test the dc motors and locomotion possible with our tires and motors, but it became apparent that although there was room for an arm and some controllers on top of the base, the bottom had the motors exposed without protection to anything that may be small enough to bump into the motors and wires. We caught this problem early on and have been working on a 3D printed CAD design since to mitigate that risk, but we imagine it would have been a high risk to leave the robot without protection near the motors, since a splash of water or rocks may have been able to smash into the motors and wires and cause them to potentially rip off or short out. However if our 3D printed design has insufficient room for multiple controllers, motors, batteries, robot arm, and small trash bin then it may be in the teams best interest to invest in an already built aluminum frame from online websites, since most electronic stores now a days have a limited stock of robotics bodies thanks to COVID-19's effects on production companies.

Another not so obvious risk that came from working on the chassis and driving system is that the team has had to wait on a finalized prototype base before getting a chance to build onto the machine. This is another low risk as we have found a way to have everyone work on different elements of the project without having to feel held-up. Again, we have mitigated the risk of being held back and delayed by constantly working on different parts of the project so once the base is settled and done, it will no longer need to be replaced and all the troubleshooting will be with either the GPS or sensors. But if for some reason our chassis were to give out or one of our motors were to stop working while building our Litter Bot, then we would just have to take our previously working chassis and print it again or buy it, as well as buying another motor. From Ricardo's experience of working with motors, no one motor has ever given out and stopped working while others continue to, so the likeness of having to replace a motor is low once they are protected by a better base. But we will be prepared to replace a motor if necessary thanks to planning ahead of time and buying extra components in case something fails.

F. Social Distancing due to COVID-19 Campus Closures

All team members have selected a feature or two to work on and each member has the hardware and software to start on the feature and get it to a point where it could be demonstrated and integrated into the lab prototype. Our communication has been mostly using MS Teams and Discord so far as we are approaching the point where we would need to integrate our features, once we get to that point we will have to meet on the university campus or another location as we do not require the campus labs to test our project. We will exercise the necessary precautions such as wearing masks and keeping our distances.

VIII. DESIGN PHILOSOPHY

When our team all got together and agreed that we wanted to help mitigate the man-made litter pollution and reduce the direct impacts that it has on Earth, we knew from the beginning that we would have a robotics project ahead of us. However, we had no clear vision on if our robot would be bipedal, quadrupedal, have a vacuum suction to pick up trash, use an arm to move it into an arm, etc. Then we decided that if we want our device to be able to work on beaches or streets, the best way for it to maneuver is to incorporate a four wheel drive system, so that all motors work together to move around fluidly. The next page shows an early concept sketch of what the team had in mind when we thought of a 4WD car with an arm to pick up trash. Originally, we even wanted it to be solar powered, based on how power hungry the electrical components would be, small solar panels just would not suffice. Therefore, we moved to two power banks hidden under the arm inside of a PLA base, as can be seen at the end of the section.

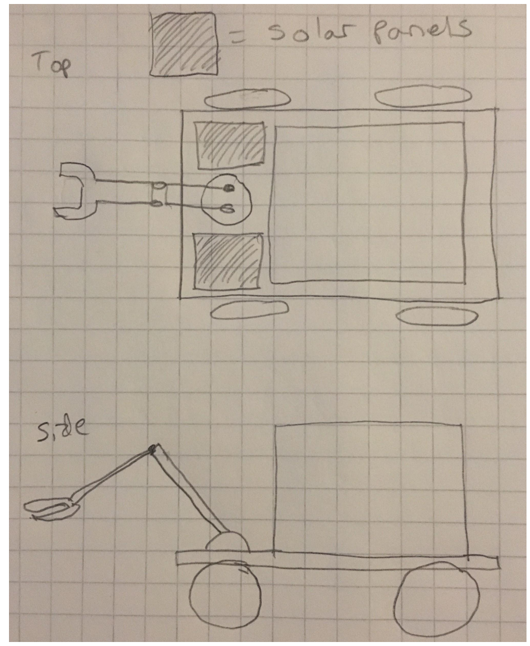

Figure 9 - Early Lab Prototype Sketch of a Litter Bot Design [25]

Based on the design above, we knew from the beginning that tow features would be getting a robot arm to work with a driving system. Then we started to construct our design idea, as elaborated in section III of the report, and we eventually added a GPS feature and machine vision into our design philosophy because we wanted this new revolutionary device to be autonomous and pick up trash of its own when set down.

Surely enough, as the weeks went on and as testing was done, with extensive research, we decided that we could ditch the solar panels of the sketch and just rely on having our device run of mobile power that could be charged by the user after they finished cleaning their area. Below can be seen our deployable prototype in early March with our old motors, but new tires and a new lexan base, and most noticeably a green arm made from 3D printed PLA pieces that house six SG90s servos.

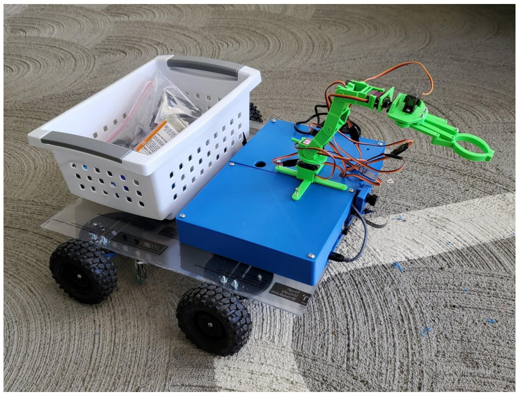

Figure 10 - Deployable Prototype as of March 2021 [26]

Again, the team's design philosophy has been based on getting an AWD system with a camera in front that can detect litter that has been submitted to the microcontroller's database, which can be expanded in the future with new pieces of trash! In the end, we still went for the design that we had sketched in the beginning and not only made our drawing come to life, but we also went through a few revisions with it and some other pieces, as explained in more detail in the next section, the deployable prototype, until we reached this final design of Project Litter Bot, shown below.

Figure 11 - Litter Bot Deployable Prototype in April2021 [27]

IX. DEPLOYABLE PROTOTYPE STATUS

Jumping into the second semester of the senior design litter bot project, we are working to make improvements to our lab prototype design from the end of Fall 2020. The team was satisfied with the way the separate features were working last semester, based on our initial fall 2020 design punch list. We were able to have all the features work properly and although most of them met the measurable metric we have been aiming for, some features such as the arm and object detection did have trouble being as accurate as we would have liked for them to be, so we are working of improving them with more testing for our deployable prototype. We are also working on improving our robot's all-wheel drive functionality to be more versatile with the addition of a stronger chassis and bigger wheels with better grip/thread, but we have to run tests to make sure that the new modifications can still meet the required speed we anticipate our device to work at, with and without heavy loads. The perimeter check or GPS function is also getting reworked on with more testing to improve its accuracy. We have started off this section of the report by going through each of our features and how we plan to test them in order to prove that we can meet our desired measurable metrics for the project, or on how we plan to improve them based off of testing them individually.

A. Robotic Arm & Grip Claw Testing

Deven will be in charge of this task since he is the head in the design and development of the arm. He will test the code created by him that will show all of the movements of the arm using the 6 different servo motors. This can be tricky and he will be working on this from February 8th to

March 19th. The expected result would be fluid motions of the arm so that it can go in every direction with the 7 different servo motors. Then Deven will execute the second phase of the arm and debug the code accordingly so that the arm can move in every direction and be ready to integrate with the machine vision. He will be working on this from March 15th to April 31st working with Vadim so that we can detect trash and properly dispose of it. The expected result of this would be to have simple code and allow the arm to function with the machine vision and detect trash and then the arm can move to discard the trash bin located on the chassis. The third phase of the testing would be to test if the arm can pick objects up and into the trash regardless of the orientation along with testing the machine vision to adjust the claw to grab the trash. I will be partnering with Vadim to integrate his machine vision so that this test can be executed. I will be working on this from April 1st to April 19th and at this time I expect this to be a functional arm but it may still have its glitches but I will have almost a month to test and achieve the final design of the arm. The expected result would include the ability to grab objects up and being able to put them into the trash regardless of the orientation. These tests will allow for the integration of the arm to the camera to detect trash and allow for the arm to go and grab it and dispose of it in the trash bin on the chassis. The most critical points of these testing phases is the ability to complete each phase because they all build on each other to create a final design that we will then use to mount onto the car.

1. *Results of Robotic Arm Testing & Updates in Hardware / Software*

In my testing I was able to complete the arm and get it to meet the measurable metrics that we discussed in the beginning of last year. The arm passed all the tests that I put in front of it and was able to grab litter so that we can properly dispose of it and be able to clean our environment. In testing phase one I wanted to make sure that the motors were able to move on their own and get rid of all resistance within the movements so that it won't cause any problems in the future. I did this with the SG90 servo motors which had plastic gears and the tests passed. When I upgraded the motors to the MG90s the tests also passed and the movements were even more fluid. Since the gears were metal instead of plastic this got rid of any struggles the arm had with weight and made the arm function much better. This made the movements more reliable and made the arm grab trash more consistently in the end.

For testing phase 2 I wanted to make sure that my code did not have any glitches and for sure when testing the movements of the arm going down and picking up trash and disposing of it in the bin I must have tested this on my own about a hundred times. I wanted to make sure that the movements were in fact crisp regardless of start position and they were. I was able to get the arm onto the locomotion and be ready to dispose of trash but we needed some more upgrades in the other portions of the project and to fix issues with video lag that caused the bot to run over trash items. For testing phase 3 I tested that the robot was able to grab items regardless of orientation and in fact the robot was able to grab trash items on its own when coded to do so. I tested this on my own and it was able to grab items regardless of orientation and be able to function completely on its own.

In these testing phases I was able to complete all of them so that all of my measurable metrics were met and the arm was reliable so that we could use it to dispose of trash. The arm was a hard task and it was very sensitive and I dedicated many hours towards it so that my team can be successful and be able to meet all of our measurable metrics. I was able to complete the arm and be able to grab trash, we arm just working on other issues with the other features of the project and we will be able to have it properly function to meet all of our measurable metrics.

B. Testing Four-Wheel Drive Locomotion

Ricardo is going to focus on making sure that the robot will be able to drive with the proper voltage and torque to produce the speed required by our measurable metrics for the deployable prototype. Last semester, we used 12V motors that produced 120rpm in order to achieve a speed greater than 1khm per hour, but we knew that with the wheels we were using previously, they would be too small and fragile to traverse rougher terrain and work with more weight. Therefore, we are moving from the 2.5" diameter wheels to bigger wheels at about 3.75" diameter, and with better thread to be more "all terrain." This will require new tests this semester in order to make sure the motors and wheels can work proportionally to once again meet our measurable metrics for the deployable prototype.

Ricardo will run tests on the same 12V motors we used in the previous semester, but now with new tires and he will observe the change in revolutions of the wheels in meters and calculate if the angular speed is still sufficient to run at, at least at a rate of 1khm speed. Referring to the table of the "Hardware Test Plan" in Appendix B, it can be seen more clearly that he plans of testing if the motors and wheels can move around different types of terrain at a constant speed with the modified wheels. The goal of the tests is to prove that no matter if the device is on rugged rocks (like gravel), in 3" tall grass in parks/yards, or in muddy terrain, it should be able to drive around freely with as least resistance as possible, assuming the new thread helps. Again, the dates and outcomes of the tests can be found at the end of this report in Appendix B.

Another test we must run on the driving system in order to meet our measurable metric for the deployable prototype is to experiment on the loss of RPMs of the motors over time and with more load. Last semester, the motors and wheels were able to drive over grass at a moderate speed (over 1khm) but had no real load to deal with, other than the electrical components attached to the old chassis. This semester we need to run tests and prove that the motors will draw enough amps to power the motors and achieve their goal of 120RPMs, but Ricardo will be testing just how much weight can be added to the chassis before there is a significant decrease in speed, and how much weight it will take for the motors to stall and quit working. This is an essential test because our device will be picking up trash and sometimes it may have picked up bottles and cans that were not empty and have added liquid weight to the trash bin. We need to make sure the motors can still run properly after at least 10lbs of weight in order to account for the electrical components weighing in, as well as the trash. In order for the test to succeed, our motors and wheels would have to be able to pick up at least 10lbs, or more, and then once we can see that the speed has fallen below 1khm of it traversing around land, we can specify its weight limit for our marketability and our deployable prototype measurable metric. Please do refer to Appendix B for more clear test plans for the all-wheel drive locomotion.

1. *Results of AWD Locomotion Testing & Updates to Hardware / Software*

For the new deployable prototype, after I reported back to my team about all the improvements that could be made to the driving system, I had begun looking for newer wheels that still used the same 12mm hex adapter as our previou kit, but with better traction. I did get a new pair of wheels that had better grip, but at the cost of being one inch bigger than our previous wheels.

FIGURE 12 - "SPRING 2021 WHEELS FOR DEPLOYABLE PROTOTYPE " [28]

Because we had bigger wheels, I had to go back to the drawing board and once again re-calculate if these wheels would work together with the same 12V motors from last semester in order to still help us achieve speeds of at least 1km/hr, and surely enough we were still good on that and our new wheels were not an issue!

After having passed off the AWD system to a CPE team member of mine over the semester, he worked on using his 3D printer to help design a new "skeleton" for a new base for our deployable prototype. I worked over winter break with him on sending him the dimensions of all the mounting hardware, screw holes, screw sizes, thread sizes,etc. So we can make a bigger base and have our future arm, camera, controllers, trash bin and power banks fit on the same base. Once he finished with that task and passed the 3D base with a piece of Lexan onto me, I then moved onto once again drilling holes into the Lexan base in order to mount brackets for the DC motors and in order to run the wires from underneath the base up to the controllers. To my surprise, the new Lexan base my partner chose is very hard to cut through because Lexan is polycarbonate plastic rated as having "an impact strength that's 250 times that of annealed glass" [29].

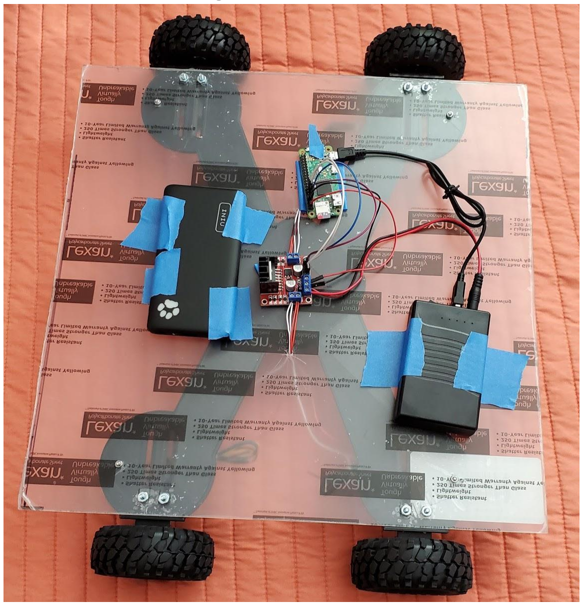

FIGURE 13 - "SPRING 2021 EARLY BASE DESIGN FOR AWD SYSTEM " [30]

As seen above, there is a black 3D printed "X" shaped skeleton supporting the Lexan plastic base and I had finished mounting the old motors with the old controllers and the old power bank, but this time with a new one as well that is disconnected. That new power bank is for the other components when they get integrated, as I will touch on in the next section.

When the new wheels with bigger threads, referenced in figure 8, arrived, I did not realize that the rims were loose and there was no cushioning in the tires. I then had to go buy some foam and super glue from a local store, cut out four circular shapes with the diameter of 3.3 inches, and then I stuffed them in the tires and super glued the rims onto the edges of the plastic tires for a secure fit to make sure the wheels don't come apart when testing.

Now that there were no more surprises and everything was ready to go, I conducted a test case for the new design to see how it performs on grass, gravel, cement, and with more weight than the previous design's 5lb test. Below is the test chart that I used.

TEST ID [Team Member]	Description / Method	Testing Range	Expected Results (Measurable Metrics)	Actual Results	Pass Fail
AWD Motors Speed Consistency [Ricardo]	Plan to test if the motors can constantly output at least 1khm speed on rugged asphalt, over loose aggregation of rock (gravel), on wet mud in a park field, and on 2.5" tall grass.	2/8/21 – 2/21/21	Driving at >=1khm should not be an issue on the test surfaces, which are where the litter bot is capable of operating on.	At minimal load, weighing in at 4lbs, the device was able to go 47ft at 2.3km/hr consistently over cement through 15+ trials and drove well over gravel and grass with mud patches.	P A S S
4WD Motors Weight and Torque [Ricardo]	Plan to test if the motors can output close to 120rpms as weight gets added with dumbbells to make sure motors draw required power with a heavier load until reaching the stall torque.	2/8/21 – 2/21/21	The motors will have heavy amp draw after ~12lbs of weight on the chassis and cause a decrease in torque, but will have the strength to continue operating.	The Lexan base could not hold up 12lbs and have the device turn, but the motors have the torque to go forward and backward at speed close to 1km/hr. A sturdier base would allow the correct movement.	P A S S| ? ?

FIGURE 14 - "AWD LOCOMOTION TEST PLAN FOR SPRING 2021 (APPENDIX B)" [31]

I then ran tests with the new base, wirelessly once again using the WASD keys of my laptop in order to control my device outside, and I recorded and logged multiple trials of the new design performing over rocks, climbing 1inch gaps, driving over cement, and turning in taller grass patches to show off the better performance of the new tires, as well as a more upgraded version of the battery from last semester from the same manufacturer. The AWD locomotion therefore proved it was able to perform on all types of terrain that we anticipate to work on and then I moved onto testing the speed it could go with the same motors and bigger tires. I measured out a 47ft long runway from the end of the backyard to the side of my house and averaged out 15 trials that successfully ran from the 0ft mark all the way to the 47ft mark. Surprisingly, running those tests took longer than expected because it was difficult for me to drive the car with a laptop in one hand and record all the trials with my phone in another hand. I also made sure to run this test when the newer battery had a full 100% charge and by the end of all the testing, terrain and speed testing, it still showed over 80% battery life. The results of the 47ft race test proved that the average speed of our device was 2.3km/hr , which is just over twice as fast as our desired measurable metric, therefore our goal has once again been met. The last thing I was able to work on and test before passing my device onto my teammates was the weight limit the new base can support. Unfortunately, I had high hopes that this device would be capable of transporting around 12lbs of weight, but I soon found out that was not the case.

FIGURE 15 - "BASE IMMOBILE AND BENDING AFTER 12LB WEIGHTS ADDED " [32]

I found that although this new Lexan base was much harder to cut through than the previous semester clipboard, it proved to be more of a problem when weight was added onto it because it would cause the Lexan to bend. This led to the wheels not being aligned correctly and when I added one 5lb dumbbell, and two 2.5lbs ankle weights, plus one mmore 2lb dumbbell, the motors had a very difficult time moving forward and backward at an excruciatingly slow speed, and they could not turn left or right at all. This was a shocking surprise for me however because in the previous semester with the old, smaller wheels and the clipboard, I threw a 10lb dumbbell on the clipboard and was able to drive the motors and device around my room with no problem! This leads me to believe that once again, it is not the wheels being underpowered or not necessarily the stall torque, but more so the base itself is causing the issue of not being able to support much weight. Once I get the device back and have it more integrated from my team's components, I will have to test it again for its maximum carrying capacity, although we never intended for our robot arm to grab heavy pieces of trash so in the end, this may not necessarily be a problem to prove our device works for picking up light litter.

C. Battery Drain and Voltage Drop Testing

As the electrical engineer of the team, Ricardo is also conducting tests on the power supplies for the deployable prototype. Not much can be said right now about how we can test the battery duration of all devices working together since this early in the semester all team members are currently working to test their hardware individually, but we can focus on testing the power supply to the four 12V motors powering the movement of the litter bot.

For our deployable prototype, the team has found it better for us to use two separate power supplies: one specifically for the 12V-DC motors and the other one for the combination of microcontrollers, servos, and other hardware. This is definitely not the most energy efficient way, especially when it comes to charging to the device, but it allows us to avoid having to integrate voltage regulators and separate adapters for different input connections. But focusing on the power supply for the motors, we will be using the same 12V 3000mAh Li-Po battery from last semester in order to power the motor controller that distributes power to all four motors. Ricardo will be testing this battery pack to determine how long the battery can last from 100% charge to about 20% charge while running the motors without any arm and other hardware mounted onto the chassis while driving over grass to determine the duration with a minimal load. The same battery test will be run a second time, but this time with 10lbs-15lbs of weight driving on rugged cement in order to determine how long the battery lasts when the motors are being worked up and drawing more amps in order to provide more torque. The goal of these tests will be to see if the battery can last over 30 minutes (while providing at least 1khm) in the more basic and harder situations that the robot could deal with. If the test fails, we will need to replace our battery with one of a bigger capacity in order to meet our desired measurable metric for the deployable prototype.

Ricardo will also be testing the battery (in the two same conditions as above) if there is a voltage drop in the battery over time, which will result in loss of torque, and therefore loss of speed. The ideal goal is to have the battery be true to the manufacturer's word and not have it drop voltage as it decreases, but if the test proves the motors are losing torque, it will require either a bigger battery of the same voltage, or a DC-DC buck converter that can regulate a constant output voltage of 12V to the motors. Once more, feel free to refer to the end of the report in Appendix B for a more visual representation of the test plans.

1. Results of Battery Testing & Updates to Hardware / Software

At the start of the second semester of senior design, I had already started looking for a new battery that we could use to further implement all the devices we would be using. Now that we need to integrate the arm, machine vision, and the gps feature i mentioned very briefly in the introduction of the report, I needed to find a way to make sure each of my team had the power they needed for their components to work properly, and on the go! In searching for the battery I used last semester, I found another battery from the same company that offered more outputs at different voltages, which I initially thought could help with powering servo motors for the robot arm and two other microcontrollers for the GPS and object detection features.

FIGURE 16 - "TALENTCELL MULTI-OUTPUT LI-ION BATTERY" [33]

But learning from when I ordered the first set of motors last semester, I read all the specifications of the battery this time and I soon realized that this battery just would not meet the requirements for this new semester and the new goals we hoped to achieve. I now was searching for a battery that could provide 2.4A to a new microcontroller a teammate is using and provide 3.0A at 5V for a microcontroller connected to all the micro servos that we are using for the arm, of top of 12V and 3A max input needed from the motor controller for the AWD system.

With all these tight restrictions, I ended up making the decision so far that it would be best to end up using 2 different power supplies. What I have been trying to avoid since the beginning of the project is now coming to life, but I have tried seeking batteries that can provide for all our features and there are none on the market that are under $150. Because this project is completely funded by the team and we have already exceeded our expected budget with all our components, I finally decided on a separate battery, shown below, that can provide 3A constantly out of all of its terminals and it has a much higher battery storage capacity than necessary.

FIGURE 17 - "INIU UPOWER+ USB POWER BANK" [34]

With this new battery, I have made it possible for the team to test all of their microcontrollers power together for future integration. Now that there are three 5V USB ports that all output 3A each and with a 10,000mAh rating from the manufacturer, powering the micro servo motors, and 2 separate microcontrollers with pi-hats attached *should* all work properly, but time will tell as the semester goes of and the team can integrate more pieces together after they finish testing everything.

Lastly, I decided to upgrade from the last Li-Ion battery pack I was using for the AWD system and go from a 3000mAh power bank to a 6000mAh power bank from the same manufacturer. The battery is bigger and heavier, but this time it also has more protection circuits built into the battery, so not only are we getting more time out of the power bank for the motors, but the power bank is also more safe and protects itself from frying and causing any damage to the project.

FIGURE 18 - "SPRING 2021 AWD SYSTEM POWER BANK" [35]

With this new battery, there is protection from over-charge, discharge, and short circuiting if anything were to happen from charging the battery. Another reason that I decided it would be a good idea to upgrade the battery is because I thought in the future, the added weight from the robot arm and extra devices plus more pieces of trash in a new trash bin would all add up and make the Litter Bot heavier. That would result in the motors working harder and therefore drawing more current from the motor controller into each bridge so it is safer to have more ampere capacity on that chance than to stick onto the old battery.

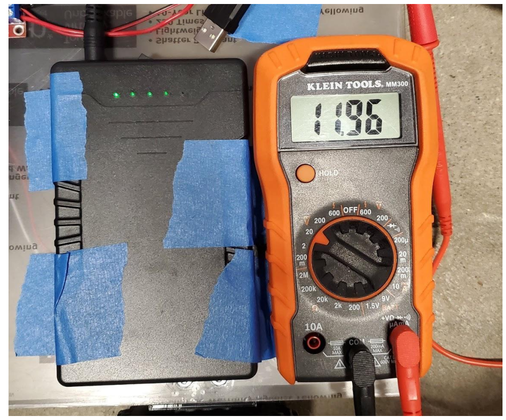

FIGURE 19 - "MEASURING THE VOLTAGE OF 12V BATTERY AT 80% CHARGE" [36]

I also measured this new battery to make sure it is true to its word and I can confirm that at about 80% charge (4 of 5 green lit dots), it holds close to a 12V reading, as seen in figure 15. This battery is overall just a better version of the previous semester and it will be in charge of providing all the amos to the four power hungry motors, while the other power bank with three USB ports will be in charge of making sure the microcontrollers and servo motors have enough power. But I am confident through my testing that both batteries will last well over 30 minutes when under constant use in the future for our deployable prototype!

D. Testing the Machine Vision Detection

The Machine Vision testing will be done by Vadim to make sure that objects are properly detected once the camera is mounted in the desired location on the robot and the robot is steered towards an object of interest. The objects would be identified from 1.5 meters away as litter or something to avoid such as a person. When an object is identified, if the object is not in the center horizontally but on the left or right then the locomotive will be guided to rotate the chassis slowly to put the object in the middle and adjust the direction if needed then move forward until it is within the reachable distance of the robot arm. Then the arm would get the signal when it is time to attempt to grab the object of interest in front of it.

We would also need to test to see if the object detection can be functional for a long period of time while being powered by a battery without crashing, overheating of the microcontroller or other unforeseen issues.

1. *Results of Object Detection Testing & Updates to Hardware / Software*

The object detection feature can easily detect multiple objects with 70% accuracy from over 5 feet away, or 1.5 meters. In this case, it was plastic bottles that were used in testing. The object detection feature was used to guide the drivetrain towards the detected litter object by telling it when to turn or to go forward. There were some issues with video lag causing it to drive like a drunk robot crashing into things and over steering but after slowing down the motors and creating delays with steps, it can now reliably find and drive up to a litter object close enough for the robot arm to try to pick up. So farThe first time around when I tried to add delays into the code to make up for the video lag, I tried multithreading as well as putting the robot to stop and wait a short time before looking for another object again. For the object detection, all the measurable metrics have been met.

E. GPS Boundary Testing

Vaukee is in charge of making sure that the robot will not leave within a certain radius from its home location. The test for this feature is looking for increased accuracy as the robot gains access to clear sky compared to being inside or near buildings. For this test, we are hoping to gain more than 50% increase in accuracy and precision when the robot's GPS has access to clear sky compared to when it is inside. When it is inside the precision of the GPS module is at around 20 meters. When the GPS has access to clear sky we can expect that the precision can reach up to being within 10 meters. As mentioned from a decently well documented work about the BerryGPS that we are using, "a HDOP value of 1 or below would give you an accuracy of about 2.5M" [37]. A lot of GPS nowadays usually sit around an accuracy of the mentioned 2.5 meters. If we can fall into this range, this will overall increase how well the border is defined.

We want the best accuracy so making sure the robot is in view of clear open sky is crucial but the issue is that this condition can't be met in various situations. Trees, buildings, and various objects affect the accuracy of GPS so we must test for how this affects our robot. With such conditions, we can still be happy that we are at an accuracy of 10 meters like mentioned before. This also means that we must compensate for the accuracy and reduce the radius of the geofence by the said amount.

A test to see if we can reach the same distance within the accuracy numerous times and have the robot be told to return will be necessary as it tells us that we can trust the set values. The radius can always be changed depending on the environment the robot is bound to so that the robot will avoid hazardous obstacles such as roadways or bodies of water.

The next thing that we must do is to integrate two features that work well with each other and the AWD system that Ricardo is working on is the perfect pair for the GPS. This test will go over the previous mentioned tests with the two features working in conjunction.

1. Results of GPS Tracking Testing & Updates to Hardware / Software

A. Test 1: Accuracy Inside and Out

For the first GPS test, we want to see how accurate the GPS is based on certain conditions. The conditions that we are testing is: GPS receiver inside or with obstacles to clear sky and GPS receiver outside. It is to be expected that the GPS receiver outside would be more accurate compared to the latter. When the GPS has a fix and is receiving data, the accuracy is horrendous having a deviation of over 30 meters and up to 60 meters.

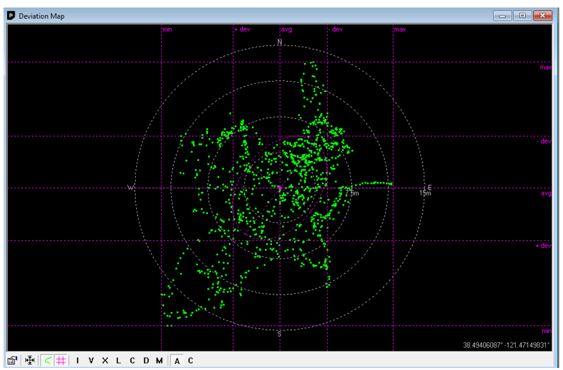

Figure 20. Deviation Map of the Averaged GPS Location (Inside) [38]

The figure above shows that the deviation from the GPS is around 15 meters. If we look closely at the center and the green dots (the current GPS locations), there is an ellipse there with the dots taking the shape of the ellipse. While the app is showing us the data, these dots are making a motion line that you can say represent the motion of the satellite(s) in space.

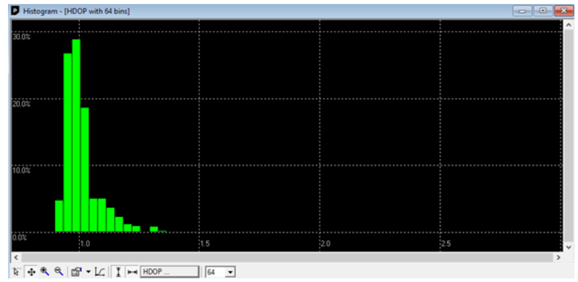

Figure 21. Histogram of the HDOP (Horizontal Dilution of Precision) (Inside) [39]

The figure above is the HDOP (Horizontal Dilution of Precision) which tells us how accurate the GPS is currently at with the current fix. This value starts from 0 as being completely accurate and upwards. At an HDOP value of 1, we can expect the accuracy to be around 2.5 meters. We also notice that with more time, this histogram will start taking the shape of a bell curve or Gaussian curve. There have been various cases where the HDOP was around 3 but in this case, we stay very close to a nice HDOP of 1.

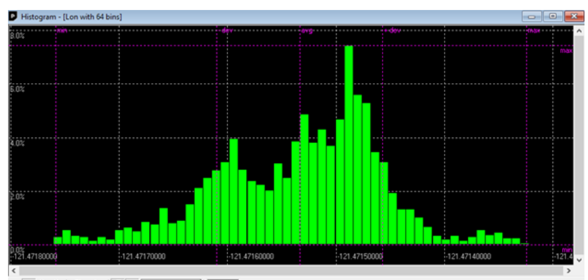

Figure 22. Histogram of Longitude Readings (Inside) [40]

Like the previous figure of the HDOP, the longitude histogram starts taking the form of a bell but because we are inside the "bell" comes out wider thus giving us a higher deviation. The same goes for the histogram for the latitude as shown below except the readings are slightly better.

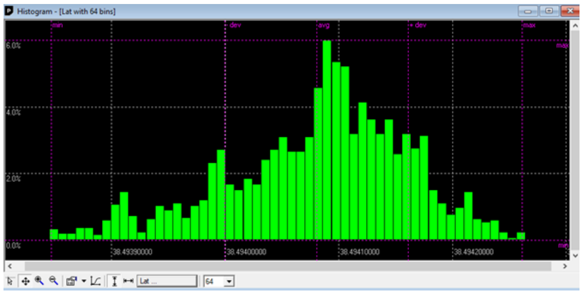

Figure 23. Histogram of Latitude Readings (Inside) [41]

Once we go outside, the accuracy increases greatly and the deviation is not as bad as what we were getting while we were inside. We have another histogram recording for the HDOP, Latitude, and Longitude for the GPS receiver being outside as well.

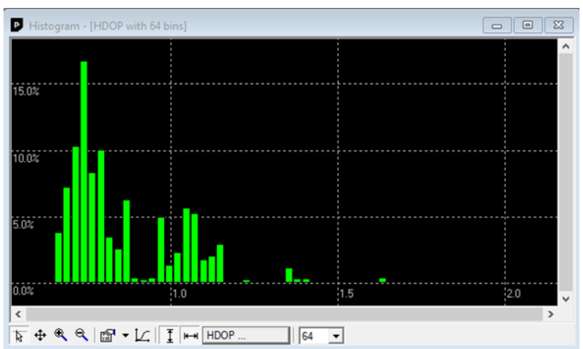

Figure 24. Histogram of the HDOP (Outside) [42]

As you can see, the data retrieved from the GPS about the HDOP increased over 50% with the average HDOP value of less than 0.5. There are some points where the HDOP is greater than 1 but these are obtained when the U-Center App for Windows has booted up within minutes alongside the boot up of the Raspberry Pi Zero W.

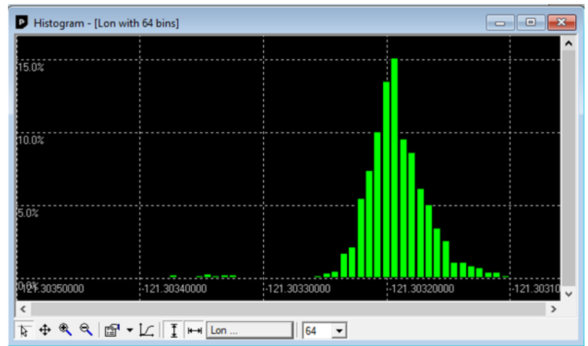

Figure 25. Histogram of Longitude Readings (Inside) [43]

When the HDOP is less than 0.5, our deviation decreased greatly and the accuracy increased as well. The max error was about 7 meters while the deviation had actually settled down near the 2.5 meters and even under that value. We now know that the accuracy is met with the device specifications and we don't need to show the histogram for latitude but it will be shown anyways as these two are like two peas in a pod.

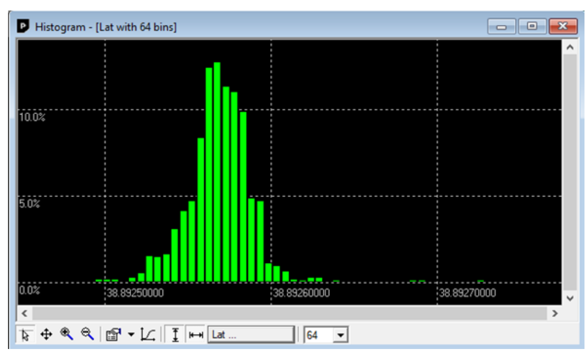

Figure 26. Histogram of Latitude Readings (Inside) [44]

B. Out of Bounds Signal Repeatability

As for the second test that was planned, it was found to be inconclusive because the GPS jumps everywhere. Increasing the radius makes the geofence work better but if the radius is small from the home point, then we can have false reports. For this to completely work we can keep the radius the same but we have to account for the deviation or error for the latitude and longitude readings. We can use the error estimate given from the GPS NMEA sentence and factor that into our calculations. In the simple sense, we can add a radius for the deviation to the current location. Then we want that new circle to be completely inside or completely outside the geofence of the home point. This works but there is too much error that must be compensated for that makes the robot inefficient in the sense that it can leave an extra 8 meters (for example) from the geofence. If the geofence was set to 20 meters and we have our current location with the error of 8 meters then the robot would have left 28 meters of the home point. In the opposite sense where the signal for the robot being within the geofence, it would limit the robot's freedom. We can use the same example as stated previously. except in this case the 20 meters minus the 8 meters would mean the robot can move within 12 meters of the home location and have roughly 452 m^2 to move around in. This would also mean we may have a dead zone of 16 meters and a loss of 640pi m^2 of area but the robot has to move through this space anyways to send the out of bound signal. The dead zone would signify that the robot would not really know where it is in a sense as this would be like a tri state where it sits between 0 (for completely inside) and 1 (for completely outside).

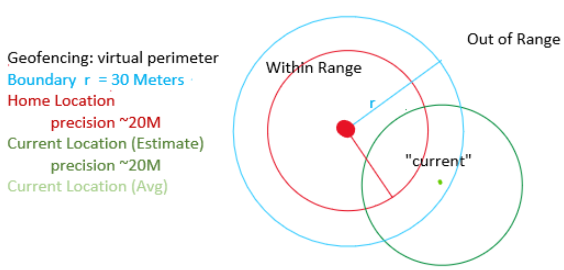

Figure 27. Geofence Depicting Location with error estimate [45]

This figure doesn't show the justice that was previously described but it helps the individual imagine what is happening. With this, the 2nd test we want has failed as GPS readings are quite random.

F. Deployable Prototype Status as of April 26th Deadline

Finally, it had been a very busy April, but the team managed to put in enough hard work and passion to get our deployable prototype working to our feature set and measurable metrics, as of our revised Spring 2021 feature set punch list. The camera ended up ditching OpenCV and operated with less video lag after no longer using that program, so it helped with getting the robot to drive in the correct directions with less delay. We also added an ultrasonic distance sensor to the front of the device so it can stop at about 8 inches away from a bottle in front of it, with some wiggle room for error. That was a last minute integration that definitely benefited the efficiency of the device, and we even added one to the top of the arm where it grips bottles, so when a bottle is in front it would command the arm to close shut as opposed to waiting till the end of the code to close itself, and risk knocking a bottle over. The figure below shows a front view of the Litter Bot with both sensors working together.

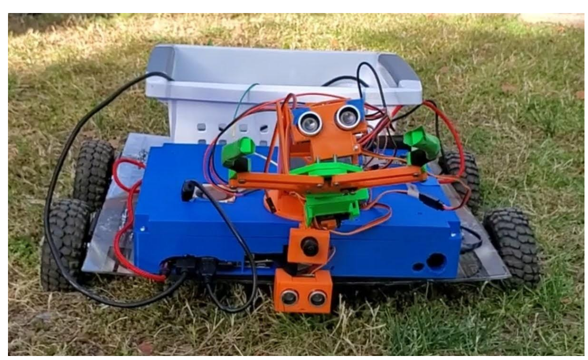

Figure 28 - Distance Sensors and front view of Litter Bot [27]

X. MARKETABILITY FORECAST

In order to determine the marketability of our device, we have to go back to our roots and determine what our vision was for developing the litter bot project we have been working to build to life. Litter pollution is infecting the waterways in our society and trash left within parks and roadways is also leaving unhealthy environments around the globe. There was a rough idea of who the target audience would be for our litter cleaning device, especially because we knew from the beginning that this being a college student only funded project would limit the hardware and experience we could invest into our device. We believe there is definitely a market for inventions that can help companies or cities clean the environments more efficiently and more cost efficient. Although our second semester prototype is definitely more advanced in every way than our previous lab prototype device, we understand and will address that with more improvements, time, and funding, we can appeal to more groups in the market seeking to clean cities and even neighborhoods if we can work out kinks to include the general public as a market.

A. Market for Cleaning Beaches

As stated in the societal problem section of the report, there is much concern with how much litter is polluting the ocean. To reiterate, about 60-80% of the trash found near oceans is plastic, whether it be from tourists or from it being washed up onto the shore [3]. It is no surprise that there would be trash that ends up on the beaches, especially because so many people like to go there for leisure time and because they are popular stops for groups looking to have a great time partying. But what is concerning is just how much trash is getting thrown around the beaches with no concern for who will pick it up or what the microplastics will do to the ocean.

Thankfully, there are volunteers and people hired by the cities these beaches occupy that know the dangers of plastic being left around, but it can be tedious and very costly to have labor workers go out and pick up litter that ends up on the sandy shores. As a matter of fact, a study was done in 2018 for the cost of cleaning litter polluting oceanways and it analyzed that “a cost of $5,000 to $20,000 per day, it would cost between $122 million and $489 million for one year...those figures don’t include equipment, disposal or labor costs” [40]. It is obvious that cleaning oceanways is costly for everyone involved, and that is why we believe that with some possible improvements to hardware, such as with ph sensors, and more funding for waterproofing (to an extent), we can market our device to be able to to help clean some of the litter that is abandoned on the sand and then gets released into the ocean.

For a one time purchase per device, cities can get their hands on a Litter Bot and deploy them around their oceans on sand and have them clean up the litter all around the area that they would set with the GPS functionality. Although our device was built of the vision of helping keep the waters clean, we also realized through development that we can expand our market to more cities through cleaning their parks!

B. Market for Cleaning Recreational Parks

Halfway through developing our lab prototype the first semester, the team realized that the original feature set for our device can also double dip into features that would be needed for cleaning wide open areas such as parks. Due to the recent

COVID-19 outbreak that happened last year, there has been an increase in people going outdoors and spending time together as friends and families in parks. Whether it be through riding bikes, playing sports, or having a picnic, parks are another land source for groups of people to gather around.

Unfortunately, with more people going to parks, there have been more instances of litter seen lying around and complaints from city inhabitants who feel uneasy going with their families to litter polluted recreational parks. One of the thousands of examples is that in Seattle, a popular tourist city location, it was reported that the "departments across the city have been working for weeks on a comprehensive plan that can be quickly implemented following City Council approval of additional funds" and once a briefing was sent to the city council, it was estimated that the proposal added up to roughly $5.6 million in funding [41]. Again, this is just one of the thousands of cities all around the nation (and globe) that require their parks to be cleaned for safety concerns but lack the millions of dollars to keep up with maintaining a park regularly. Therefore, we believe that there is definitely a market for our Litter Bot within the cities that have problems keeping litter off their grass for sports and away from their playgrounds for children safety. Our deployable prototype would just meet the requirements of reducing litter in open parks within cities, but of course there is always room for improvement such as adding more sensors to stay away from people if any were around. But as it stands our Litter Bot can be a great addition for city parks and having them get cleaned up, but with the current constraint of having them clean when the sun is out and no one is around, ideally when the park is closed or earlier in the day of weekdays before the most park traffic happens.

C. *Market for Cleaning Litter Along Traffic Routes*

Over the course of creating project Litter Bot, it has become more apparent in the outside world that trash has been more visible near freeways and highways, moreso this past year than any other. This could likely be due to the COVID-19 pandemic shutting down services to keep the streets and roadways clean, as well as budget cut restraints for the states. Based on some research, litter making a resurgence on the roadside appears to be a mixture of both.

Here in the state of California, we have a department of transportation agency, with headquarters in Sacramento, called Caltrans and they are working to keep roadsides clean through volunteers "adopting a highway" or by sending employed workers out in groups to pick up trash near cars. This can not only be costly for companies such as caltrans, but also dangerous for the workers and volunteers cleaning up trash near roadways when cars are driving by, risking their lives at the hands of distracted and impatient drivers nearby. Due to the COVID-19 pandemic, it was reported by Caltrans that "it wasn't feasible to keep the crews socially distanced and to properly sanitize the PPE workers wore to keep them safe on the road, so they had to suspend the [adopt-a-highway] program" [42]. Our device can help reduce the number of people putting their lives at constant risk significantly! With only one employee or volunteer going out and setting a Litter Bot device (or a few at once) out and setting it to pick up litter on one side of the road via its perimeter feature, there is less human life risk associated and it will end up being more cost effective than paying for the labor of workers.

A spokesperson for Caltrans by the name of Drabinski even admitted that

"Caltrans spends $50 million annually on litter cleanup" [42]. Again, if the state cleaning agencies were to purchase our litter bot devices to help mitigate the man made litter pollution on the side of the roads, they could save millions every year! Currently during the second semester, our deployable prototype is not fully suited and equipped with the best servos and motors to pick up all sorts of trash on the roadside other than lightweight plastics or small pieces of trash. In the future, if we could rework our arm to have stronger motors and redesign our chassis to be more center heavy, we could potentially create a prototype that appeals to the market that cleans freeways and roadside trash!

D. *Prototype Revisions & Improvements for Fabrication*

In order for our deployable Litter Bot to be more readily available for the Market and world to use, changes to the hardware and software would need to be made, especially if we are planning on mass producing them to have multiple bots out at once cleaning together. When it comes to the robot arm we will have to manufacture it faster since we 3D printed our arm so a better way to produce the arm faster would be to buy an arm from a manufacturing company and mount it onto the chassis instead. This would save production time and so much more time with building the robot. We would want the arm to be made out of metal so that it could survive natural conditions like rain, snow, and wind. When it comes to the chassis we would implement a shell on the outside to protect the hardware and make it look more appealing to the eye so that it can be sold. This shell would cover everything except for the arm and the trash bin . This would prevent any possible damages to the hardware and provide longevity of our product. Since we would have to install a shell to the bot then we would have to have heat sinks and add fans to the hardware to prevent overheating. This would make our product more reliable and safer for the environment and the consumer. We could also add a bigger battery that can last longer and make sure that all of the hardware parts are getting more power than needed.

In terms of our geofencing feature with GPS, we can improve how the robot will "path plan" based on how intricate we want the geofence to look. Currently the geofencing feature uses the GPS in conjunction with the haversine formula to create a circle as the boundary. If we want to complicate it more, we can look at it like a piecewise function and convert the polar graph into cartesian with multiple points to define the geofence. This means that we have to find the cartesian line equation for specific parts of the geographic area. This is too complicated. Instead we can maybe use the GPS to map its own geofence but this defeats the purpose of it not leaving the commissioned area as it will leave the area to define where it can't go. This requires a human to drive it around to set up the area which is more sound. As for the geofencing feature, keeping it to a simple circle is much more efficient until we learn a new skill in completing an algorithm for it. It is also very easy to convert from polar to cartesian so we can effectively make a square instead of a circle.

XI. CONCLUSION

A. *Conclusion - Societal Problem*

We have a problem as a society when it comes to pollution. Litter is piled up in places like the Great Pacific Garbage Patch which was created by humans who carelessly litter onto the ground. Most people do not realize but that litter has the potential to reach our oceans and pollute our waterways. This causes the waters to be contaminated with chemicals from things like plastic bottles and the fish drink that water and they get sick. The wildlife also does not realize that this is trash so then they eat it thinking it is food and that ends up in their stomachs which is indigestible, and the result is that they die. Littering is a major problem to marine life in oceans and other bodies of water with beaches. Many people that have parties on beaches or carelessly leave trash near the oceans are contributors to things like global warming that can be a direct result from their actions. Tourism has a major impact towards litter getting into the oceans because litter gets blown away into the ocean by wind poisoning the environment in which the fish lives in.

Litter, even if it doesn't poison the fish or the environment, can also block sunlight which is vital to the ecosystems in the ocean and other bodies of water. This causes things like sea otters to have a disrupted ecosystem because they eat sea urchins that eat the coral on the coral reefs. Coral reefs thrive off of sunlight and depend on it to live but when litter is there blocking that, it can cause problems and as a result some wildlife would die off. The major impact that some people are still denying in our current year is the direct impact that pollution on our lands causes global warming. People that litter most times are ignorant to where it may end up. Litter that is thrown on the ground like plastic is not biodegradable which means it cannot be broken down by natural processes. Littering is a major contributor and incineration of things like plastic bottles would cause greenhouse gasses to rise and this would result in an overall increase in global temperature. Our world is constantly changing, and production rates are increasing on things that have potential to pollute the Earth. This is a result of the demand from consumers and then obligations by corporations to supply them.

Policies have been implemented and fines have been given to offenders, but it is very difficult to keep track of everyone who pollutes the lands. This prevention of littering is based on the integrity of people and their decision of disposing it correctly or incorrectly. The impacts of climate change have been more vastly spread and more people have become aware. Our efforts in the next couple of years will determine the lifespan of Earth as we know it. Global warming is a major problem that we are facing, and many people are ignorant to its effects and how it can tarnish the world. Awareness and enforcement are key to defeating global warming because soon enough it will be too late to save Earth and we would have wished that we have taken action before.

B. Conclusion - Design Idea

Our team plans to tackle this littering problem by developing a litter picking robot to help prevent more litter from getting into the ocean. The major hardware components of the robot consist of a chassis that holds the robot components together, the wheels and the motors that drive them, the robot arm that picks the trash, the machine vision that use the cameras to guide the robot's navigation and the arm to grab the trash and the Raspberry Pi that would be controlling everything. This robot would drive itself around at places like beaches using machine vision to guide its way towards trash while avoiding other obstacles such as people and water. It would then pick this trash with a robot arm guided by machine vision and distance sensors then place it in the trash bucket on the chassis. This would complete a cycle and cause less hassle upon people like sanitation workers who have high physical labor jobs. This design idea creates an innovative engineering approach to problems that are very serious and vital to the preservation of keeping Earth healthy longer.

C. Conclusion - Work Breakdown Structure

Given that we have to work online with minimal meetings due to COVID-19, we would have less of an ability to help each other with the tasks and work together. We will be using Python on a Raspberry Pi for the most part because it's easier to deal with given the circumstances. We have divided our project into several major features: Identifying Objects, Drive Train, Navigation System, Holding Objects with Robot Arm, and Power Sources.

Vadim will be the lead for Identifying Objects which would be using a camera attached to a Raspberry Pi with the OpenCV library. Since this will be the main eyes of the system, we can also use the camera to help navigate with the help of computer vision when it identifies objects as litter or not litter so that we know if the robot needs to go towards or away from the object.

In order to get around, we have the drive train which Ricardo will be the lead of since he is our only EEE major, he has more knowledge of it than the rest of us. It will be all wheel drive so that the robot has less of a chance to get stuck somewhere and would allow us to drive over unpaved terrain. The code will utilize Python 3 using a Raspberry Pi Zero W to keep it simple and within reach.

Then we have the Navigation System which would help the robot stay in an area within a given amount of meters with the help of GPS so that it doesn't wander off and get lost. Vaukee will be leading this feature which gives us an option to have a path that the robot will take to try and clean up rather than randomly finding litter. When the navigation system sends a signal, then it will light up the robot and notify the user that the robot is of course and try to readjust itself to go back into its set boundary.

Deven will be in charge of the robot arm portion of the project. This will also be controlled with a Raspberry Pi using Python code. First he will make the arm move with simple code then move on to make it move in a more fluid manner when it goes to grab the object that has been identified as litter by OpenCV.

Ricardo will be in charge of the power supply. For testing purposes, we will start with using power supplied directly to Raspberry Pi controllers either with a usb connected to the microcontrollers or with a direct AC-to-DC power supply connection from the walls. Because our motors need 12v to operate and most raspberry pis operate at 3.3v or 5v, we will need to wait on the robotic arm and sensors that Vadim, Vaukee, and Deven are working on in order to determine how much power will be consumed per hour. Once all controllers and motors are taken into account, then we will use either Lithium-Ion batteries and create our own power bank that connects to a controller or bridge and supplies power to them all, or we may have to resort to having usb power connections to the wall or another pre-made power bank capable of high power for over 10 minutes. The solution to the power bank will likely come near the end of the project when all parts are complete and is expected to take around 25-40 hours to figure out the most ideal sources of power for the prototype.

D. Conclusion - Project Timeline

Now that the work breakdown structure is set and each member from team 10 is given features to work on a test, there needs to be a way to visually track the progress that the team is making. The team was assigned to work on creating a Gantt chart, which is a visual bar chart that helps illustrate what tasks are being done during certain time frames and who they are being done by. Vaukee went ahead and took initiative to format the Gannt chart the team would refer to for the remainder of the senior design course and the team filled out in a sequential order what activities for the features they were expected to work on in a sequential and weekly manner. These activities have deadlines created by each team member and they are required to be met by the selected team member. If they are not met we have promised to mention it to the team and we can help each other out to stick to the deadlines.

The team has assignments that range from the beginning of the first semester in August all the way to the final presentation of the device in May. The Gantt chart is full of course assignments that the team works on as a whole, such as the occurring report section update assignments and outgoing team leader reports that highlight how the project is going. Aside from the team tasks, we have each team member showing their responsible tasks to complete a set feature and when they are expected to complete the tasks. These responsibilities were based off of the work breakdown structure assignment and feature set punch list from the fall semester. This will be our guide to the end of the project in May 2021. We understand that life occurs and we are very involved in our project and each member is devoted to completing the feature set they have selected.

Our project timeline shows that Vadim will be working on using OpenCV in order to get machine vision working properly throughout October. Ricardo will be designing a more suitable base to get the robot locomotion working with reduced physical obstacle interference from the end of october to mid november. Deven will use an initial arm built by him to allow him to complete the feature of grabbing small objects for the month of November. Vaukee will be implementing the GPS aspect of the project through the end of November, allowing the Litter Bot to have a boundary. The Gantt chart also shows all of our contributions to the feature set of our Litter bot.

Not only did the team create a Gantt chart to visually guide the project, but a PERT diagram was also created and uploaded to the team's Microsoft OneDrive and it was created to show the project's task dependencies as well as the project's overall milestone. A milestone, as decided by the team, includes finishing successful tests on feature sets that we each worked on that contribute to the overall completion of our project. We all have goals that we are trying to attain in the month of November and these goals will be expressed in the PERT chart that we will complete. Other milestones include course milestones such as completing the bigger report and OneDrive upload course assignments throughout the semester. These milestones will give us as a team a reference to where we are currently in the project and if we need a new pace to allow the project to succeed we can do that.

Milestones by each team member for the time being will be the following. Ricardo will develop a chassis and have the efficient amount of power to the multiple Raspberry Pi microcontrollers, the robot arm and for the bot to move along different terrains which requires more power. Deven will develop a robot arm that can move using Python code to grasp small objects and put them into a trash bin. Vaukee will give the Litter bot GPS and create a "safezone" for the bot to travel to avoid any possible hazards like water. Vadim will use machine vision to identify objects that can be used on the arm to allow the bot to become autonomous. These features that we have expressed in our feature set will be included in our prototype in December.

We have completed the first three assignments of the semester and we are currently finishing assignment four on the first of November. We have five weeks until the prototype is due and we just have 3 assignments left to complete that include the risk assessment, project technical evaluation, and the lab prototype presentation. We are almost complete with this Fall semester and then we will be using that prototype to aid us through the Spring semester. In the Spring we will be expanding on the project and creating the best possible version of our build. We will be improving our machine vision recognition, we will be using an arm that will be the best and determine if we need to improve our code and add some degrees of freedom. We will also be improving the chassis and any power implications that we think that need to be improved on. Then lastly we will improve our build to have an impeccable GPS recognition and allow our bot to be absolutely autonomous and self sufficient.

E. Conclusion - Risk Assessment

The Litter Bot will have some risks when building and operating it. The risks that we have have mainly come from the power and the ability for it to catch fire. When it comes to the robot arm, the multiple servo motors and a raspberry pi which has the potential of overheating can cause the arm to catch on fire. Since the arm will be bolted to the chassis then if this arm catches on fire then it can be very crucial for the project if in fact it does catch on fire. If this were to happen then we will follow proper procedure to put the fire out and assess the damage. The other risk associated with the arm is the risk of harming the operator. Since the arm moves fast and has many joints, it has the risk of pinching fingers if someone was to move the arm. These moving parts can inflict pain to oneself and we must assess the risk when operating the arm.

On the software side of the arm, there is always a reason to malfunction and when all of the parts are put onto the bot we will run many tests as a team through virtual means and prevent these small malfunctions from happening during demo. The risks above will be accounted for in our final prototype. The team has concluded that if there was to be damage to the arm then we will purchase a new arm that is the same so that we know how to prevent these accidents from happening again.

Our navigation system relies on GPS and the potential risk for this would be the inaccurate acquisition of location data, hardware failure, and software failure. The GPS is tried and true as it has been with us for a long time and is quite robust. The only thing we are worried about in our case of hardware is water damage or ESD (electrostatic discharge). Prevention of water damage includes a decent IP rated casing. ESD will be covered in the risk assessment of our power supply system. The change in software may play a role in preventing our navigation system from working but the risk is minimal.

There is always a risk of unreliable data obtained from the GPS module but we also have information that can be obtained from the IMU. The IMU contains many modules like an accelerometer, gyroscope, and magnetometer. These components may provide some redundancy to prevent many risk factors that we probably haven't taken account for.

Machine vision has some risk with misidentifying objects as something that was not intended. If it were to confuse one object with another it could try to pick an object too heavy or an object too valuable to be thrown away as trash. This can be mitigated by adding a large number of images for each object so that it has a bigger selection to identify objects from more properly. Also, there's a risk of it not identifying objects fast enough if it has too many objects in the selection to identify, so we upgraded the microcontroller from Raspberry Pi 3 to 4 which has a faster processor by 100mz per core and 4 times more ram. A faster processor usually means more heat from the chip, in which case we got a hopefully sufficiently large one which has been keeping it cool enough so far.

Furthermore, there is a big risk of not completing one or more features on time. If we needed to test how some of the features worked properly we would need to test it with other features. For example, we need machine vision and the robot arm to work together where the machine vision would identify an object and the robot arm would then know to try and pick it up. Another example would be the drive train working with gps, since the gps can't keep the robot within a designated perimeter without the drive train and the robot wouldn't know where to go if it got lost without the gps.

The team plans to complete certain aspects of the project and then hand our parts off to the team leader and have the leader demonstrate the project. We will handoff the features to the team leader while practicing proper social distancing. We have included our risk assessment chart to create a visual for the reader and display our context into a readable diagram. These include the risks that have been mentioned based on the probability of it happening and the severity of the risk on a scale of one to five. The risks that we have are not hazardous but they have potential of happening and this is why we assess this into our project.

F. Conclusion - Revised Problem Statement

Realizing our societal problem was a big hurdle in of itself as there exist many high impact and high severity issues. We ended up going with the problem of litter or waste that would eventually end up in the ocean. Our focus is to mitigate the overall contamination of our precious oceans. This phenomena is currently happening all over the world with the coastal cities contributing to much of the ocean contamination. There exists various issues that may be solved merely by mitigating ocean waste.

Our solution provides a cascading effect. For example, if we start with urban parks this will allow our parks to stay cleaner and safer for children and animals. The resulting effect of this means that less waste ends up in our rivers and if our rivers carry less waste then the ocean will not be as contaminated. Less waste in the river will also have positive effects for the life that thrives there and the same goes for the ocean being a huge mass of water that supports all life. The biggest player in polluting the ocean and thus polluting the planet is Asia. Trash in the ocean contributes to global warming as sunlight and heat cause the plastic to release powerful greenhouse gases, leading to an alarming feedback loop. As our climate changes, the planet gets hotter, the plastic breaks down into more methane and ethylene, increasing the rate of climate change, and so perpetuating the cycle. Impacting marine life will impact us as well. The food chain can be disturbed as the main source of food for certain species dwindles. The original target of litter was to have a robot near waterways or on beaches to more effectively collect litter but from what we have it would be easier to have the robot move on mostly flat surfaces like urban parks where most folks frequent.

As for our design idea, we decided we didn't need to modify the current feature set as we only need to optimize them. For example, we stated that we wanted machine vision to detect certain objects like water bottles 1.5 meters away but reducing that to 1 meter will be much more beneficial when it comes to determining the object at hand. We can get a higher accuracy reading. Vadim opted into using an Nvidia Jetson Nano for better machine vision performance.

Our current multi axis arm was just a show that we can get the arm to work properly and grab a bottle but our new arm will be able to hover the bottle over the bin to be dropped. The new arm will be able to move with much more freedom. Our 4-wheel drive is working as it should using all terrain style wheels and the GPS perimeter is also working. The only problem with the GPS perimeter is that it isn't very accurate when there is no access to clear sky meaning that if there are lots of buildings or trees the accuracy will drop. It is expected that the GPS will not be greatly affected by this problem when it's outside in a park with a decent amount of trees. This also means that our work break down will remain relatively the same as it and the timeline greatly relies on our feature set. We do expect to add on to both the work breakdown and timeline as some things are not completely certain further into the future.

G. Conclusion - Device Test Plan

In prototype design, having a test plan is a surefire way of getting the correct final results. In our case, we want Project Litter Bot to be able to navigate around within a certain range of a home location and pick up litter that has been identified with computer vision. For this to succeed, we want to divide and conquer by working and testing on each feature of Litter Bot.

The all-wheel drive system is going through rigorous testing as it needs to be able to move through various terrains at a constant speed of 1km/h and the dc motors must maintain a constant load and torque. The power system is tested to keep power to all devices and the motors. Testing on the motors must allow them to operate for 30 minutes. The robot arm is being tested for repeatability in picking up objects consistently and in various positions.

The GPS boundary or geofence has to consistently tell the computer of the robot that it has gone out of bounds and must return into bounds within the accuracy of the GPS system itself. Our machine vision is put to the test by facing off against various types of objects in different conditions such as longer distance or different light levels. We expect machine vision to be able to detect objects within 1.5 meters. After all the individual testing of each feature, we plan to pair two features with each other: machine vision with the robot arm and the AWD system with the GPS boundary. The test for the first pair being machine vision and robot arm is to allow for machine vision guiding the arm in picking up litter. The next pair of AWD and GPS is ensuring that they work in conjunction with the individual tests still being involved.

H. Conclusion - Market Review

The market for a maintenance type robot is very small and immature but the technology is definitely there. Currently the demand isn’t as great and the people in the world are getting careless and lazier as time goes on. People just want convenience so they throw their trash just about anywhere. It is just sad and we can’t really enforce the rule of “No littering.” There are numerous signs that say “No Littering” with language stating the fee that will incur if the offender is caught. Usually these people are never caught. This means that people of good heart or people who are paid to have to clean it up.

Our design might just make such a behaviour worse but the premise is to make the world a cleaner and pollutant free place. We believe our device will mostly benefit the employees of the government and small businesses. The government tends to spend millions of dollars on cleaning and maintaining our environment through paying employees and the tools required. Let's assume that an employee at Caltrans makes $16 dollars an hour in a typical full-time shift with a work week of 5 days a week for 8 hours a day. This means the establishment will be spending over $30,000 on one person a year. We can also assume that the simple tools for picking up litter such as a trash picker and a bucket can cost as low as $20. If Caltrans employs over 4000 maintenance employees in 2019 this means that they spent over $120,000,000 in the year not including the cost of tools and replacement tools. We can also assume that the actual hours of picking litter is more than half of that meaning that less than $60,000,000 is spent as labor. Currently the design cannot accommodate working next to moving cars near the highway but despite the fact, we can put out 20,000+ Litter Bots to match the cost. This is a one time cost versus an annual cost so companies such as Caltrans can save a lot of money and use it for other maintenance!

I. Conclusion - Test Results

We have come a long way to get this far into our senior project. For this assignment, we need to test all the individual features to a measurable metric. To start off, Ricardo has passed all but one test. The first test is for a consistency in speed. The speed must be kept consistent at 1 kilometers an hour over various terrains and it will also have a load that it must carry. For this test, the robot will also be carrying about 4lbs on its back. The other test is for consistency with the RPM of the wheels and the current draw that comes with it when there is a high load. Then he will be testing the battery life of the system. The goal of this test is to make sure that the battery can sustain the system for about over 30 minutes.

For Deven's part, he is in charge of the arm and will test each servo to make sure they all work together to reach an object. He will also be testing for bugs in his programming so that the arm can be integrated into the whole system. After this is taken care of the end-effector or the gripper will be tested to make sure that a bottle or can can be grabbed from various positions.

Vaukee is in charge of the geofencing and will be testing the accuracy and precision or repeatability of the system. The accuracy is based on whether the GPS module is inside or outside. For the repeatability or precision test, the test of whether the robot will return within the radius of the geofence will be looked into.

Vadim is working on machine vision and will be testing to see if his feature will allow the robot to detect multiple objects and keep up to a 70% accuracy. After he has made sure that the accuracy is at 70% or above, he wants to make sure that the robot can be guided by his feature to a bottle or can that is on the ground. While he is doing this, the test for a signal to tell the robot arm to grab an object will be emitted. The Jetson Nano will also be tested for durability as it will be running at almost 100% throttle so that it will not run into issues later on such as crashing.

Finally, the end of this extensive report of Project Litter bot ends with the concluding statements of the two-semester long project and with multiple pages that showcase the references that were used for our studies or for our hardware and software. After the references, we have a glossary that defines in more detail one of the jargon used by our engineers throughout the report or during presentations and we finally wrap up the document with all of our appendices that have also been referred to in the report, but show in more detail the hardware components and software code that made our project come to life, as well as additional appendices defined in the table of contents.

J. Conclusion - Post Litter Bot Project Audit / Hindsight

For this Litter Bot project, we now understand the terrors of system integration that we were warned about since the beginning. We had individual features that we thought were ready and it would be an easy plug and play with the entire project but we now know that this is not true. We experienced many setbacks but despite the lack of confidence in our project we were able to complete it to the measurable metrics and produce a deployable prototype a few weeks later than we anticipated.

Although we were able to get all of our feature sets to work properly independently, the Spring semester proved that integrating the arm and having the camera detect bottles with either too fast or too slow driving motors was very problematic. Half of the second semester of senior design was spent focusing too much on optimizing features separately, and not enough time was spent on testing all the features together, which led to very-last minute design changes and started costing the team more money than expected. Further specifications on what went wrong and what went right will be described in the rest of the report. If there was one big lesson to be learned by the team and used earlier, it would be to get together sooner and organize more meetings to test components together near the end of the first semester and at the beginning of the second semester in order to save money in the end and get more measurable metrics completed to their full extent.

In hindsight, if we could go back to the beginning of the project and start over again, the biggest thing we would change is to take advantage of more weeks in the first semester to meet up and integrate our system sooner. If we had known that getting the robot arm would be such a hassle to try and get to work in different orientations, we may have changed the feature set to take out the GPS feature and just work on a device that can detect trash and pick it up in a more straight or outlined plan. Path planning is something that we definitely would have incorporated into our build to make it a more useful device to help clean up parks, beaches, and fields in general like we have been working towards. We all do believe that if it were not for the notorious Covid-19 pandemic outbreak causing the university to close down, we would have definitely had more incentive to start integration sooner since we would be meeting more in classes. But all of us being unfamiliar with one another caused us to work more independently in the first half of the entirety of senior design.

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Glossary

Anthropogenic: originating in human activity.

Autonomous Robot: intelligent machines capable of performing tasks in the world by themselves, without explicit human control.

Climate Change: a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

Global Warming: a gradual increase in the overall temperature of the earth's atmosphere generally attributed to the greenhouse effect caused by increased levels of carbon dioxide, chlorofluorocarbons, and other pollutants.

Integrated Assessment Model (IAM): term used for a type of scientific modelling that tries to link main features of society and economy with the biosphere and atmosphere into one modelling framework.

Litter: trash, such as paper, cans, and bottles, that is left lying in an open or public place. Disposable masks and gloves (due to the COVID-19 Pandemic in 2020) can be accounted for as well.

Machine Vision: the technology and methods used to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, process control, and robot guidance, usually in industry.

Microplastic: extremely small pieces of plastic debris in the environment resulting from the disposal and breakdown of consumer products and industrial waste.

Plastic: a synthetic material made from a wide range of organic polymers such as polyethylene, PVC, nylon, etc., that can be molded into shape while soft and then set into a rigid or slightly elastic form.

Pollution: the presence in or introduction into the environment of a substance or thing that has harmful or poisonous effects.

Pulse Width Modulation (PWM): a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The average value of voltage fed to the load is controlled by turning the switch between supply and load on and off at a fast rate.

OpenCV: a library of programming functions aimed at real-time computer vision

Appendix A. User Manual

User manual

Parts Needed

1. 1x USB Keyboard
2. 1x USB Mouse
3. 1x HDMI Cable
4. 1x Monitor
5. Wifi

Setup

1. Be sure the batteries are charged, turn them on.
2. Connect a mouse, keyboard and monitor to setup VNC on the Jetson Nano and Raspberry Pi.
3. Establish a wifi connection on the Jetson Nano and Raspberry Pi.
4. Unplug the mouse, keyboard and monitor from the microcontrollers.

Operation

1. Connect to the microcontrollers via wifi.
2. Run the litterbot program by typing “python3 /home/team10/litterbot.py” in the terminal on the Jetson Nano, run the arm code on the RPi by typing “python3 /home/pi/arm.py” in the terminal.
3. Place the Litter Bot in a location to search for litter.
4. Watch it try to find and collect litter.

Appendix B. Hardware

Table B-1: Hardware Device Test Plan [46]

TEST ID [Team Member]	Description / Method	Testing Range	Expected Results (Measurable Metrics)	Actual Results	Pass Fail
AWD Motors Speed Consistency [Ricardo]	Plan to test if the motors can constantly output at least 1khm speed on rugged asphalt, over loose aggregation of rock (gravel), on wet mud in a park field, and on 2.5” tall grass.	2/8/21 – 2/21/21	Driving at >=1khm should not be an issue on the test surfaces, which are where the litter bot is capable of operating on.	At minimal load, weighing in at 4lbs, the device was able to go 47ft at 2.3km/hr consistently over cement through 15+ trials and drove well over gravel and grass with mud patches.	P A S S
4WD Motors Weight and Torque [Ricardo]	Plan to test if the motors can output close to 120rpms as weight gets added with dumbbells to make sure motors draw required power with a heavier load until reaching the stall torque.(Although in Theory the arm would not pick up such heavy trash, just light, empty litter)	2/8/21 – 2/21/21	The motors will have heavy amp draw after ~12lbs of weight on the chassis and cause a decrease in torque, but will have the strength to continue operating.	The Lexan base could not hold up 12lbs and have the device turn, but the motors have the torque to go forward and backward at speed close to 1km/hr. A sturdier base or motors with more torque at lower RPMs would allow the correct movement.	F A I L
LiPo Battery Duration & Voltage	Going to test the 3000mah locomotion battery to last over 30+ minutes of constant use	2/12/21 – 2/15/21	The battery pack is expected to provide close to 12v for its duration, as stated by	After 1.5hr long heavy/constant use, the battery went from ~80%	P A

Drop Test [Ricardo]	with each motor using around .5A due to load torque (weight on the machine) and make sure the voltage drop from 100% charge to the 30-minute mark supplies the appropriate 12v to the motors still.		the manufacturer, but there is a chance it'll drop significantly every 20% it is drained.	to ~60% and measured 10.86v, which is an acceptable voltage drop that still provided the power for the motors and controllers to operate properly.	S S
Robot Arm movement with the servo motors [Deven]	In this portion I will be using the code I have written to make the 6 different servo motors try and pick things up from different angles within 1ft	2/8/21 - 3/19/21	Fluid motions of the arm so that it can go in every direction with the 6 different servo motors.	The motors were tested and they passed the movement aspects of the arm and allowed for a wide degree that it can reach.	P A S S
Debugging Code for the robot arm integration with the machine vision [Deven]	In this section I will be debugging the code to make sure that the integration with the machine vision can run smoothly without any glitches.	3/15/21 - 3/31/21	The code should be simple and allow the arm to function with the machine vision and detect trash and then the arm can move to discard the trash	The code is properly debugged to work with the machine vision just working on video lag problem that causes the robot to run over the bottle	P A S S
Testing the orientation of the trash and arm response [Deven]	I will test if the arm can pick objects up and into the trash regardless of the orientation along with testing the machine vision to adjust the claw to grab the trash.	3/20/21 - 4/19/21	Ability to grab objects up and into the trash regardless of the orientation.	In my testing the arm is able to grab the bottles in multiple orientations due to the design of the claw.	P A S S

Test for GPS accuracy with access to clear sky and near obstacles that tend to affect accuracy [Vaukee]	The accuracy of GPS inside without access to clear sky is horrendous being at just under 20 meters. The GPS module will be tested outside with access to clear sky with another condition of being near accuracy affecting obstacles.	2/10/21 - 2/13/21	An increase in accuracy of more than 50%. Being close to normal GPS performance of 2.5 meters of accuracy is a plus.	As expected the accuracy of the device shot up greatly although it does vary greatly as GPS coordinates are quite random. Proof of this is represented in the histogram comparing the readings from inside and outside.	PASS
Test for repeatability of GPS "out of bound" trigger [Vaukee]	Within the accuracy obtained from the previous test, we need the robot to react properly to an out of bounds signal.	2/14/21 - 2/17/21	The robot can re-enter the boundary upwards of over 20 times within the accuracy of the previous test ** 20 times is very low and unrealistic as it should probably be well over 100 for a proper test **	The test is considered inconclusive as GPS signals are almost random but it does seem like they could possibly be moving based on how the satellites are moving in space. We can get an out of bound signal even though the device is within 15 meters of home.	FAIL
Test for Object Detection 1.5 meters away with 70% accuracy	Multiple objects to be detected within close range of the robot	2/15/21 - 2/18/21	The robot can detect objects within 1.5 meters away with 70% accuracy	The robot can detect 5 objects within 1.5 meters range from the front of the robot with about 50-60% confidence	PASS

Test for functionality of operation of machine vision with locomotive [Vadim]	We need to see if the locomotive can be guided by the machine vision towards objects of interest without issues	3/7/21 - 3/24/21	Machine vision can detect an object of type “litter”and guide the locomotive towards it.	The camera used for object detections guides the motors to a bottle, but currently working to reduce video lag for more stable / consistent movement.	P A S S
Test for functionality of operation of machine vision with the robot arm [Vadim]	The machine vision needs to tell the robot arm when to pick up a litter object.	3/7/21 - 4/5/21	The robot arm will grab an object in the designated location that machine vision guided the locomotive towards.	The robot arm can pick up an object in front of the base after having the camera detect it and drive towards it, but so far only works with a wireless input command for the arm, not fully autonomously.	P A S S
Test for functionality of the microcontroller if it can continuously work without issues on battery [Vadim]	It will be turned on with object detection for an hour while being powered by a battery	3/7/21 - 3/24/21	Normal operation for the entire hour detecting objects without issues, no crashing, no overheating	The Jetson Nano operated normally without crashing or overheating while detecting objects powered by the robot’s battery.	P A S S

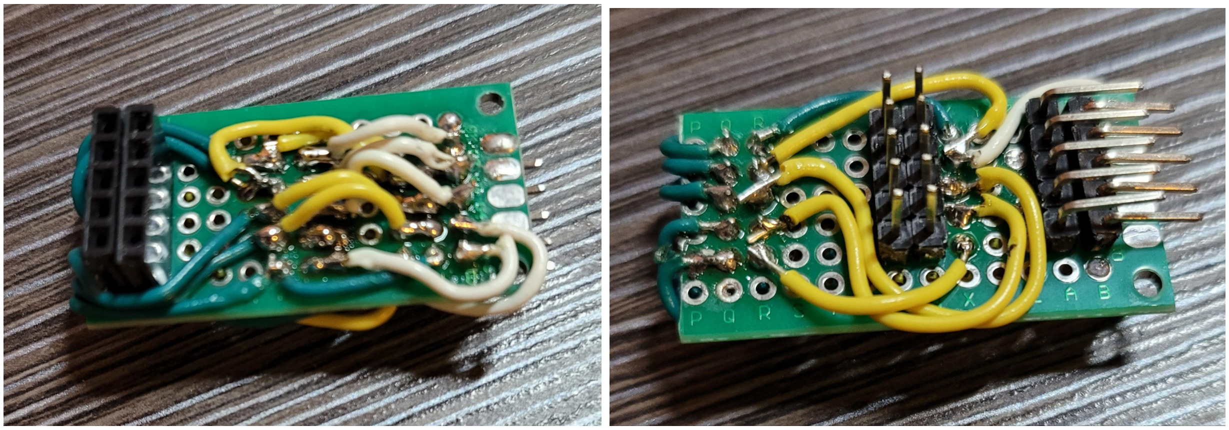


Figure B1. Protoboard I2C Bus Extension for use with the Adafruit Servo Hat and Berry GPS-IMU (Unused) [47]

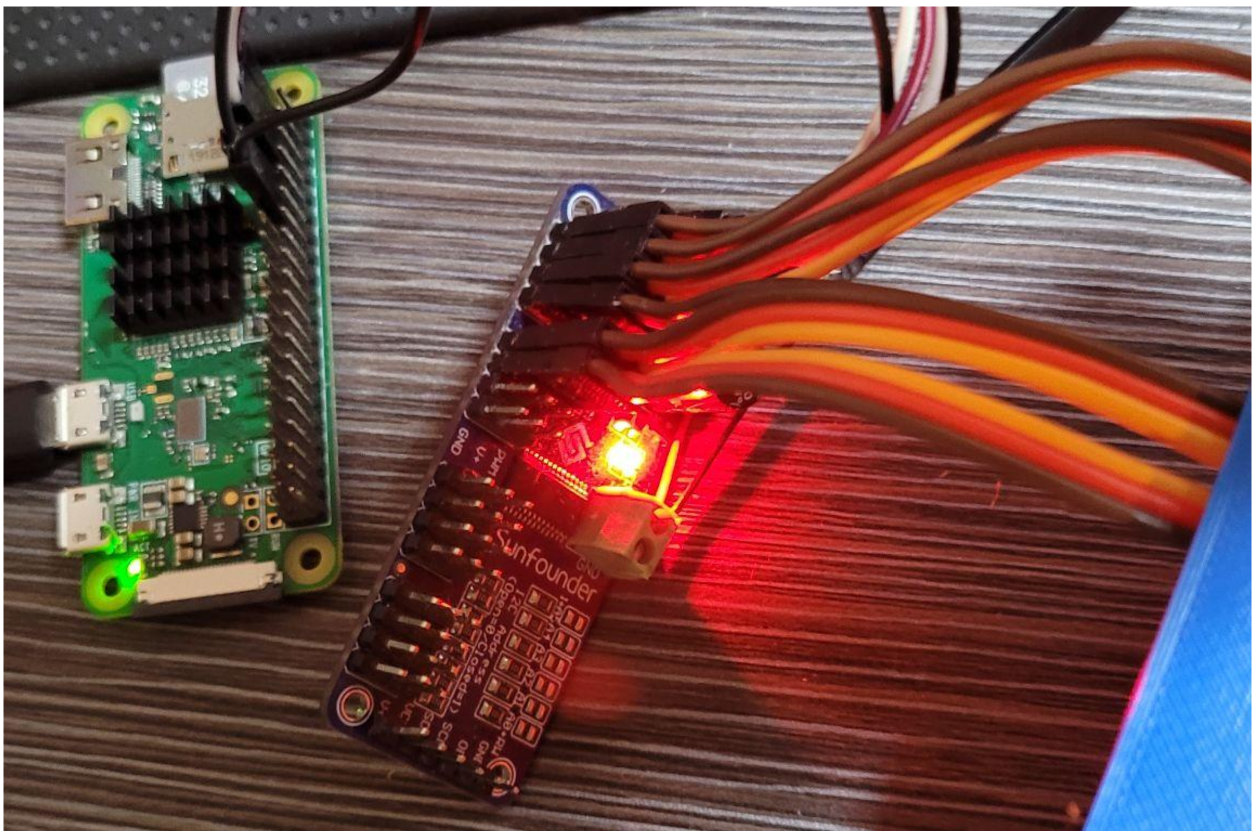


Figure B2. Raspberry Pi Zero W with Sunfounder Servo Hat connected via I2C [47]

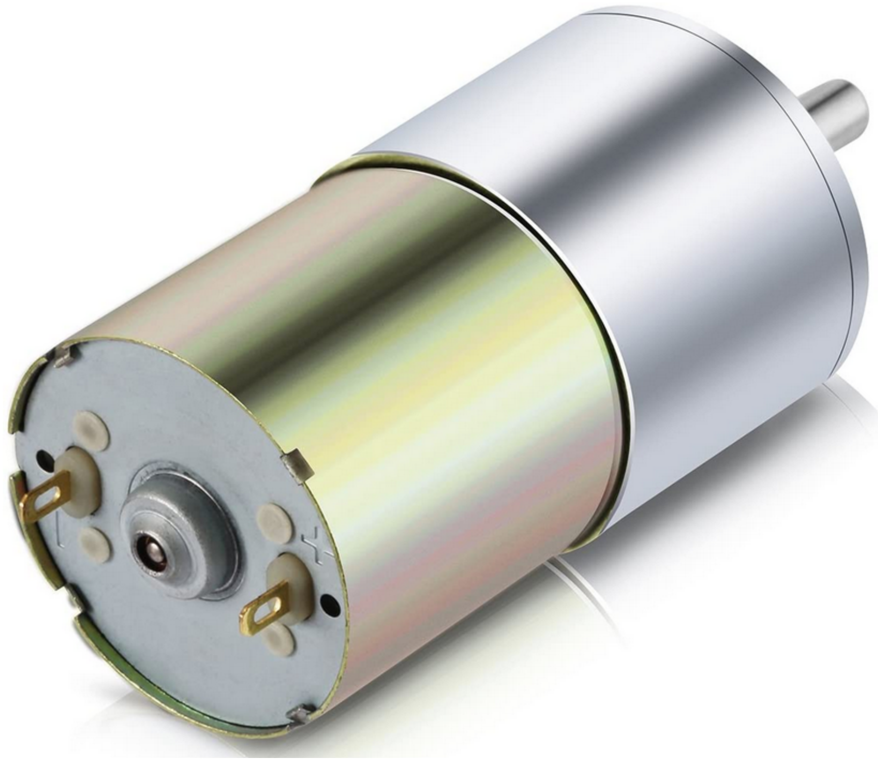
Figure B3. Jetson Nano [47]

GPU	128-core Maxwell
CPU	Quad-core ARM A57 @ 1.43 GHz
Memory	4 GB 64-bit LPDDR4 25.6 GB/s
Storage	microSD (not included)
Video Encode	4K @ 30 | 4x 1080p @ 30 | 9x 720p @ 30 (H.264/H.265)
Video Decode	4K @ 60 | 2x 4K @ 30 | 8x 1080p @ 30 | 18x 720p @ 30 (H.264/H.265)
Camera	2x MIPI CSI-2 DPHY lanes
Connectivity	Gigabit Ethernet, M.2 Key E
Display	HDMI and display port
USB	4x USB 3.0, USB 2.0 Micro-B
Others	GPIO, I^2C, I^2S, SPI, UART
Mechanical	69 mm x 45 mm, 260-pin edge connector

Figure B4. Jetson Nano Specifications [48]

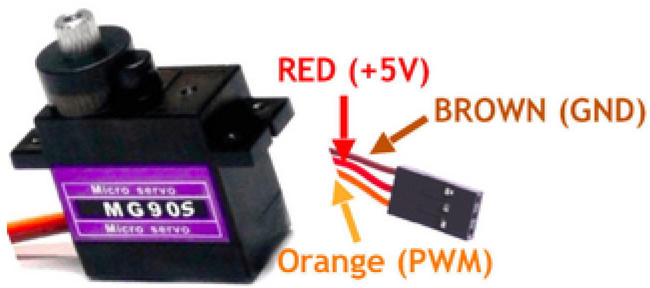
- Low current consumption, <200uA when using Periodic mode.
- Receiver Type;
  72-channel u-blox M8 engine
  GPS/QZSS L1 C/A, GLONASS L10F,
  BeiDou B11, Galileo E1B/C
  SBAS L1 C/A: WAAS, EGNOS, MSAS, GAGAN
- 3.3v supply
- NMEA, UBX binary, RTCM
- UART 4800/9600/38400/115200/230400/460800 bps
- Max update rate 10 Hz
- Horizontal position accuracy <2.5m CEP
- Acquisition sensitivity -148dBm
- Tracking sensitivity -167dBm
- Hot start <1s
- Assisted start <3s
- Cold start <26s
- Orbit prediction
- 1PPS Sync
- Fix/PPS LED
- One external pin for wake up
- Embedded antenna
- Connector for external antenna
- SuperCap to help store ephemeris data.

Figure B5. Berry GPS-IMU V3 on the Raspberry Pi Zero W (Top) GPS Specifications (Below) [51]



Specifications:
Rated Voltage: DC 12V
Reduction Ratio: 1: 31.6
No-Load Speed: 100RPM
Rated Torque: 4.5Kg.cm
Rated Current: 1.1Amp
D Shaped Output Shaft Size: 6*14mm (0.24" x 0.55") (D*L)
Gearbox Size: 37 x 24.5mm (1.46" x 0.96") (D*L)
Motor Size: 36.2 x 33.3mm (1.43" x 1.31") (D*L)
Mounting Hole Size: M3 (not included)

Figure B6. Geartisan 100RPM 12v DC Motor for Deployable Prototype (Top) Specifications (Below) [52]



TowerPro MG-90S Features

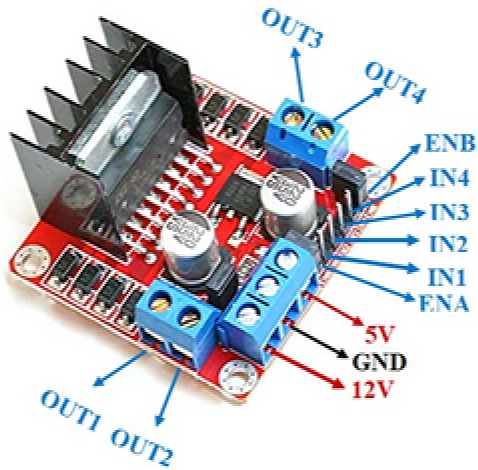
- Operating Voltage: 4.8V to 6V (Typically 5V)
- Stall Torque: 1.8 kg/cm (4.8V)
- Max Stall Torque: 2.2 kg/cm (6V)
- Operating speed is 0.1s/60° (4.8V)
- Gear Type: Metal
- Rotation : 0°-180°
- Weight of motor : 13.4gm
- Package includes gear horns and screws

Figure B7. (Clone) Tower Pro MG90S (Top) Specifications (below) [53]

MG995 Features and Electrical characteristics

- Metal geared servo for more life
- Stable and shock proof double ball bearing design
- High speed rotation for quick response
- Fast control response
- Constant torque throughout the servo travel range
- Excellent holding power
- Weight: 55 g
- Dimension: 40.7×19.7×42.9mm
- Operating voltage range: 4.8 V to 7.2 V
- Stall torque: 9.4kg/cm (4.8v); 11kg/cm (6v)
- Operating speed: 0.2 s/60º (4.8 V), 0.16 s/60º (6 V)
- Rotational degree: 180º
- Dead band width: 5 µs
- Operating temperature range: 0ºC to +55ºC
- Current draw at idle: 10mA
- No load operating current draw: 170mA
- Current at maximum load: 1200mA

Figure B8. (Clone) Tower Pro MG995 (Top) Specifications (Below) [54]



L298 Module Features & Specifications:

- Driver Model: L298N 2A
- Driver Chip: Double H Bridge L298N
- Motor Supply Voltage (Maximum): 46V
- Motor Supply Current (Maximum): 2A
- Logic Voltage: 5V
- Driver Voltage: 5-35V
- Driver Current:2A
- Logical Current:0-36mA
- Maximum Power (W): 25W
- Current Sense for each motor
- Heatsink for better performance
- Power-On LED indicator

Figure B9. L298N H-Bridge (Top) Specifications (Bottom) [55]

Appendix C. Software

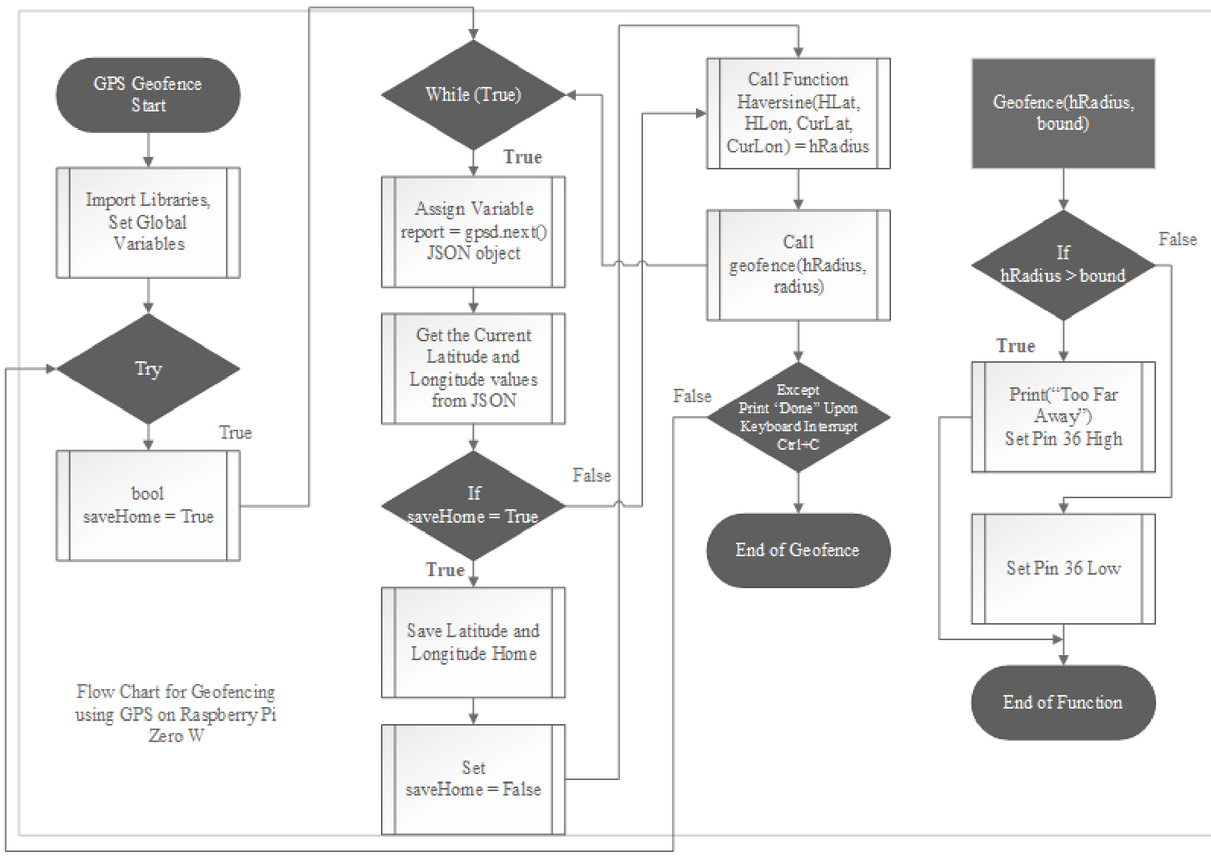


Figure C1. GPS Geofencing FlowChart/Pseudocode [56]

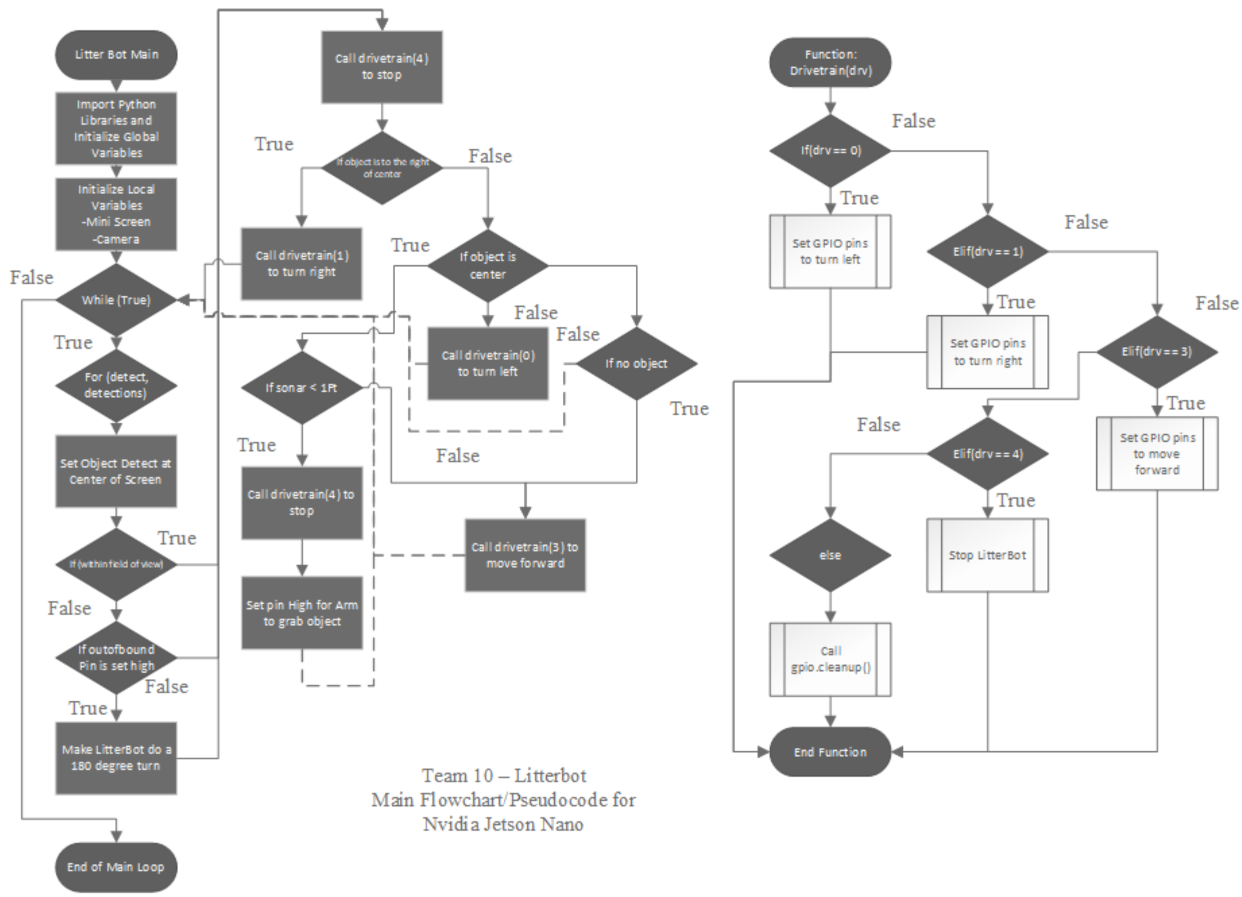


Figure C2. LitterBot FlowChart/Pseudocode [56]

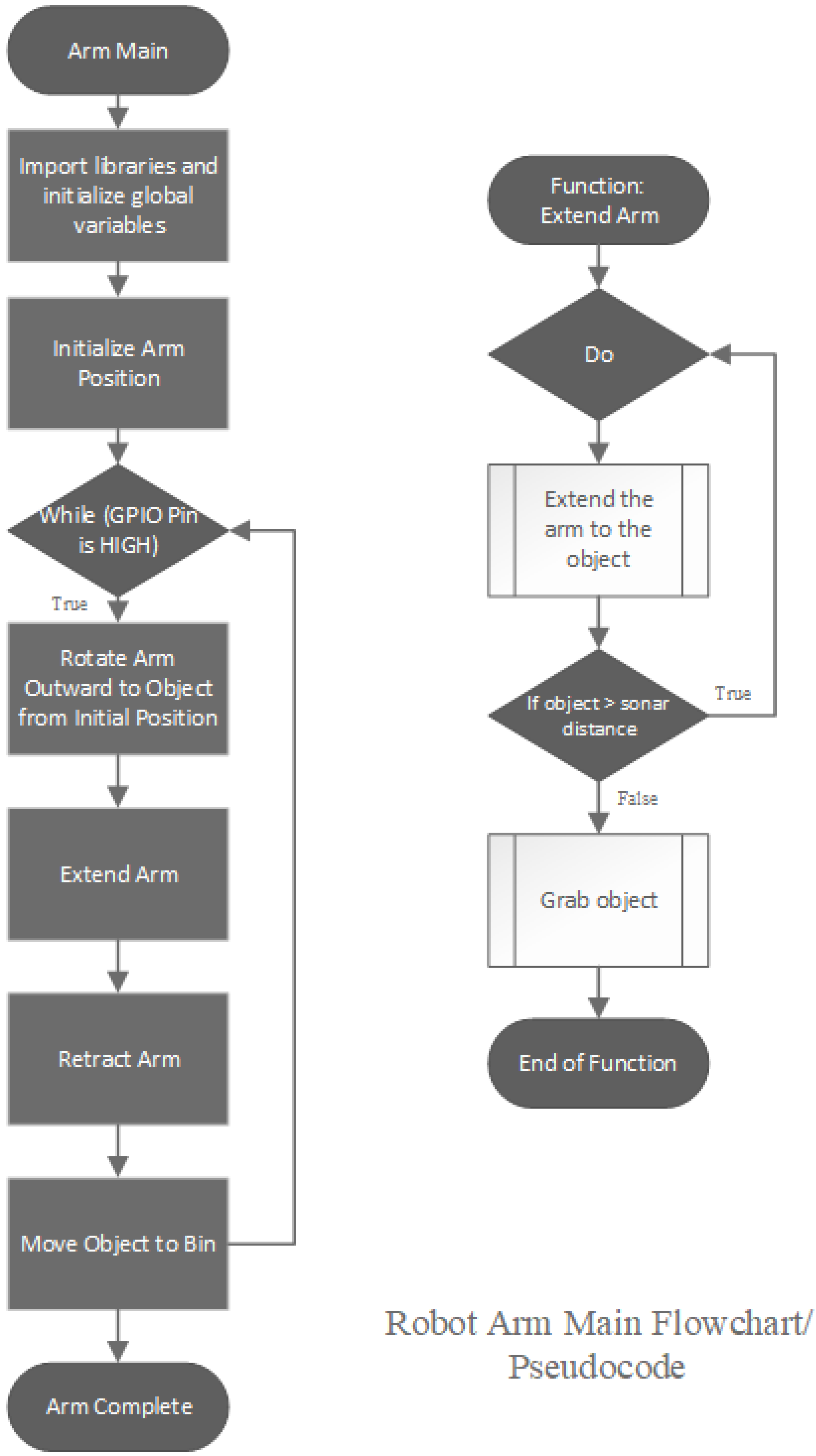


Figure C3. Robot Arm Flowchart/Pseudocode [56]

Appendix D. Mechanical Aspects

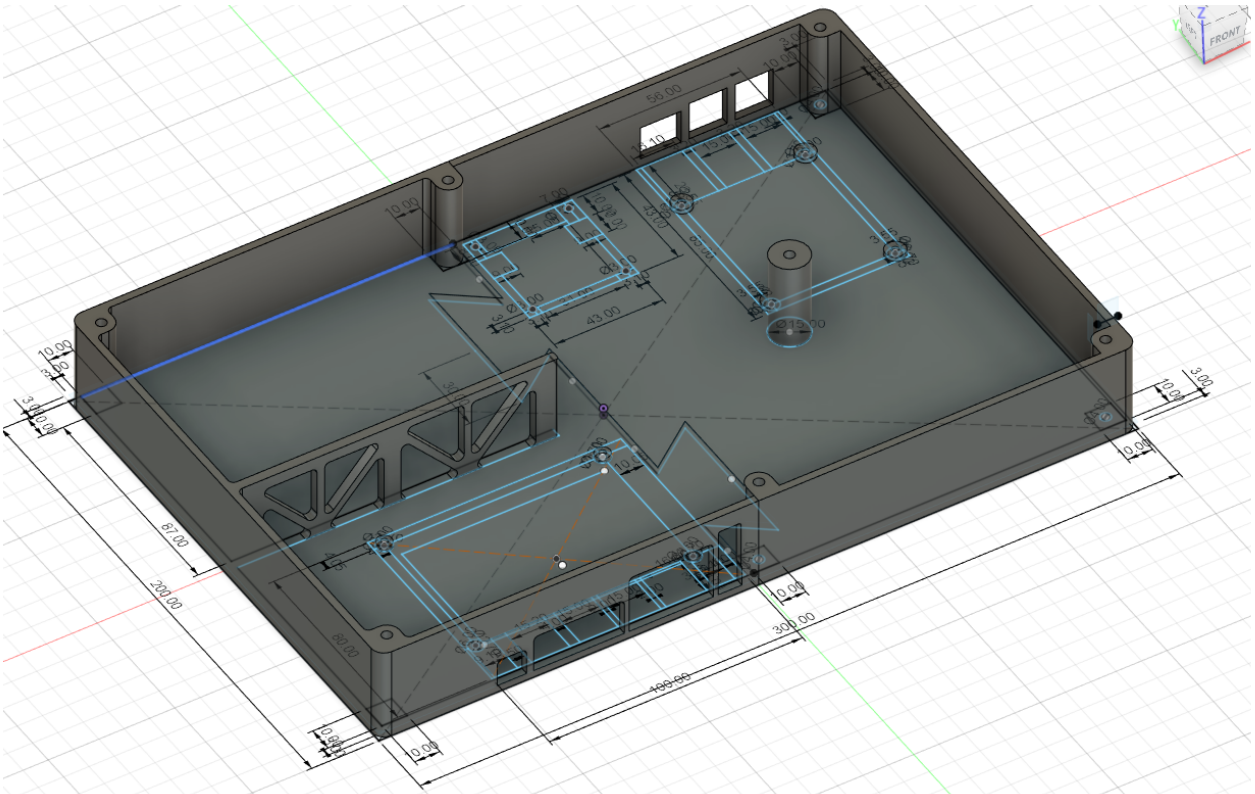


Figure D1. Electronics Components Case [57]

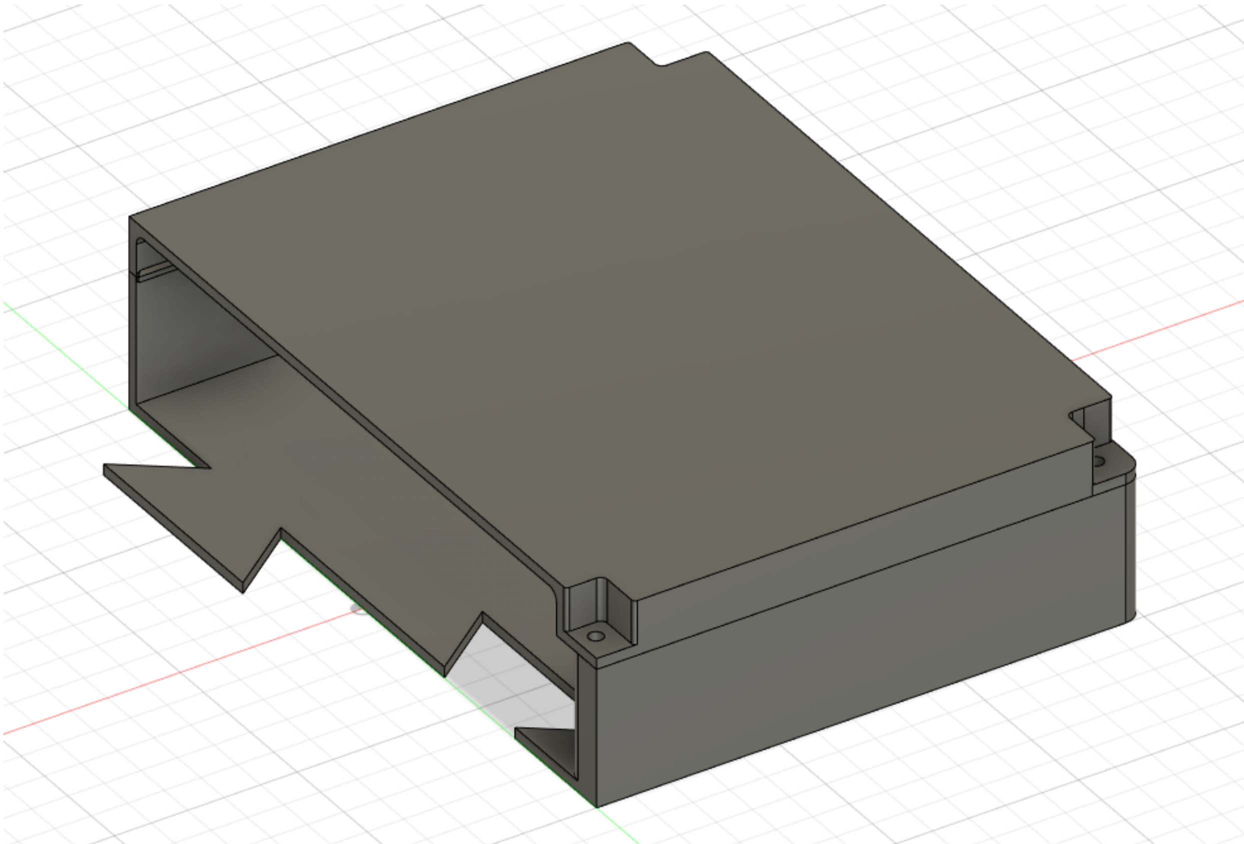


Figure D2. Right Half of Electronic Components Case with (Symmetrical)Cover [57]

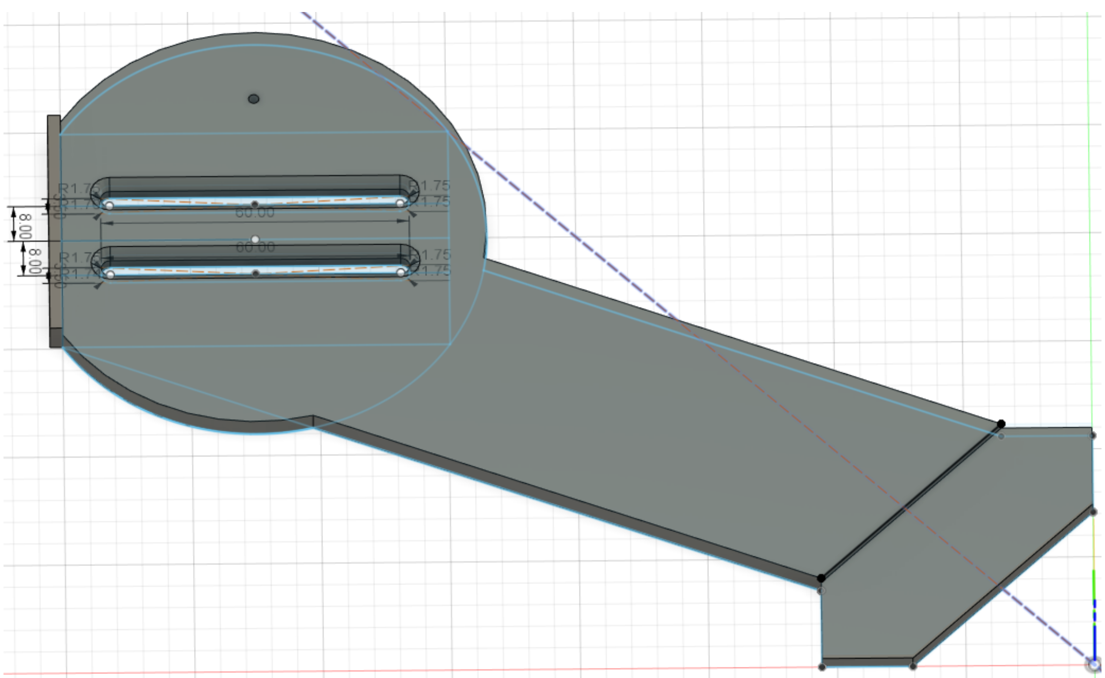


Figure D3. Chassis Arm 0 [57]

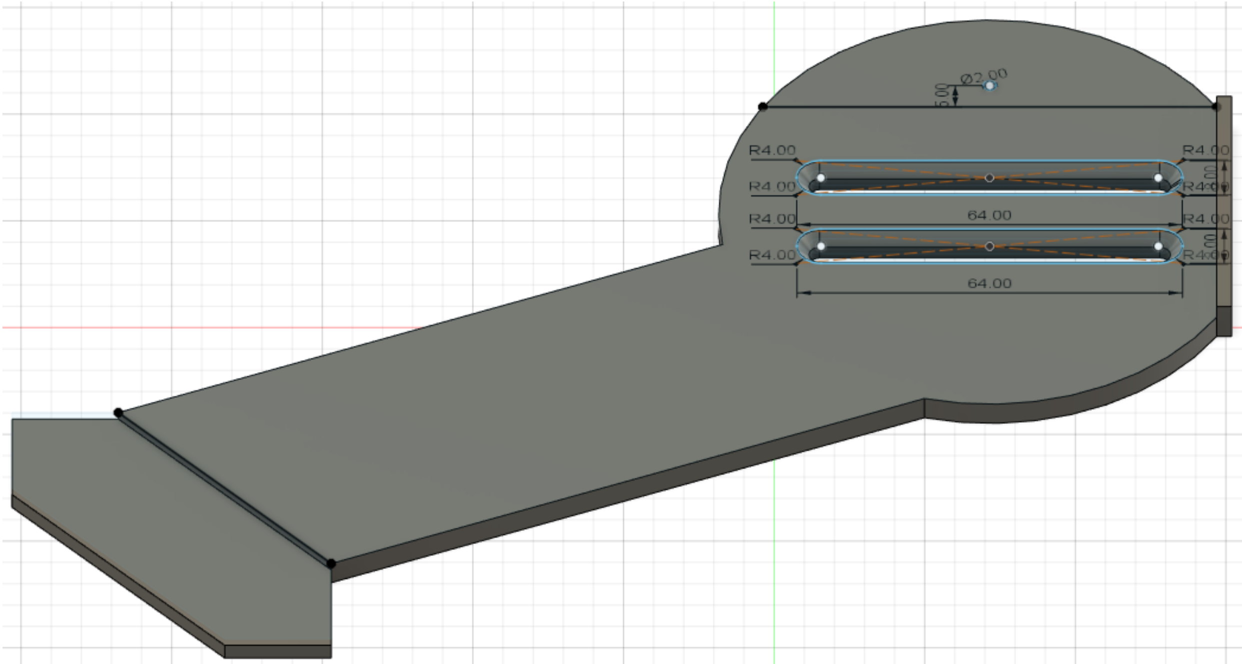


Figure D4. Chassis Arm [57]

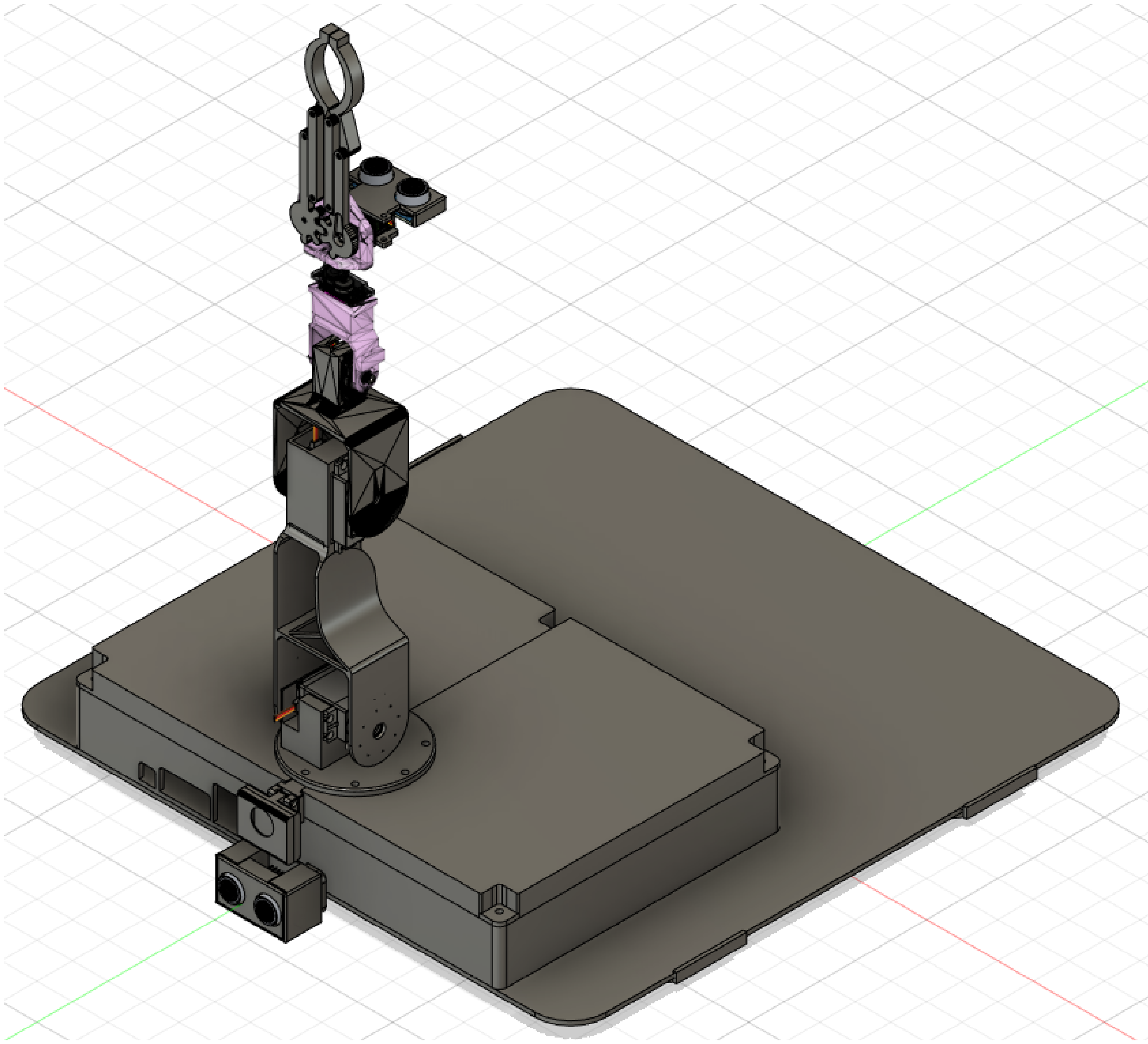


Figure D5. 3D CAD Incomplete Chassis with Arm and Sensors [57] Parts seen in pink are borrowed from user named holgero from Thingiverse [58] while the rest are a remix for our use case. Big servo adapter [59] Small Servos adapter [60] Sonar sensor casing [61].

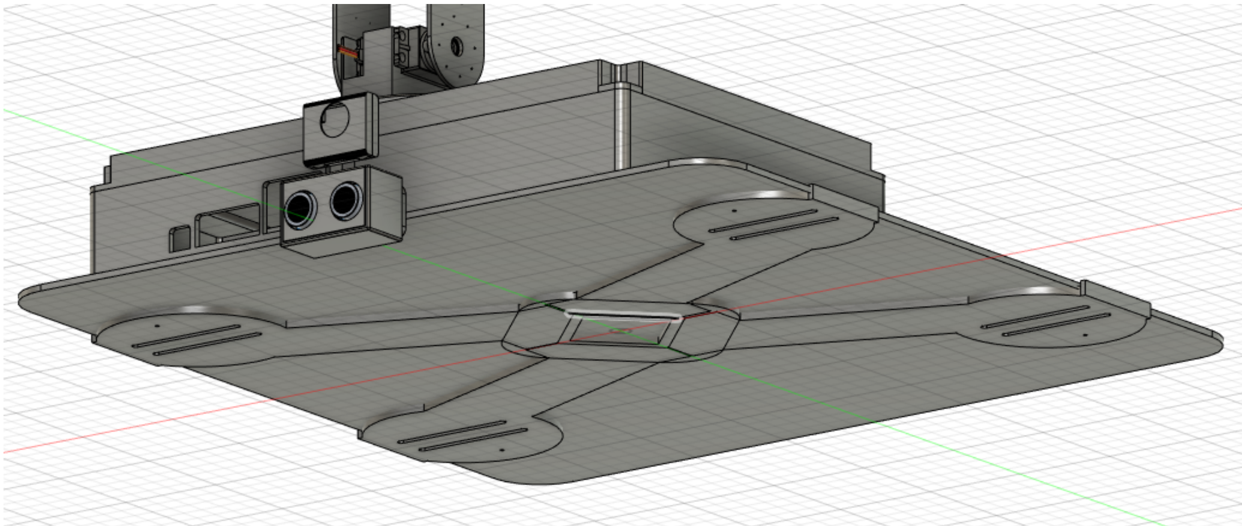


Figure D6. Chassis Bottom View [57]

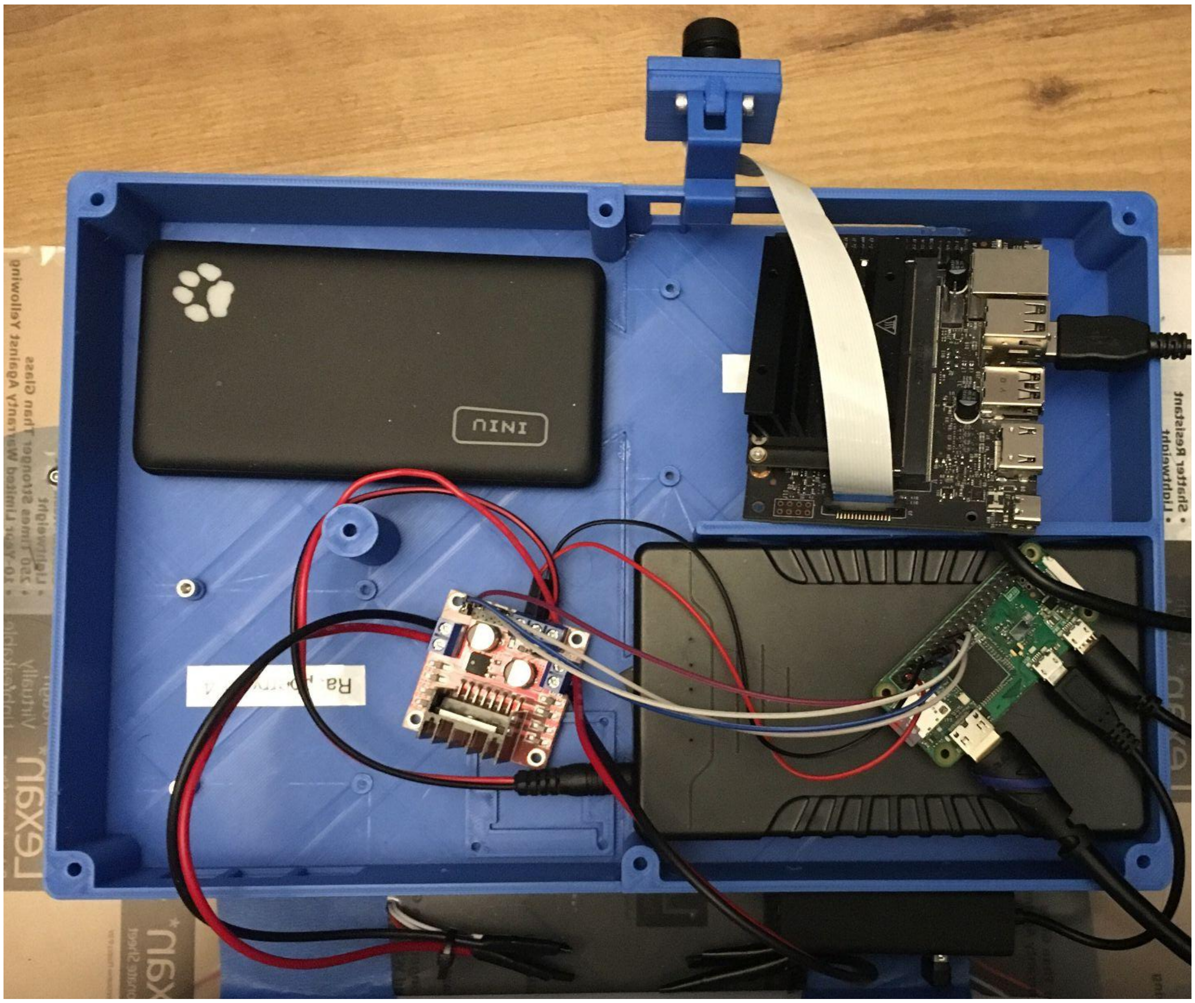


Figure D7. Initial Components Mockup with Temporary Camera Mount [57]

Figure D8. New Robot Arm in Orange PLA (Not Final Arm) [57]

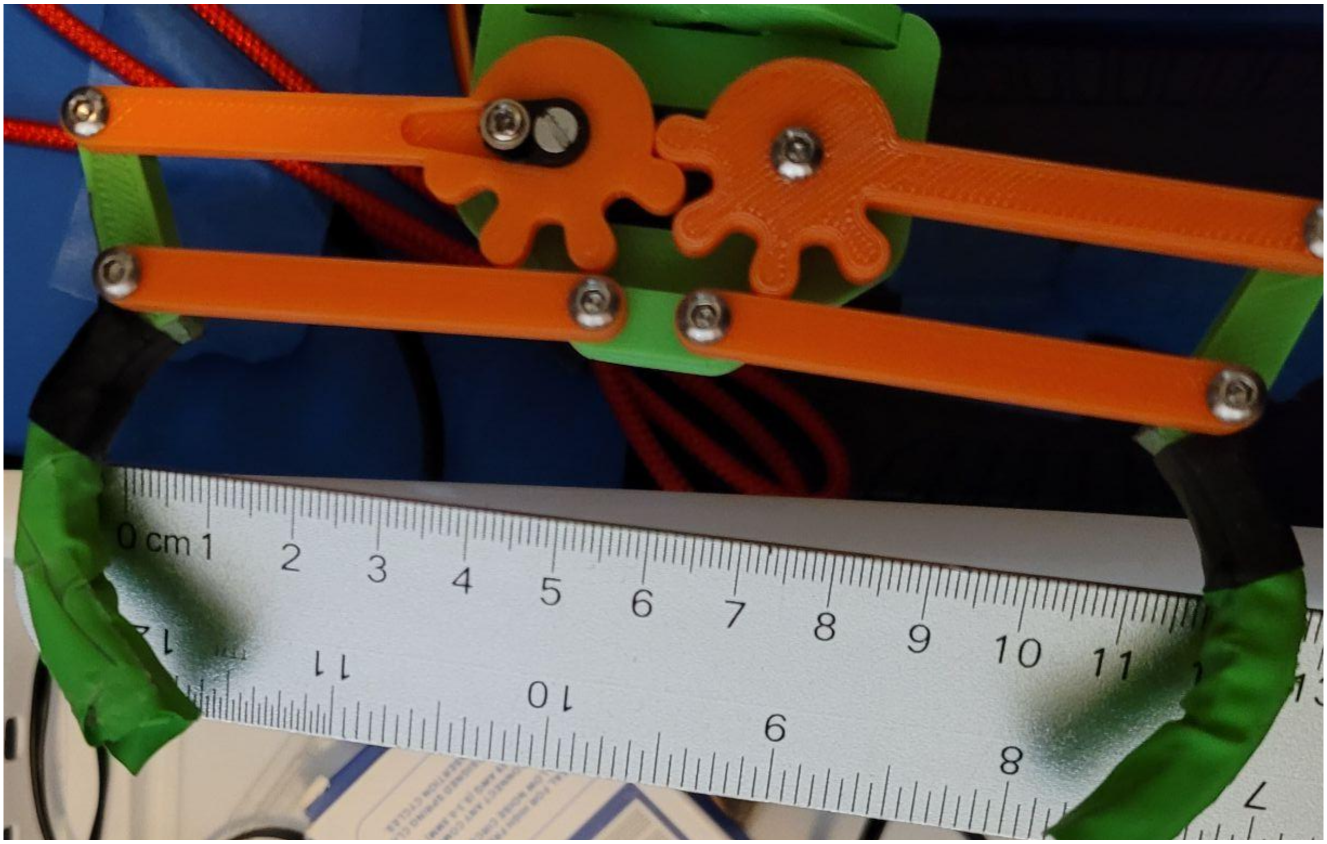


Figure D9. New +22mm (lengthwise) Extended Grip Parts to get outer width of ~11cm and minimum opening of ~10cm printed in Orange Hatchbox PLA and Green 3DSolutech PLA. [57]

Figure D10. HC-SR04 Sonar Sensor in Orange Hatchbox PLA Case [57]

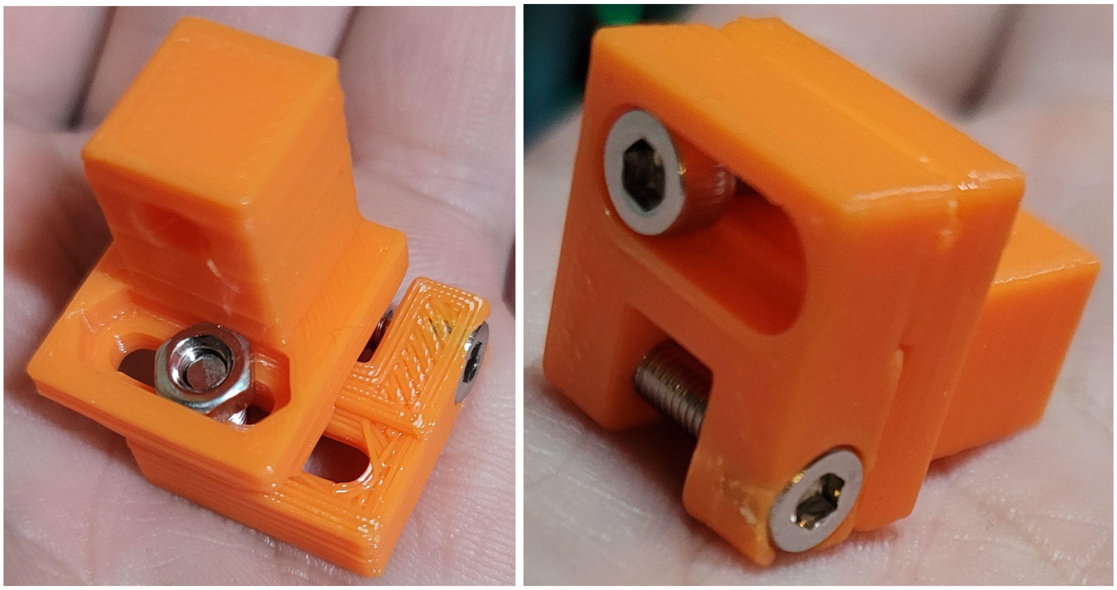


Figure D11. Camera Case Mount with Sliding Functionality [57]

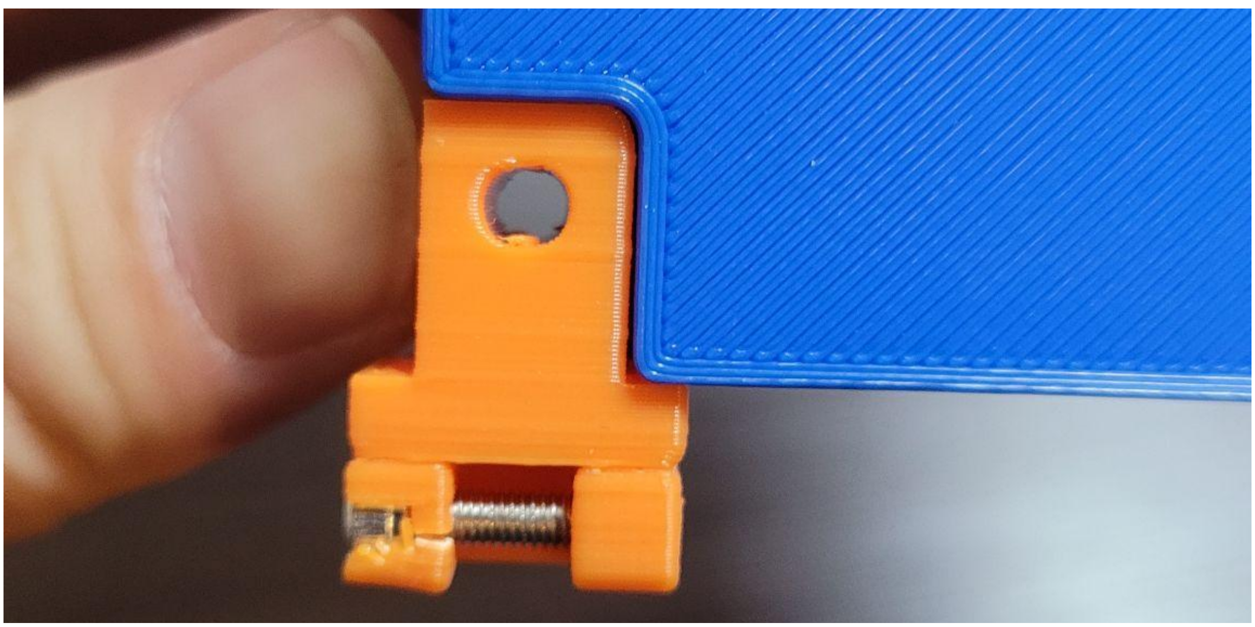


Figure D12. Camera Case Mount Test Fit [57]

Figure D13. Spring Tire Dimensions [28]

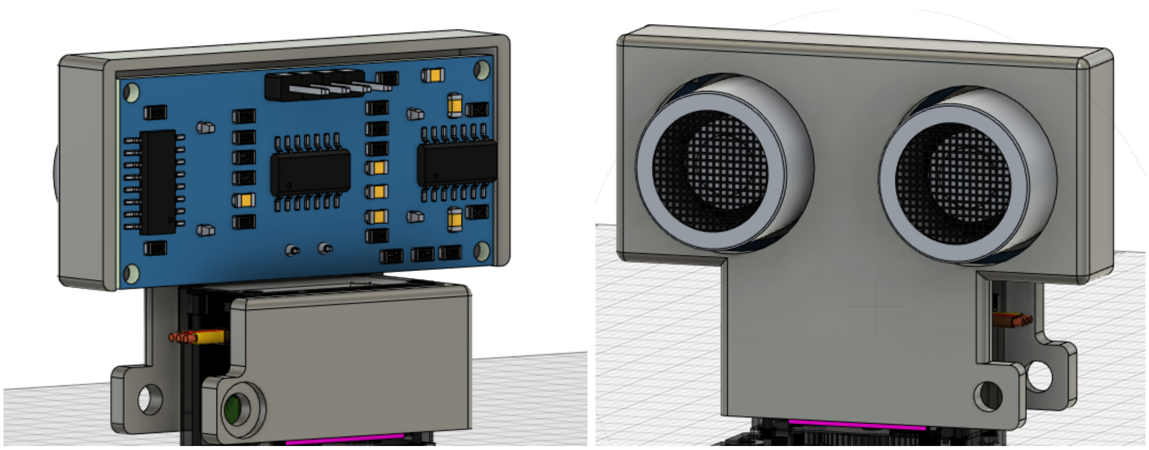


Figure D14. Arm Mounted Sonar Rear (Left) Front (Right) [57]

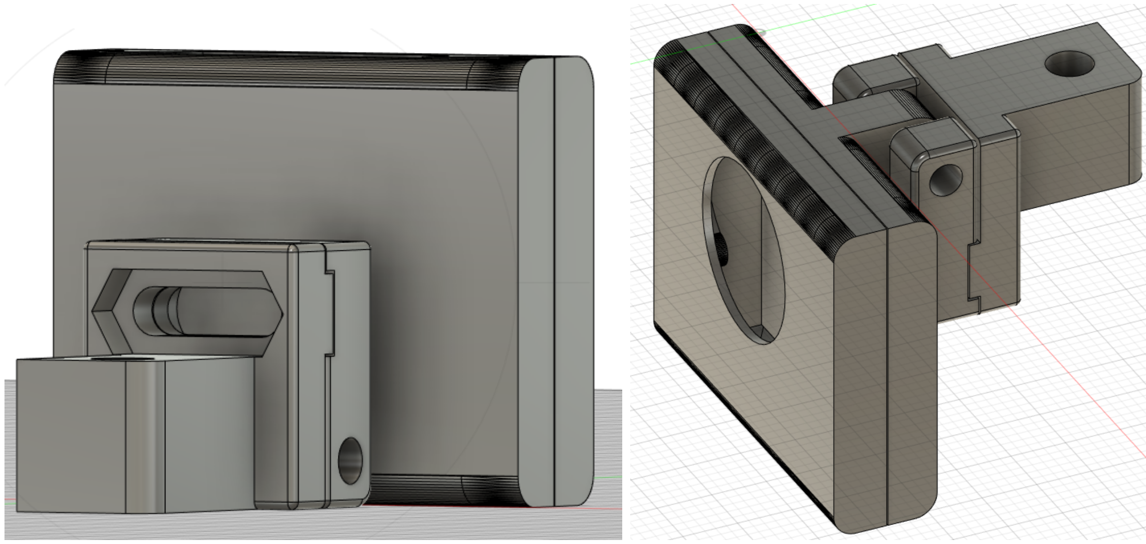


Figure D15. Camera Case and Mount Rear (Left) and Front (Right) [57]

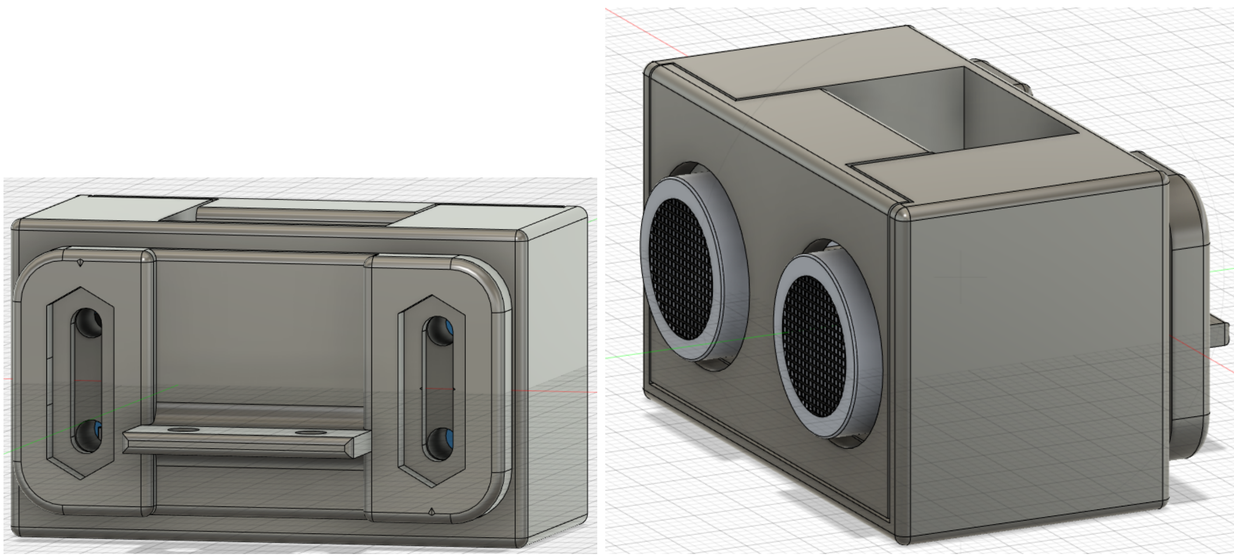


Figure D16. Front Center Mounted Sonar Rear (Left) Front (Right) [57]

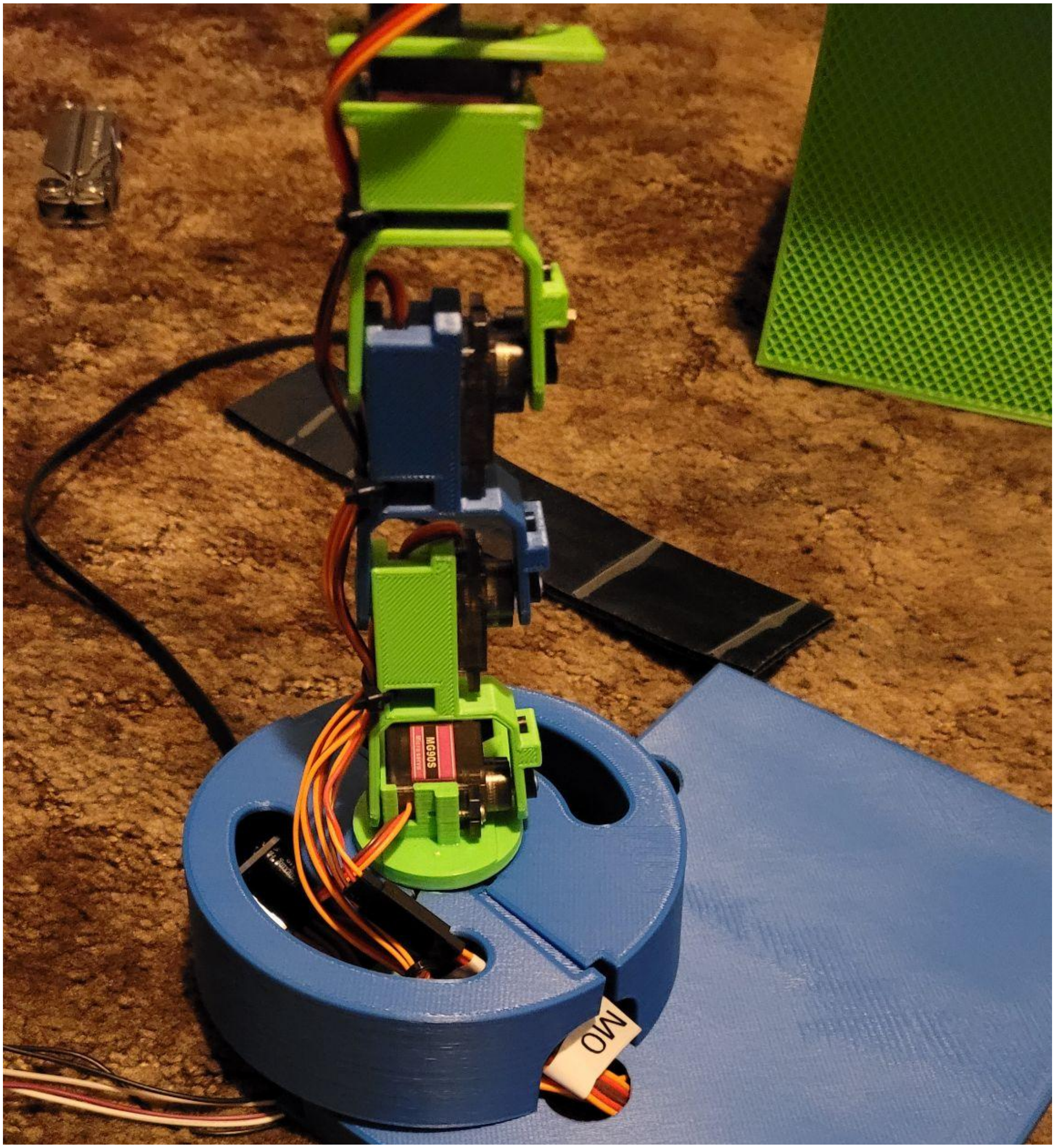


Figure D17. Second Arm with Stabilizer and tight cable management [57]

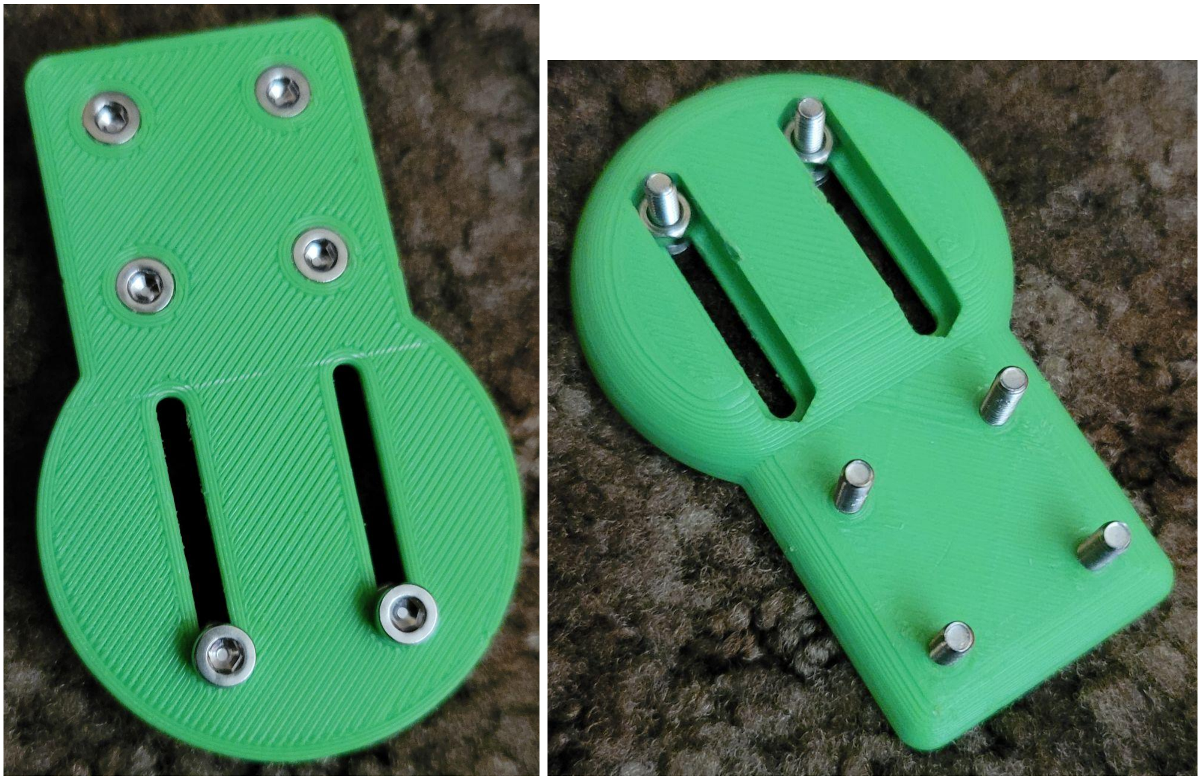


Figure D18. Wheel Extensions [57]

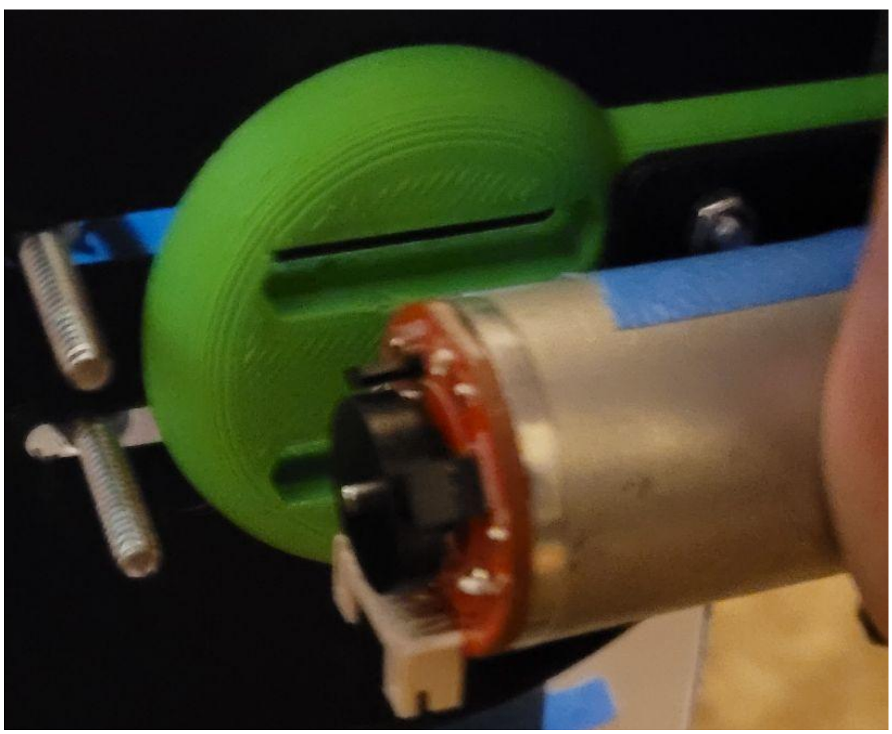


Figure D19. Wheel Extension Mockup [57]

Appendix E. Vendor Contacts

- Vendor Contacts are *NOT APPLICABLE* for Project Litter Bot as Team 10 was not granted outside resources from any companies.
- Special thank you to Professor Russ Tatro for providing the team with constant constructive criticism on how to improve the drive train to be more efficient through the use of Pulse Width Modulation and for helping with the project during office hours.
- Special thank you to Professor Neal Levine as well for helping team 10 with robotics related problems and teaching the team about equations and processes to buy robotic components to help meet the team's measurable metrics without overpaying for extra equipment.

Appendix F. Resumes

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Vaukee Lee

vaukeelee@csus.edu - linkedin.com/in/vaukee-lee-878b31189 - https://bitbucket.org/vaukee

PROFILE

Passionate future engineer looking to expand his horizons beyond just computer engineering.

EDUCATION

Bachelor of Science CSU Sacramento, Computer Engineering **Expected Grad:** Fall 2021

Courses: Adv. Computer Design, Computer Interfacing, Computer Network+Internet, Adv. Logic Design, Computer Hardware Design, Data Structure+Algorithm Analysis

TECHNICAL SKILLS AND KNOWLEDGE

Programming Languages: Java, x86 Assembly, C, Verilog/VHDL, and Python

Tools: jGRASP, Eclipse, IntelliJ, PyCharm, Wireshark, Virtual Box, VM Ware, Visual Studio Code, Visual Studio, Fusion360, Version Control (GitHub/Bitbucket), MatLab, MS DOS, and MS Office

Hardware: NEXYS 4 DDR FPGA, Raspberry Pi, Arduino, STM32 Nucleo, Terasic DE0-Nano, Parallax Propeller Activity Board WX, SKR V1.3 (3D printing controller board)

Other: PC building, soldering, troubleshooting

WORK EXPERIENCE

Chevron *Customer Service Representative* August 2016 – Current

Manned the cashier and took care of an average of 5+ problems that customers bring up a shift. Performed daily tasks such as brewing fresh coffee, trash, cleaning, dusting, and troubleshooting technical difficulties in order to keep operations running smoothly.

Carl's Jr. *Crew Member* January 2013 – December2013

In a given shift, 10+ consumable goods (with multiples of more than 5 of each) were prepared for the current and next shifts and sent out 50+ incoming orders in a fast-paced environment ultimately reducing the overall load for the team.

PERSONAL/SCHOOL RELATED PROJECTS

Advance Computer Organization

- "MIPS Style" Pipelined Datapath Design

  With a given instruction set, a working CPU was modeled in a two-man team by implementing a simple 5 stage pipeline in a couple hundred lines of code with the use of Verilog. Major components modeled were a program counter, memory address, register file, adder, ALU, control, hazard detection, forwarding unit, pipeline registers, data memory, and multiplexers.

Computer Interfacing

- x86 Assembly and MASM

  An introduction to Windows 98 and MASM Debug using VMWare. Programs were ~30 pairs of hex values. A simple yet complex incrementing themed logic was implemented allowing the user to understand how to navigate through MS DOS and debug errors. x86 assembly is then translated to C with some in-line assembly.
- Raspberry Pi

  This activity covers device connection, Python, TCP/UDP, and GPIO pin use. The focus uses a mix of TCP client to server communication and GPIO pin usage. It was a gateway-esque project leading into IoT that remotely blinks an LED "n" number of times based on the number(n) that is inputted into the terminal after a prompt.

Computer Networks and Internets

- Socket Programming

  With the use of Python, a pair of modules were made for a TCP client/server communication with the specific application of a webserver using PuTTy. A simple html file was created for access upon inputting the IP address followed by the port number and the name of the html file.

3D Printing and CAD

- Designed an oil catch can mount for a Mishimoto catch can which goes on a 2018 Honda Civic Si in Fusion 360. This design is published on a website called Thingiverse and has over 40 downloads.
- Design of a geared set of wheels for a Micromouse competition. This design features a #10-32x1in screw with a MR115-2RS 5x11x4mm bearing clamped in between a piece of PLA and the screw. This combination is fitted into the center of the geared wheel and covered by a screw on wheel cover with size m20x2.5. It greatly strengthened the previous design of using just plastic improving the ability for the wheel to roll smoothly with increased rigidity.

Automotive

- Turbocharging of a naturally aspirated '94 Civic Ex. The project included sourcing parts, extensive research, and soldering or crimping wires with the use of wiring diagrams. The vehicle made use of a plug-in module (Hondata s300) to the existing factory OBD1 ECU expanding the ECU's capabilities. Slight hardware modifications to the ECU were required. The vehicle has a stock horsepower of 125 and produced 182 hp and 179 ft-lbs. of torque to the wheels at 10lbs of boost on a dyno.

Ricardo Navarrete Jr

ricardonavarrete@csus.edu

CAREER OBJECTIVE

Adaptable Electrical and Electronic Engineering major ([GPA_VALUE] GPA) currently attending California State University-Sacramento, with 2.5+ years of work experience. Aiming to leverage a proven knowledge of volunteer recruitment, member retention, and organizational vision skills to successfully fill the Upcoming Electronics Engineer role at your company. Frequently praised as hard-working by my peers, I can be relied upon to help your company achieve its goals.

EXPERIENCE

KSSU RADIO, Sacramento, CA
Promoter Disc Jockey, Aug 2018 - Present

- Bring new ideas and events to the community
- Collaborate and plan events with other school organizations
- Set up events outside of standard university hours to meet event quota
- Maintain stability in the radio department, inform management when issues arise and help resolve them

LOGGERS UNLIMITED, Grass Valley, CA
Logger Groundman, Dec 2017 - Jan 2018

- Prepare workers for job sites
- Labor Work

POOLE PAINTING AND FINISHING, Bellevue, ID
Painter, Jun 2016 - Jul 2016

- Read job orders and inspect workpieces to determine work procedures and materials required.
- Clean surfaces of workpieces in preparation for coating, using cleaning fluids, solvents, brushes, scrapers, steam, sandpaper, or cloth.
- Immerse workpieces into coating materials for specified times.
- Examine finished surfaces of workpieces to verify conformance to specifications; then retouch any defective areas.

EDUCATION

CALIFORNIA STATE UNIVERSITY-SACRAMENTO
Sacramento, CA
Bachelor of Science (B.S.) Electrical and Electronic Engineering Candidate (Expected graduation May 2021)

- **Relevant Coursework:** Network Analysis, Introduction to Logic Design, Electromechanical Conversion, Electronics I & II, Introduction to Microprocessors
- **Extracurricular Activities:** Sacramento State Student Radio Station

ADDITIONAL SKILLS

- Bilingual Spanish Speaker
- House Electrical Work
- Car Mechanic
- Basic Coding in C++, Python, and Spin Code

DEVEN ROBINSON

Professional Summary

Creative and detail-oriented aspiring Computer Engineer perusing a Bachelor of Science degree. Collaborative, and a team player that thrives in challenging tasks as demonstrated by advanced college coursework in Computer Science and Electrical Engineering. Interested in obtaining an internship or entry-level position in the Engineering field.

Experience

7 Flags Car Wash, Fairfield, CA

Service Advisor, May 2018 - Present

- Advised services to guests based on needs.
- Provide exceptional customer services
- Oversee financial transactions
- Encourage others to meet goals
- Train service advisors and give new ideas for selling points.

Kendal Merchandising Company, Richmond, CA

Retail Sales Merchandiser 1, June 2017 – May 2018

- Provide excellent customer service to members.
- Organization and communication skills.

Education

California State University, Sacramento

Bachelor of Science in Computer Engineering (In Progress)

Skills

- **Computer**: Adobe Photoshop/Illustrator, Java, Python, PHP, Basic SQL, Raptor, html, css, x86 Assembly, C, basic Circuitry, MS Office, Spiceworks, Sharepoint and social media (Facebook, Instagram, etc…)
- **Language:** English (Native), Spanish (basic proficiency)
- **Professionalism:** Public speaking, Active Listening, Time Management, Organized

Academic Projects

CPE 186: Computer Hardware Design – Replay Buffer

I collaborated with a team of 4 to create a Replay Buffer that receives TLP packets and validate then through error checking processes. ***Fall 2019***

CPE 185: Computer Interfacing – Autonomous RC Car

I collaborated with a team of 4 to create an autonomous RC car that used a Raspberry Pi(main controller) and an Arduino Uno(secondary controller) that communicate together to create safety features like automatic braking with redirection, and recordings of the drive in case of accidents. ***Summer 2019***

CSC 142: Advanced Computer Organization – Data-path and Control Unit for a pipelined system

I collaborated with a partner to create a pipelined system that includes hazard detection unit, handle exceptions, and forwarding. ***Spring 2020***

Academic Awards

- Armijo High School, Fairfield, California
  Spring 2017
  Seal of Biliteracy

- Armijo High School, Fairfield, California
  Spring 2017
  Golden State Seal Merit Diploma

Vadim Babiy

vadimbabiy@csus.edu

SKILLS

Programming Languages: C, C#, Java, Python, PHP, Verilog, VHDL

Operating Systems: Windows, Ubuntu, OSX

Multilingual - Ukrainian, Russian

Projects

Senior Project - Litterbot

Using Python 3, coded the machine vision, drivetrain, and robot arm on a Jetson Nano and Raspberry Pi with sonic distance sensors working together

Micro Greenhouse

Worked with a group building an autonomous greenhouse that makes sure the plant gets optimal conditions. Coded a user interface in Python on a Raspberry Pi connecting multiple Arduinos via i2c with a web interface showing sensor readings

Unity3D

Using C#, coded multiplayer games on multiple platforms including iPhone, Android, HTC Vive VR, Windows, OSX and Linux

Python

Wrote scripts to scrape webpages for data and organize accordingly. Also scripts that scan and organize files and folders according to folder name and its contents with the help of RegEx

EDUCATION

California State University of Sacramento - *Computer Engineering B.S.*

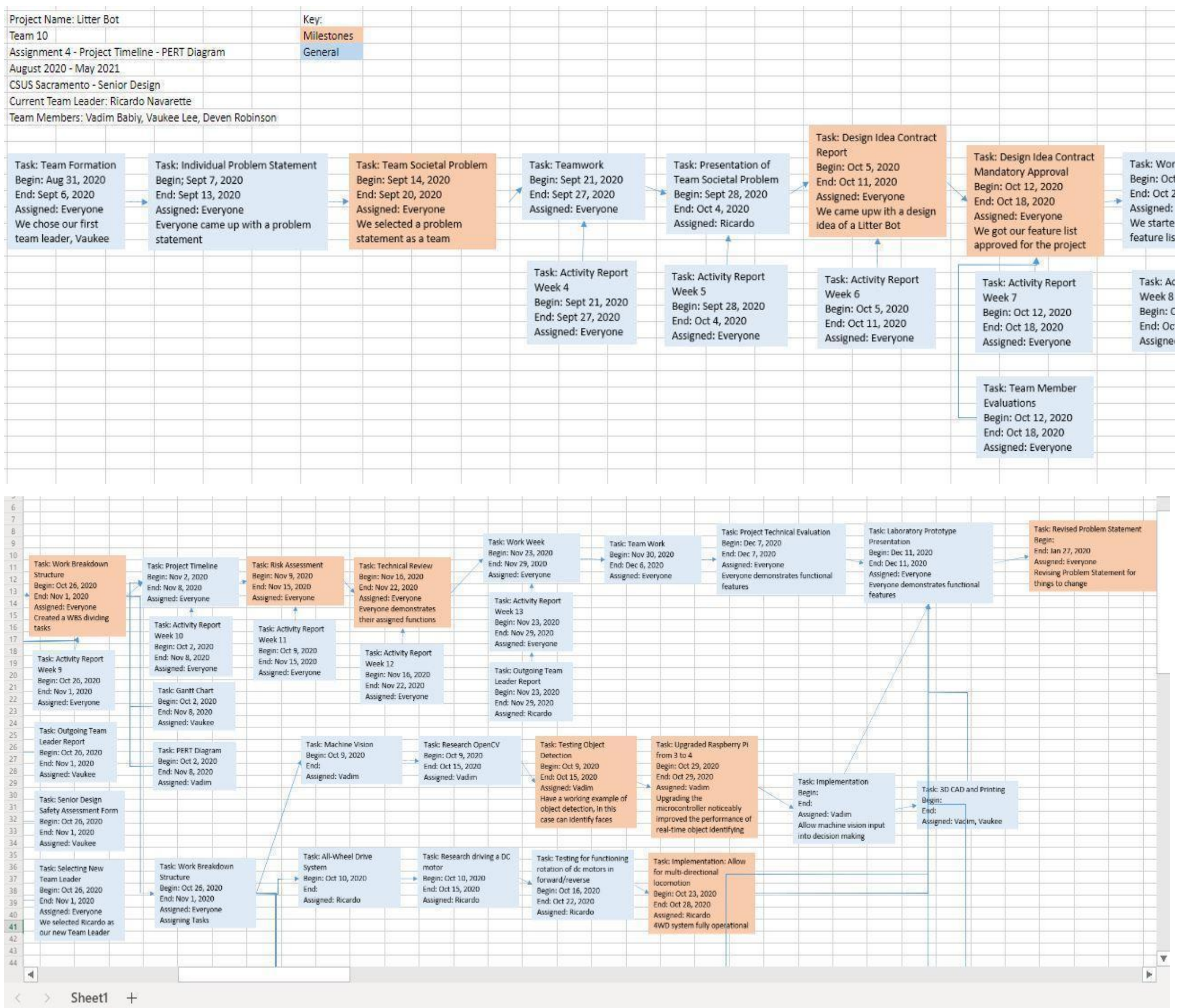
Sierra College, Rocklin - *Associates in Computer Science*

Appendix G. Team 10 Assignments Throughout Senior Design

Table G-1: Work Breakdown Hierarchy for Fall 2020 [62]

Features	Tasks	Activities (Work Packages)	Estimated Completion Time (Hours)	Start Date	End Date	Due Date	Assigned	Co-Assign	Status	Date Updated	Comments
1. Identify Objects using Machine Vision				10/9		2020-10-30			In Progress	2020-10-15	
	1.1 Research/Implementation Software/Tools			2020-10-09		2020-10-27			In Progress	2020-10-15	
Task Lead: Vadim		1.1.1 Look into OpenCV	12				Vadim		In Progress	2020-10-15	optimized C/C++, library multi-core processing
		1.1.2 Look into TensorFlow Lite	12				Vadim		In Progress	2020-10-15	
		1.1.3 Python and Libraries	12				Vadim		In Progress	2020-10-15	
		1.1.4 C/C++ and Libraries					Vadim		Not Started		
	1.2 Research/Implementation Hardware			2020-10-09		2020-10-27			In Progress	2020-10-15	
		1.2.1 Raspberry Pi 3	3				Vadim		In Progress	2020-10-15	
		1.2.2 Camera (usb vs camera port)	2				Vadim		In Progress	2020-10-15	
	1.3 Camera Mount					2020-10-27			Not Started		
		1.3.1 3D CAD and Printing	10				Vaukee		Not Started		Mount design on hold need certain progress level
2. All-Wheel Drive System				10/10		2020-10-30			In Progress	2020-10-15	
	2.1 Research/Implementation Motor Types					2020-10-17			In Progress	2020-10-15	
Task Lead: Ricardo		2.1.1 DC motors	4	2020-10-10	2020-10-17		Ricardo		Completed	2020-10-15	* Current in Research and Testing
		2.1.2 BLDC motors	1.5	2020-10-11	2020-10-11		Ricardo		Completed	2020-10-15	* These are possible motors in consideration
		2.1.3 Stepper motor	3	2020-10-10	2020-10-14		Ricardo		Completed	2020-10-15	
		2.1.4 Servo motors	3	2020-10-10	2020-10-12		Ricardo		Completed	2020-10-15	
	2.2 Research/Implementation Motor Drivers					2020-10-22			In Progress	2020-10-15	
		2.2.1 H-Bridge	2	2020-10-13	2020-10-14		Ricardo		Completed	2020-10-15	* Current in Research and Testing
		2.2.2 Stepper motor driver	1	2020-10-13	2020-10-13		Ricardo		Completed	2020-10-15	
		2.2.3 ESC (Electronic Speed Controller)	4				Ricardo		Not Started	2020-10-15	
	2.3 Chassis					2020-10-27			In Progress	2020-10-15	
		2.3.1 Build Sample Body for Motors and Controllers	6	2020-10-17	...		Ricardo &	Vaukee	In Progress	2020-10-15	*will either be 3d designed and printed or purchase
	2.4 Sensing										
		2.4.1 Incremental Encoders					Ricardo		In Progress		
3. Holding small objects with robot arm				10/10		10/30			In Progress	10/15	
	3.1 Research/Implementation Object Interaction			10/12		2020-10-27			In Progress	2020-10-15	I have ordered the pi and robot arm for testing of the python code than can control the servos and allow the robot to function.
Task Lead: Deven		3.1.1 Ability to grip small objects using Python fluid motions with the servo motors	2				Deven	Vadim	In Progress	2020-10-15	
	3.2 Research/Implementation Arm Motion					2020-10-27	Deven		In Progress	2020-10-15	
		3.2.1 Simple Arm	1						Not Started	2020-10-15	
		3.2.2 Multipoint Arm	4				Deven		In Progress	2020-10-15	
	3.3 Research/Implementation hardware			10/12		2020-10-27			In Progress	2020-10-15	
		3.3.1 Microcontroller	1				Deven		In Progress	2020-10-15	
		3.3.2 Initial robot arm for testing purposes	1				Deven		In Progress	2020-10-15	
		3.3.3 Servo Motors	2				Deven		In Progress	2020-10-15	
		3.3.4 Servo Motor Driver	3				Deven		In Progress	2020-10-15	* there exist tutorials where drivers aren't used on R
	3.4 Research/Implementation coding styles			10/10		2020-10-27	Deven		In Progress	2020-10-15	
		3.4.1 Use of python to control servo motors	3				Deven	Vadim	In Progress	2020-10-15	
		3.4.2 debugging code to grip small objects	6				Deven	Vadim	Not Started	2020-10-15	
4. Navigation System				2020-10-05		2020-10-30			In Progress	2020-10-15	
	4.1 Research/Implementation Software/Tools								In Progress	10/15	
		4.1.1 Python / GPS Libraries	4	2020-10-13			Vaukee		In Progress	2020-10-15	
Task Lead: Vaukee		4.1.2 OpenPlotter	4				Vaukee		Not Started	2020-10-15	A way to use information received from gps
		4.1.3 MissionPlanner	4				Vaukee		Not Started	2020-10-15	
	4.2 Research/Implementation Hardware					2020-10-27			In Progress	2020-10-15	
		4.2.1 GPS Dongle	4				Vaukee		~~Canceled~~	2020-10-15	Researching possible cancel
		4.2.2 GPS Hat for RPi	16	2020-10-14			Vaukee		In Progress	2020-10-15	BerryGPS-IMUv3 10 Degrees of Freedom
		4.2.3 IMU	6	2020-10-14			Vaukee		In Progress	2020-10-15	the hat for the RPi includes this
		4.2.4 Accelerometer	2				Vaukee		Not Started	2020-10-15	the hat for the RPi includes this / part of IMU
		4.2.5 Gyroscope	2				Vaukee		Not Started	2020-10-15	the hat for the RPi includes this / part of IMU
		4.2.6 Magnomometer	2	2020-10-14			Vaukee		In Progress	2020-10-15	the hat for the RPi includes this / part of IMU

Figure G1. PERT Diagram Snippets as of Fall 2020 [63]



Link to view Team 10's Gantt Chart and PERT Diagram files:

https://mysacstate-my.sharepoint.com/:f:/g/personal/sac21544_csus_edu/EmNWnulbyeBInkIpK5CdktkBnwVlLWmuIaPDL1oBWZPyiw?e=oDQird

Table G-2. Team Hours Documented from Fall 2020 - Spring 2021 [23]

ONLY based on Activity Reports (September 2020 - April 2021)

FALL 2020

WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	TOTAL HOURS (Fall)	
Vadim	...	....	...	10	12	23	15	6.5	23.5	16.5	12.5	18.5	10.5	148	Vadim
Vaukee	...	....	...	10	16.1	20.75	8.5	15	23	17	11	10	6	137.35	Vaukee
Deven	...	....	...	9	10	11	8	10	9	10	14.5	9.5	9	100	Deven
Ricardo	...	....	...	11	20	18	10	20	20	17.5	16	11.5	18	162	Ricardo
														547.35	**TEAM**

WINTER BREAK

SPRING 2021

WEEK	1	2	3	4	5	6	7	8	Sp. Brk	10	11	12	13	TOTAL HOURS (Spring)	
Vadim	62	23	14	18	14	11	12	13	...	44	51	40	49	351	Vadim
Vaukee	77.2	12	13	15	13	15.5	26.5	16.5	...	60.7	42	16	31	338.4	Vaukee
Deven	53.5	17	13	14	10	16	16	19	...	31	25.5	15	19.5	249.5	Deven
Ricardo	55.5	22.5	18	20	11	18.5	21	12.5	...	37	33.5	25.5	25.5	300.5	Ricardo
														1239.4	**TEAM**