

ALiCE

Autonomous Litter Collection Equipment



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Chapter 1: Executive Summary

With the advancement of technology, life for humans in general has continued to improve and advance by a huge margin. The technological devices that we use daily, weekly, or even monthly has helped make our lives easier than ever before, but what if, instead of using the technology to our benefit, we were to use it to help better the environment? There have been a multitude of creations that helped better the environment such as solar panels and wind farms that create a beneficial amount of renewable energy that helps reduce emissions. Another creation is electric cars that help reduce the use of gasoline that is harmful to our environment. Although these creations aim to help the environment, they also in some kind of way, benefit humans as well. That's why we wanted to create a design that 's sole purpose is to help its environment and that only. After some discussion, it was decided to create a device that helps beach areas.

This then started with the creation of the Autonomous Litter Collection Equipment (ALiCE). ALiCE is our design that aims to help keep the areas of the beach clean and free of potential items that can harm any kind of animal or plant that may reside near or at the beach. ALiCE will be capable of driving using machine learning, able to map out the area and drive in said area also while it is constantly improving its mapping and driving capabilities to help prevent any possible collisions that can happen.

ALiCE will have wheels that are capable of driving in sand, which is a loose and unstable surface that can constantly be altered at any given time. For that reason, the wheels would have to be capable of decent off-roading, stability, as well as durability to keep our design moving around and not tipping over. In order to use these kind of wheels, we would need a motor with enough torque and power to keep those wheels constantly moving without expending all of our power. Speaking of power, ALiCE will be running on rechargeable batteries, in order to keep ALiCE from needing as much human intervention. The batteries should also have a long life span so ALiCE can operate as long as possible. ALiCE is also equipped with a camera that can detect any kind of trash that is laying around at the beach. For this design, we currently aim to detect only aluminum cans, plastic bottles, and glass bottles, since we believe that those three things tend to be trash you would see the most at the beach. Once an object that fits the description of what we are aiming for, ALiCE will make its way towards the object and pick it up. It will be picked up by a robot arm that is attached near the front of the body and once the object is picked up, the object will be scanned in order to figure out what material the object is made of. We will use a spectrometer in order to implement this. The spectrometer is capable of using and measuring light in order to identify and or analyze materials. There

are some long term plans for us to implement for ALiCE if we are able to implement them. One of them is for ALiCE to be able to pick itself up if it were to tip over. For that we would need a device that is strong enough to push the floor and lift ALiCE enough for it to land back on its four wheels. Another one is to create a self-docking station, so that when ALiCE is about to run out of power, it will head to the self-docking station and turn itself on. We may also be able to set it up so it can charge itself when connected to the station.

Chapter 2: Project Description

2.1 Project Background and Motivation

In today's society, it has become more common for people to leave trash in places it does not belong, places such as parks, rivers, and more importantly beaches. Our group has decided to focus and provide a solution to combat marine debris. Marine debris; man-made objects that enter the marine environment through careless handling or disposal, intentional or unintentional release, or as a result of natural disasters and storms - is one of the ocean's most pervasive, yet potentially solvable, pollution problems. The presence of marine debris, coupled with its physical, ecological and socio-economic complexities, poses a severe threat to the sustainability of the world's natural resources.

Beachgoers find it convenient to leave trash behind, and they are unaware of the detrimental effects that these actions can cause to the environment, specifically sea-life. Litter and debris along the beach, including on sea turtle nesting beaches, soon makes its way to the sea where turtles and other marine life may consume or be trapped by these items. Clean, debris-free beaches will be beneficial to not only tourists and visitors but most importantly sea turtles and other marine life.

What if there was a way to reduce the amount of trash on these beaches? That's the question our group has decided to dedicate our senior design project to. We as a group will come together to solve one of the greatest problems of our generation by designing and developing a promising project. This project will feature a handful of subsystems containing both software and hardware that coincide with each other. The decision to choose this project will not only be a demanding project that will push us to the limits of our capabilities, but it will also make a positive impact on the environment and protect the 8,436 miles of shore line here in the State of Florida.

The motivation for this project is to take this challenge and use it to build something that can help benefit the environment. Using our design complete with convolutive hardware and software and using it to help marine wildlife would be extremely beneficial. We hope that with our design, we will be able to inspire companies, communities, or others to seek action on restoring and bettering the environment for the sake of those who are not able to, such as animals and plants.

In addition to protecting the environment with the creation of our project, our main motivation is to successfully complete the requirements of the senior design program. We wish to take this opportunity to show why we have made it this far and why we should be

able to call ourselves engineers. We as a group would also be motivated to use this project as a stepping stone to helping us become better at communicating, collaborating, and planning as a team. These skills will become extremely important once we graduate and are making our way into the industry.

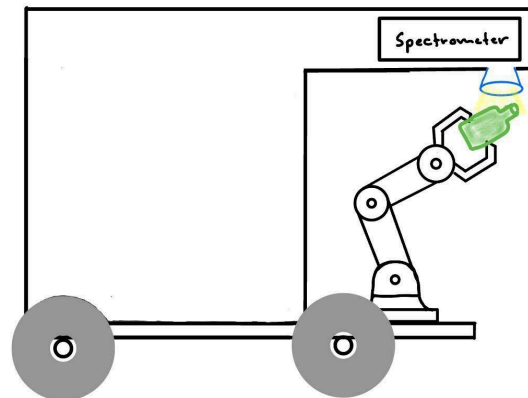


Figure 2.1: Hand-sketch preliminary design

2.2 Current Commercial Technologies and Existing Projects

BeBot

BeBot is a beach cleaning robot, essentially very similar to the project that we plan to create. BeBot utilizes a rake to pick up any waste from beaches, nature reserves, golf courses, etc. It contains a sifter that separates the trash from the sand. BeBot uses batteries and solar panels, which makes it 100% electric and does not use or produce any damaging gasses. It maneuvers using track-style propulsion and it is operated by a remote control that has a range of 150 meters. It contains a docking system to place the BeBot on before and after using it.

The BeBot should be stored in a temperature ranging from 41 to 86 degrees Fahrenheit. BeBot lasts up to 3 hours, and it takes up to 8 hours for it to charge. It has a maximum speed of 2.7 kilometers per hour and is able to carry weights up to 400 kilograms (about 881.85 pounds). The tray collection of BeBot has a capacity of 100 liters.

The BeBot has some similarities when compared to our design, ALiCE. The idea and goals of ALiCE are the same, in which we aim to clean the beach environment using an autonomous robot. However, the difference is that while BeBot utilizes a rake style system that scoops up trash, we are using a robotic arm that detects and picks up trash on the beach. This will help keep sea-turtle nesting areas safe from being accidentally scooped up. Also, they use remote control with a range limit while we plan to have ALiCE to be autonomous that does not have a remote controlled limit or operator engagement. This will allow an operator to monitor and manage multiple systems rather

than a single unit. Lastly, ALiCE will be equipped with a spectrometer to sort recyclables from trash and also leave seashells on the beach where they belong. ALiCE will also be 100% electric and have swappable battery capabilities.

iRobot Roomba

The iRobot Roomba has been a commercialized smart-home product that has had much success in the last decade. In September 2002, the company introduced the first Roomba model. Less than a year later, iRobot was selling a million units a year. Although early models were known for zigzagging randomly to achieve full room coverage, the semi-autonomous cleaning robot still had much success. In the last decade, the engineers behind the Roomba have fully transformed the mechanical maid to sweep, vacuum, and mop different types of flooring in homes and offices. iRobot's latest models feature a new visual simultaneous localization and mapping (vSLAM) navigation system, allowing it to clean more efficiently. Some of the other features Roomba include are cliff detect sensor, obstacle detection bumper, floor tracking sensor, acoustic and optical sensors (for detecting areas with excessive dirt and debris).

Our plan is to emulate this technology and apply it to a beach or waterfront environment. ALiCE will incorporate the same key technologies that are embedded in the Roomba design. While Roomba's are limited to indoor use only, ALiCE will be an industrial grade robot that can withstand extreme everyday environmental conditions. Although our design will be about 10x the size of a Roomba, we will have the ability to pick up items ranging from cigarette butts to 2-Liter Soda bottles.

Beach Metal Detectors

Some hobbyists take to the beach to search for hidden treasures buried in the sand, and as luck would have it, prove to be pretty successful in their searching. Metal detectors are commonly used to locate belongings left behind such as jewelry, old-coins, and relics. The two common techniques used today are Very Low Frequency and Pulse Induction, both techniques similarly use coils to transmit and receive electromagnetic fields. Depending on the type of metal below the sand line, the electromagnetic field responds differently, which will trigger the indicator and the operator will then dig to find their reward. While this helps keep metals out of the sea, this is more of a hobby and the drive behind this is for personal gain. ALiCE is a conscious effort to help the environment with almost no tangible reward. As a potential stretch goal, this technology could be incorporated later on and our system can begin to collect metals just below the surface.

Summary

The ALiCE (Autonomous Litter Collection Equipment) aims to address the issue with litter on beaches through the design of an autonomous robot and its purpose to collect debris and trash. Moving right into the core components of ALiCE, the robot rover is equipped with sensors, a robotic arm, a power supply system, spectrometer, and a PCB design that will act as a control center. This rover is designed to navigate on the beach in different environments while avoiding obstacles. The robotic arm is used to collect the debris that the camera vision will detect and is placed in an onboard recycle or trash pan.

ALiCE will be outfitted with a VIS-NIR Spectrometer used to analyze items recovered from the ground and determine whether the item is recyclable or not. The power system of ALiCE is built on sustainability and will include an efficient battery that can supply power to the entire system. The enclosure will protect the system from the earth's elements and allow cooling to prevent any failures.

The motivation of ALiCE is mainly inspiring other communities and organizations to provide innovative results for a cleaner environment. This project explores current ideas and technologies we learn from and relate our project to. Learning about these existing solutions helps with understanding requirements and needs for the project as well as gain inspiration. We can use these ideas to creatively construct ALiCE.

2.3 Goals and Objectives

The function of ALiCE is for it to be able to successfully navigate its way through the sand while avoiding the water and large obstacles. It should also be able to successfully navigate over gravel as well since gravel could be found on some beaches. While ALiCE is making its way through the sand, it is scanning the floor in front of it using a camera to look for potential trash. When something has been found that is not sand, ALiCE will make its way towards the object so that it is close enough for the robotic arm to pick it up.

Basic Goals:

- Collection - Collect aluminum cans, plastic bottles, and glass bottles at the beach and place them into three different bins based on the material.
- Navigation - effectively navigate and localize the area of the beach tasked with cleaning.
- Obstacle Avoidance - avoid large obstacles and bodies of water that may damage the rover.
- Identify - accurately identify recyclables, trash, and seashells in real time.
- Ease - deliver a system that will take minimal training and operate independently.

Advanced Goals:

- Implement machine learning for the navigation of ALiCE
- Be able to distinguish aluminum cans, plastic bottles, and glass bottles from all other trash noticed at the beach

- Able to determine the material of the trash and sort them by placing them into different bins
- Robotic arm should be able to pick up trash in less than 5 seconds

Objectives:

- Camera Vision and Machine learning to navigate around obstacles and approach debris on the beach.
- Measure across visible and near-infrared wavelengths to accurately identify items recovered with fast readout capabilities.
- Measure items ranging in size i.e. aluminum cans, soda bottles.
- Be able to use the camera and lidar puck to correctly determine what is obstacles that should be avoided by the rover
- Determine what is the most efficient and effective way for the robotic arm to pick up trash and avoid clashing with other components.
- Implement redundant safety systems like emergency stops and robot arm force limits.
- Design an enclosure that allows ventilation and protects the system from the elements such as sun, heat, rain, and sand.

Stretch Goals:

- Identify and avoid sea turtle crawlings, nesting, or hatchlings.
- Implement metal detection technology to recover metals below the sand line.
- Design swappable battery system, to change batteries on the go.
- Onsite docking station, with self-emptying capabilities.
- Add solar panels to help keep the system running while in the field.
- Remote viewer where operators can remote-in a troubleshoot system if necessary.
- Implement a self-recovery mechanism for AliCE.

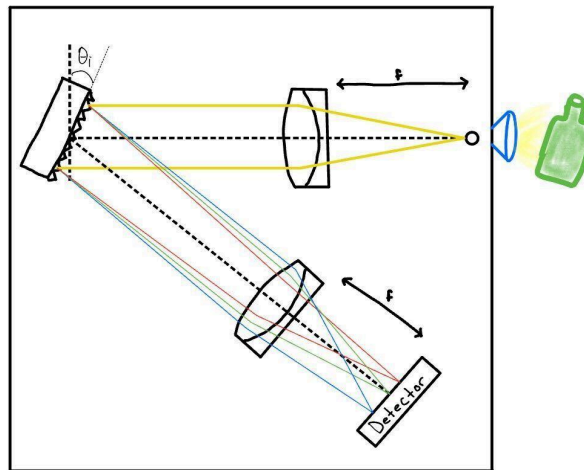


Figure 2.3: Hand-sketch Spectrometer

Hardware

Rover - Objective

The Rover is the subsystem responsible for traversing the beach for debris collection. It will be a fully automated self-driving platform outfitted with sensors, motors, and durable beach style wheels. The rover will include an enclosure that will protect PCB, power supply, and electronics from the beach environment. The rover will provide stability to successfully transport the robot arm without falling over or getting stuck on one side while it is picking up trash or traveling in heavy winds. The rover will need a basic motor and will be connected to our microcontroller. To move around on the beach and keep stability we will be using beach balloon wheels on the rover.

Robot Arm - Objective

The Robot arm is the biggest and boldest part of our project. We have access to an industrial grade robot arm and plan to utilize it in our design. The star of the show will be fitted with a claw like gripper that will be able to pick up objects ranging in size.

Spectrometer - Objective

The spectrometer will determine whether the item collected is recyclable, trash, or possibly a seashell. The spectrometer will measure across the VIS-NIR spectrum for analysis of the material. Measuring in this spectrum will give accurate results in real time.

The basic function of a spectrometer is to receive light, break it into its spectral components, digitize the signal as a function of wavelength, and read out its analysis. We will be designing and developing the spectrometer so that it is capable of measuring items ranging in size while maintaining accuracy of what type of material is being measured.

Power Supply - Objective

The power supply will be protected by the rover enclosure and will power our motors, spectrometer, the PCB, and the robot arm. We would like to have an efficiency on the power supply of at least 80% minimum but will shoot for more around ~90% for the final product. The power supply will also either be able to be plugged straight into the wall to recharge or easily accessible to be taken out and recharged then put back in between charges. We would also like to shoot for a minimum of an hour battery life.

PCB - Objective

The printed circuit board will be the brains of the operation. The PCB will have all the programming to control ALiCE to the fullest extent. The PCB will be able to interface with the motor of the rover to control driving. It will use sensors to detect where trash is and drive to the trash to pick it up. Then the PCB will control the robot arm to pick up the trash. The PCB will have a good microcontroller on it with enough memory to be able to run all the specified goals. It will also be able to easily interface with all other parts of the project.

Charging Station - Stretch goal

Our robot will be almost fully self-sufficient. The goal is to provide a turnkey solution where an operator can power up the system after it's charged and watch it go. Implementing an automated charging station will allow the system to truly be fully autonomous. That's where we design a landing pad for our rover to come home to. These charging stations would either work through wireless charging or precise programming to connect it to a charge port. The charging station would need to be mounted to a flat area on the beach such as the bottom of a boardwalk to make sure the bot can get there with no issues and without any changes to the charging station.

Software

Rover - Objective

The first objective is for the rover part of the project to be able to drive on its own while also making sure it is still on the sand. For this to be achieved, ALiCE must be able to communicate with the equipment that allows the rover to move and also the partial objective so that it can make sure it stays on sand. The partial objective is making sure

that the camera and the lidar puck are able to contribute info to both the robotic arm as well as the rover. The reason it is needed for the rover is to make sure that it stays on the sand and if there are any obstacles in the way it should avoid it. The rover should also be able to drive close enough to trash so that the robotic arm can pick it up

Robot Arm - Objective

The second main objective of ALiCE's software is the robotic arm. The arm should be capable of receiving commands from the software, and then position itself to where the trash is, and then pick it up without an issue. Once it picks up the trash, the spectrometer will then determine what type of trash it is and it is up to the robot arm to place it in the correct bin. The arm will be limited from rotating 360 degrees because the arm is placed in front and it could potentially collide with the enclosure behind it causing damage to both the enclosure and robot arm.

Trash Detection - Objective

The third objective of ALiCE's software is to be able to detect trash. The software will detect trash from the sand and be able to tell the rover to go and pick it up. The software needs to be able to make use of the camera to detect what is trash and how big is the trash. We want to make sure it doesn't pick up anything like shells or rocks that would waste trash space. We will start out with a goal of being able to pick up anything to the size of an aluminum can. We can then hope to grow this to be able to pick up something a little bigger and heavy like a beer bottle later on in the project. After picking up the trash, the spectrometer should also be able to scan the trash to figure out what type of trash it was.

Unstuck feature - Stretch Goal

One idea that we thought would be very challenging, but useful, is to implement a self-recovery mechanism for ALiCE. The arm should be able to reach the ground and exert enough force to push or pull the robot. This requires lots of mobility and strength from the arm, and a control algorithm that controls the arm's recovery mode. To determine whether ALiCE is stuck or not, we can use wheel encoders to detect if the wheels are still spinning while simultaneously, the robot is not moving.

2.4 Product Specifications

Table 2.4: Distribution of Worktable

Component(s)	Parameter	Specification
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Meca500 Industrial Robot Arm	Payload, Reach Speed	0.5kg 0.33m 150 deg/sec
Power Supply	Discharge Time, Efficiency	TBD >80%
Spectrometer	Readout Rate Sensitivity Optical Bandwidth	60Hz 1000 counts/(ms μ W) 2.0-5.0 μ m
Camera	Resolution Framerate FOV	1080p TBD 75 deg
Lidar Puck	Range Field of View Power Scan Rate	12m 360° 5v 2-10Hz
PCB	Memory, Peripherals	TBD
Motor (Drive)	Power Torque	TBD
Motor (Steering)	Torque	TBD
Control System	Processor	TBD
Proximity Sensors	Range	4 - 30cm

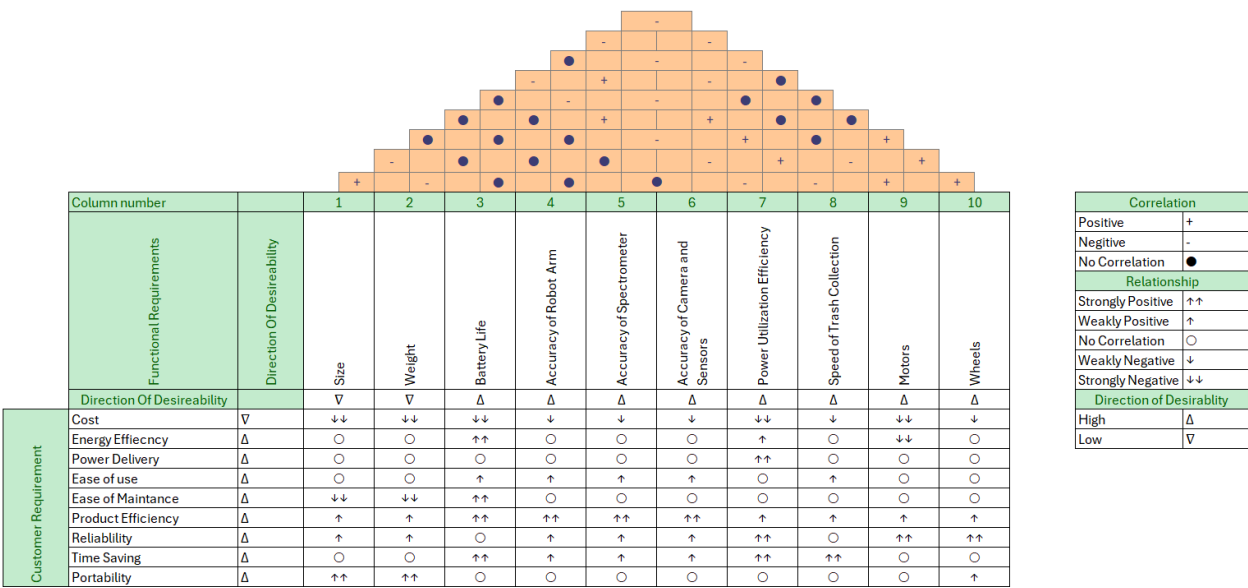


Figure 2.4: House of Quality

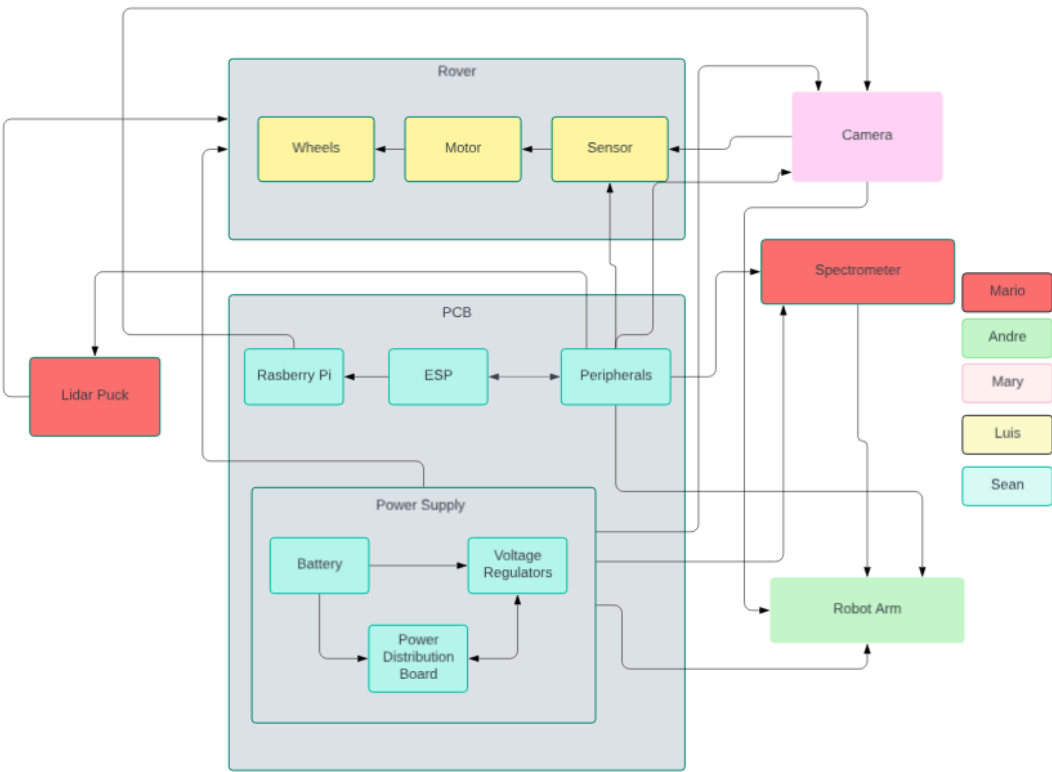


Figure 2.4.2: Hardware Diagram

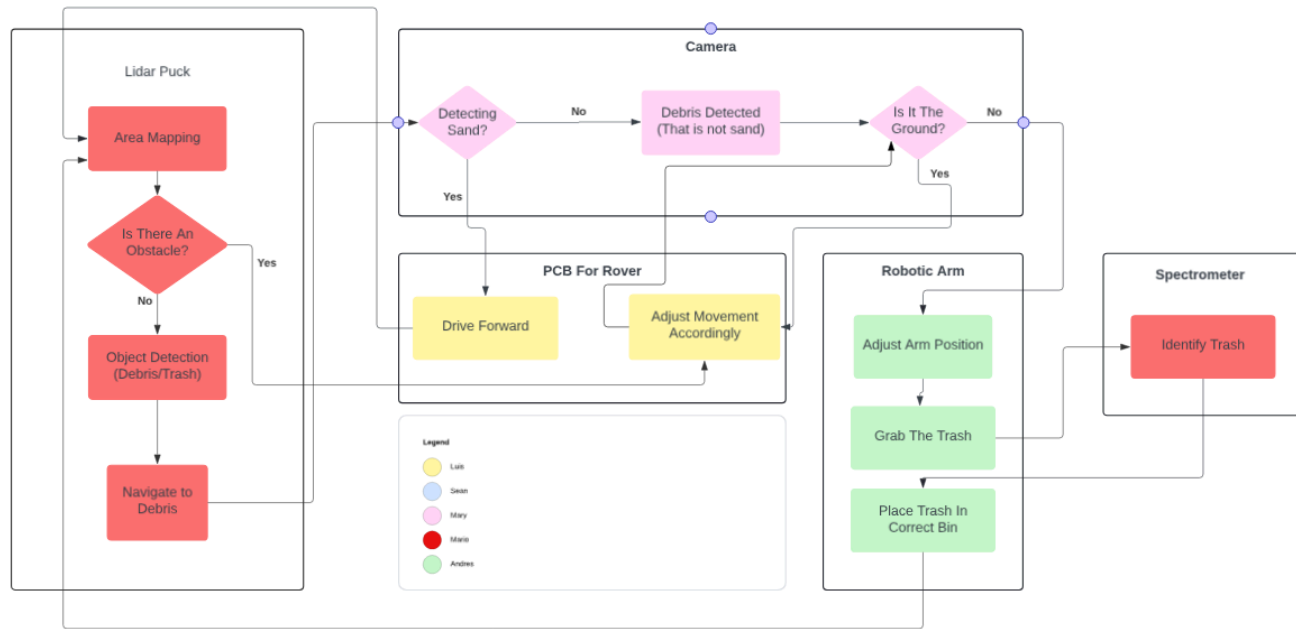


Figure 2.4.3: Software Diagram

Chapter 3: Research and Part Selection

3.1 Technology Research and Comparison

The first topic, and possibly one of the most important, under the management of technology is generally research and development (R&D); examining new product strategies, organization for research, and the sequential process of winnowing the many ideas for product research and development to an affordable level, according to technical, market, and organizational considerations. In engineering design, thorough research is crucial to ensure optimal outcomes. The research process in engineering design involves meticulous exploration and evaluation to inform critical decisions throughout a project. We begin by identifying project requirements and specifications, then conduct extensive research to gather information on available technologies, materials, and methodologies. This phase includes literature reviews, previous senior design projects, and some experimental testing to validate assumptions. Our group has compared multiple options, considering factors such as cost, performance, reliability, and feasibility within project constraints. Throughout this process, we must document and refine design ideas to ensure that the final design meets or exceeds expectations while addressing any challenges

encountered along the way. During this research, different technologies should be evaluated and compared to one another for each of the subsystems of the overall design. The comparison of technologies should be within similar scope and depth to truly gauge the technical approaches available to our design team. Once the executive decision is made to choose a particular technology, there must be some flexibility during the design to allow changes. The initial idea chosen may require adjustment or abandonment based on issues uncovered or obstacles encountered during the design phase. The process of developing a system or product is iterative, with discoveries often made during design, testing, or production. These findings can complicate or alter the product, requiring a return to the drawing board to redesign certain subsystems. Insufficient research beforehand can lead to technical setbacks or delays, as additional time may be needed to explore alternative technologies or solutions. Therefore, frontloading the research process with a thorough exploration of potential technologies for each subsystem or product segment is more efficient, reducing or eliminating research bottlenecks in the product design phase.

Hardware Research

Our design encompasses multiple sub-assemblies to complete its task of maintaining a clean and safe beach or waterfront environment. From autonomous navigation to sorting plastics and metals, this design required thorough research to find the best technological approach to launch a successful product. Our robot will employ a range of sensors, peripherals, algorithms, and other components to meet our hardware requirements and specifications. Each component and algorithm underwent thorough research and comparison with at least two other alternatives in its category.

Navigation and Mapping (LiDAR vs Camera-Based Vision)

In the last decade, there has been an increase in development of sophisticated technology that goes into creating safe and successful self-driving vehicles. One of the most crucial innovations is the technology that powers vision and navigation. There are several approaches we could've taken for autonomy, including Light Detection and Ranging (LiDAR) sensors and camera-based vision. We explored each of these two technologies and their unique benefits. Ultimately, for the autonomous portion of our design, we decided to focus on implementing LiDAR as the main source of navigation information. Our robot will still utilize a variety of sensors and peripherals as precautionary redundant safety measures.

The two technologies that are at the forefront of enabling autonomous vehicles to understand and interact with their surroundings: Camera-Based Vision and LiDAR. With camera-based vision, the system uses cameras to capture images of the environment. The data collected is processed using computer vision algorithms to identify objects, read road signs, and understand traffic signals, providing essential information for navigation. With LiDAR, sensors are equipped with pulsed laser beams, usually in the infrared spectrum, and receivers to produce a 3-dimensional point cloud.

LiDAR

Light Detection and Ranging (LiDAR) is a remote sensing technique that utilizes laser light pulses to measure distances and create a detailed, three-dimensional map of its surroundings. An active system means that the system itself generates energy – in this case light – to make measurements of the environment. LiDAR calculates the distance between the sensor and the target by emitting an electromagnetic signal as a laser beam towards a given direction. The elapsed time between emitting and receiving the laser beam is employed to calculate the target's distance. The system utilizes specially designed optoelectronics, mechanical moving parts, and high-speed data computing to develop a point cloud of its environment. A typical LiDAR data product is an extensive collection of point cloud data (millions to billions) of accurate 3-dimensional (X, Y, Z) points with other attributes like intensity, reflectivity, and distance. LiDAR technology has emerged as a revolutionary tool in various fields, including geospatial mapping, autonomous vehicles, environmental monitoring, and robotics.

Ranging utilizing Time of Flight (ToF) is a method employed in various technologies, including LiDAR, to measure distances accurately. The fundamental principle behind this technique is to calculate the time it takes for a signal to travel from a source to a target and back, using the speed of the signal as a reference to determine the distance (Equation 1). The LiDAR system begins with a laser diode or LED which is directed to emit infrared light. Direct ToF uses short pulses of light and measures the time until each pulse returns to the sensor to measure the distance to an object. Indirect ToF sensors emit a continuous wave of modulated light. A photoreceptor senses any reflections, and the timing and phase of the reflected light are used to calculate the distance to the object which produced the reflection. For direct ToF, the pulses are typically several nanoseconds wide. Shorter pulses give higher resolution but have less energy and thus the received reflection has inferior sign/noise ratio (SNR); that's one of the many tradeoffs.

$$d = \frac{\Delta t \times c}{2} \quad (1)$$

In Equation 1, d is distance from the sensor, Δt is the TOF, and c is the speed of light (3×10^8 m/s). The laser pulses impinge on the rotating and scanning mirrors, interact with the environment, reflect to the sensor and a collection of different distances are measured and produced in a point cloud. This technology creates accurate 3D maps of the environment, offering detailed insights into object shapes, sizes, and distances, even under varying light conditions.

LiDAR	
Performance Parameter	Numerical Value

Table 3.1:

Sampling Frequency	8000 samples/sec
Scanning Frequency (Hz)	Maximum: 10 Minimum: 5
Range Radius (m)	Maximum: 6 Minimum: 0.15
Scan Angle (°)	0-360
Angular Resolution	$\leq 1^\circ$
Distance Resolution	$\leq 0.5\text{mm}$
Voltage (v)	Maximum: 5.2 Minimum: 4.8
Supply Current (mA)	Minimum: 1000
Working Current (mA)	Average: 350 Maximum: 500
Price	Average: ~\$100

RPLiDAR AIM8 Performance Specifications

Camera-Vision

Camera-based vision systems are integral to autonomous vehicles (AVs) and robotics, serving as the eyes of the system. Usually, these systems utilize one or more cameras mounted on the vehicle to capture visual data from the objects surroundings. Camera-based vision systems work by continuously capturing video footage of the environment. This footage provides a rich dataset that includes road geometry, traffic participants (vehicles, cyclists, pedestrians), traffic signs, and signals. Advanced image processing algorithms then analyze these images to identify and classify objects, interpret road signs, and understand the vehicle's position relative to road markings and other landmarks. This data is then processed and analyzed to inform navigation decisions, making camera-based vision a critical component of AV sensor suites. Computer vision and AI are essential for analyzing visual data from camera-based systems. Computer vision enables the detection of patterns and shapes, while AI algorithms, especially those using machine learning and deep learning, are taught to identify objects and situations. These technologies empower autonomous vehicles to interpret visual information, facilitating informed decision-making regarding navigation, obstacle avoidance, and compliance with traffic regulations.

The benefits of incorporating camera vision may include but not limited to, cost-effectiveness, high resolution imaging, and color/texture information. While there are great benefits in certain applications within autonomy, we believe this technology does not meet our requirements. Mainly because camera vision can be directly affected

by lighting conditions. Whether it be low light, direct sunlight or reflections from the water; these scenarios can impair image quality and limit the systems ability to accurately interpret visual data. When evaluating camera vision technology, we must take into consideration the beach or waterfront environment. If our system depends on camera vision for navigation, there must be sunlight so the system can image. If the customer is considering running the system overnight or once beachgoers have left the area, the lack of natural light may affect image quality. We also considered mounting a light source to the system to supplement the camera vision; however, coastal communities are limited to the amount of artificial light on/near the beach because artificial light may discourage female sea turtles from nesting and may cause hatchlings to become disorientated and wander inland. Below are some performance specifications taken into consideration while comparing the technologies available to us.

Camera-Vision	
Performance Parameter	Numerical Value
Frame Rate	Minimum: 60fps @ 1080P Maximum: 260fps @ 640x360P
Pixel Size (μm)	2.0 x 2.0
Image Area (μm)	5440 x 3072
Resolution (megapixels)	2.30
Dynamic Range (dB)	64.6
Sensitivity (mV/lux-sec)	1900
Minimum Illumination (lux)	0.1
Voltage (V)	5

Table 3.1.2 USB Camera 1080P Performance Specifications

LiDAR vs Camera Comparison

The integration of these two technologies for our application is not a matter of deciding whether one is better than the other but rather understanding how each contributes to the success of the design. We have examined their strengths and weaknesses, and how they may enhance or inhibit our perception system, focusing on technical aspects of sensor integration and their role in developing fully autonomous navigation systems. LiDAR's key contributing factor is its ability to generate accurate 3D maps of the environment.

These maps are comprehensive, including not only the position and size of nearby objects but also the topology and layout of the terrain. The spatial data collected by the system is essential for path planning, obstacle avoidance, and ensuring the rovers' safe interaction with the environment. Unlike camera-based vision systems, LiDAR does not rely on natural or artificial light sources, allowing it to work effectively in low-light or nighttime conditions without sacrificing performance. In camera-based vision, the system excels in object identification and visual features due to their high-resolution imaging capabilities. While this could be beneficial for our application in other aspects, i.e. collecting items from the environment, it does not support full autonomous navigation along the beach environment.

Rover

After talking about the navigation and mapping of ALiCE, it is now time to talk about what part of ALiCE is going to benefit from the navigation and mapping, which is the rover. The rover is essentially the most important part of the whole project. The reason as to why is because the rover is the connecting piece to mostly every component. It uses the lidar puck's mapping of the area to drive around making sure that it avoids any kinds of objects that could harm it or vice versa. It uses the camera to find objects, and once the object has been detected as the trash we are collecting, the rover will then drive its way towards the trash. Once the rover has made its way to the trash, ALiCE will then use the robotic arm and the spectrometer. The rover has to make sure that there is enough distance from ALiCE and the trash so that the robotic arm is able to collect said trash. Once the trash is collected the spectrometer will analyze it to determine what type of material it is made out of. When it comes to the components that make up the rover, there are three main components and they are the wheels, motor, and the sensor.

Wheels

The wheels are what allows our rover to drive around the sand. These wheels should have excellent off-roading capabilities because our rover would be driving on sand and gravel which is a terrain that most wheels do not accommodate for. There are some things that we are not taking into consideration like durability. All wheels should realistically last as long as the time we have for this senior design project, so for that reason we are not considering how durable the wheels should be. If we decide to continue on with ALiCE after senior design, we can then possibly look into better durable wheels. Besides durability, there are other factors that we looked into that we deemed that are important, factors like size, cost, material, and weight.

The size of the wheel is important because we figured that we would want there to be some good distance from the ground to the body of the rover. The reason for that is when ALiCE is moving, there is a decent chance that wheels could kick up sand. We do not want the sand to kick up and land on the rover so that it will not fall in any of the components and possibly damage our components. The main component that we are concerned about is the robotic arm since it will be one of the only components that is not

boxed in or is unreachable. The robotic arm is also borrowed so we would most definitely like to return it back undamaged. When it comes to the price of the wheels, we want to make sure that it is at an affordable price range for us considering that we ourselves do not have any sponsor.

We also want it to be at a price range where we can afford to buy it more than once in that chance that something unfortunate happens to our wheels, things like, for example, hidden glass buried in the sand penetrates our wheel as our rover is moving. There are not a lot of materials you can use for tires. The main material that is used by mostly every car is rubber. There is, however, a material that is not talked about, that is very good for the tasks we need and that is polyurethane. Polyurethane is a type of plastic material that is believed to be more durable as well as having a longer lifespan than rubber wheels. Polyurethane is mainly used to navigate off road terrains like sand and gravel, which is perfect for what ALiCE is driving on.

The final factor that we reviewed was weight. There are two parts of the weight that is being thought about and that is; can the wheels carry the weight of everything on it, and also is the motor able to move the wheels, considering the weight of said wheels. When it comes to the movement of the wheels with the motor, we have to make sure that the motor is able to constantly rotate the wheels so that the car can move forward. Another thing is that if the wheel is too heavy, it would end up putting a lot more strain on the motor, which would mean that it would consume more power. So we have to make sure that the weight of the wheels is not too heavy where it would negatively affect the motor. The other part of the weight was making sure that the wheels are able to carry the weight of everything that is built on top of it. This would include the robotic arm, which weighs at around 4.3 kilograms or 9.5 pounds, the camera, spectrometer, lidar puck, the pcb, as well as the structure of the car which in total weighs probably in the range of 15-25 pounds. If the wheels are not able to carry said weight, ALiCE might be able to move forward, but it will have a difficult time in steering itself. So the wheels have to be strong and heavy enough to support the structure, but also not too heavy in order to keep the motor functioning properly. Listed in the table below are the comparisons we made in order to choose the correct wheel.

Table 3.1.3: Comparison of Three different types of wheels

Wheels:	Balloon Wheels	Standard Wheels	Omni Wheels
Movability	Moves Forwards and backwards	Moves Forwards and backwards	Moves All Directions
Size (height):	Typically Tall Wheels (Around 9-12 inches)	Can Range From Small to Tall Wheels	Typically Small Wheels (Around 4-7 inches)
Material:	Polyurethane, rubber, PVC	Rubber	Plastic and rubber

Cost (for all four wheels):	High	Moderate	Low
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Choice For Balloon Wheels

With all the specifications and requirements we need from the wheels, we were able to come to the conclusion that balloon wheels seem to be the best choice. The reasoning being that these wheels are well designed for off roading capabilities and that is something we need considering the rover will be driving around the beach. It's usually tall height is also a huge benefactor to keep our design off the ground and keep the sand off our components to prevent any kind of damage. Using our choice of balloon wheels, we have three specific wheels that we believe would be best suited to be compatible with ALiCE. These three each have their own positives as well as things that hold them back which will now be discussed.

Wheeleez Polyurethane Wheels

For one of our choices of balloon wheels we believe that it would be the best choice for us to use Wheeleez's polyurethane wheel. The reason why is because in their website the wheels are described as beach balloon wheels that are designed for a specific reason and that reason is to navigate difficult terrains. Terrains like sand, gravel, mud, and rock. This type of wheel is perfect for the fact that it has the off-roading capabilities that is needed for ALiCE since it is intended to be driven around the beach. It has a diameter of 24 centimeters or 9.4 inches which is a very good height that could keep ALiCE off the ground and prevent any sand from entering ALiCE. Also they have more options that are higher than 24 centimeters if that is not enough. The main downside of these wheels is since it only travels in two directions, it would be difficult to position itself when it is time to pick up the trash. The main detriment about the wheeleez wheel is the price with it being at seventy dollars per wheel, meaning it would cost us two-hundred and eighty dollars just to get four wheels and if any of them pop or flatten we would need to spend another seventy for it.

VEVOR Wheels

For the second choice of balloon wheels we have the VEVOR beach balloon wheels. Another choice of balloon wheels that is intended and designed for beach use. The material that the VEVOR beach wheels are made of is polyvinyl chloride (PVC). These are decently heavy wheels at least compared to the other wheel options we have explored. They weigh at six pounds each and if we were to proceed with this choice, the weight would be important to note later on for our motor choice so that we would need a pretty solid motor that is capable of rotating six pounds constantly. The price is around the same range as the first one with being \$59.99, but it is sold as a two pack, meaning it will cost \$120 for four wheels and it also comes with an air pump which could be useful if mistakes were to occur.

Extreme Max Wheels

The last wheel choice we have is the Extreme Max wheels. Same as the other two wheels we have, they are balloon wheels that are specifically created for traveling on sand. The material that this balloon wheel uses is not specified but we are assuming that the material should either be polyurethane or PVC like the other two tires we have, or it could possibly be rubber as well. The weight of the wheels fall in the middle between the other two wheels, weighing at 3.85 pounds. The cost is a little on the pricier side, being \$89.95 for two wheels so it will come out to be \$179.90 for four wheels.

Wheel Comparison

With all specifications taken into consideration, we believe that what we want is for the wheels to have no problem navigating over rough terrain like sand and gravel that will constantly have different landscapes, which is what all three of these wheels are capable of. The main deciding factor was the price. Since we do not have any kind of sponsor, any way for us to save some money for our budget is what is best for us. These three wheels did not have any kind of vast difference that would have made the other two options worth the price that they are. If there are some issues with the weight of the wheel, it would be way cheaper to purchase a better motor than purchasing new wheels.

Table 3.1.4: Wheel Comparison

Wheels:	Wheeleez Polyurethane Wheels	VEVOR Wheels	Extreme Max Wheels
Material:	Polyurethane	PVC	Not Listed
Size: (Diameter)	24 centimeters 9.4 inches	22.86 centimeters 9 inches	27.94 centimeters 11.3 inches
Load Capacity:	88 pounds 40 kilograms	77 pounds 34.9 kilograms	Not Listed
Weight:	1.5 pounds 0.7 kilograms	6 pounds 2.7 kilograms	3.85 pounds 1.74 kilograms
Cost (All Four Wheels):	\$280	\$120	\$179.90

Motor

The motor is known for turning electrical energy into physical motion. It is heavily used for any mechanical projects whether it's big or small. They are used even in everyday household items such as blenders, fans, and even washing machines. When it comes to the rover, the motor has a very important job and it's to move the wheels. It is important

to realize that there are more than one type of motor, even when it comes to small autonomous cars like ALiCE. Although there are a lot to choose from, we need to realize what requirements from the motors we should prioritize.

One of the requirements we looked into was energy consumption. What we want from the motor is to not take a lot of the power we have from the battery because there are multiple things taking from the power and it could lead to our battery for ALiCE draining fast if we are not cautious with our choices. Another thing to consider is whether or not ALiCE would use one motor per wheel, or one motor for the entire vehicle, or using three motors in total, but adding the fact that we have a robotic arm that needs to pick up trash, it would be best to have either one motor per wheel or one motor for the front wheels and one motor for the back wheels so that way the rover could have a better performance as well as better control. Since we plan on using four motors, we would have to make sure that the energy consumption of all four motors will not be an issue for our choice of battery.

Another requirement that is considered to be important is the size and weight of the motors. The reasoning for that requirement is that the motor would have to be able to fit in the design of our rover as well as not be extremely heavy to the point where the wheels can not bear the weight of the rover. This is a requirement that is not a total worry, but it does not hurt to double check and make sure that it will not be a problem now then have it affect us later. Now let's take a look at the choices we have for motors:

Brushed DC Motors and Brushless DC Motors

The first motor we will talk about is the brushed DC motor. The brushed DC motor uses electrical current that passes through coils that are set up in a fixed magnetic field. What this ends up causing, is the coils start pushing away from either the south or north magnetic pole and are then pulled towards the other south or north magnetic pole. There are fixed conductive brushes that help contribute power to the coils. All of this repeats and what is created is of course a motor. The benefits of using a brushed DC motor is that they have high efficiency and outstanding controllability. The brushed DC motor is able to reach maximum torque at certain points in the rotation. They are also used in a wide amount of applications, meaning that there would be a lot of outside resources available if something were to go wrong with the motor.

The second motor is the brushless DC motor. The main difference between the brushless DC motor and the brushed DC motor is the use of brushes. The brushed DC motor uses fixed magnetic poles and then uses brushes to make the coils move, but for brushless DC motors, it uses a rotor that has both the south and north magnetic poles attached to it while it is rotating. So instead of having the coils move, they are in a fixed position while the poles themselves are moving. Since the rotor has both of the magnet poles, there is essentially no need for current, which means that there is no need for the brushes. One downside of using a brushless DC motor is that the wiring would end up being a bit more complicated than other motors in which you just connect the power's positive and

negative terminals. Besides that there are some advantages that are also pretty similar to the brushed DC motor and one of them is efficiency. These motors are able to continuously be controlled at maximum torque as opposed to brushed DC motors which can only achieve maximum torque at certain points. Another advantage they have is that they are able to use feedback mechanisms that would allow them to have excellent controllability. These feedback mechanisms would allow the motor to precisely get the desired torque as well as the rotation speed. As a result of that, precisely controlling the motor would end up reducing energy consumption which will also help lengthen the life of our battery, which would be very beneficial for ALiCE. Since there are no brushes, there will be very little electrical noise being made, which can help prevent any harm to animals that are habitating the beach.

Stepper Motors

A stepper motor is also a DC motor just like the brushed and brushless DC motors. A stepper motor has a very similar structure compared to a brushless DC motor and a brushed DC motor in which it also has a rotor in the middle with coils surrounding it. Like a brushed DC motor, the rotor can be a magnet, but it also can be a variable reluctance iron core. In this case we will be talking about a stepper motor with an iron core as the rotor. Each coil gets energized when the rotor is aligned with the magnetic field it produces. This continues causing the motor to continue spinning. Using a stepper motor allows us to reach a higher speed, but it would end up with a lower torque. The big difference between this motor and the other two motors that were mentioned before is that the stepper motor has more precise movement which is something that we would need in order to have good positioning for our robotic arm to pick up trash.

There are a good amount of downsides for a stepper motor that should be addressed. One thing is that the motors, even when it is not moving, will always drain the maximum current. This causes the efficiency to be worse and it can also lead to overheating. It also can affect our battery life, which is not ideal for ALiCE. Another thing is that stepper motors tend to become very noisy only when it is at high speeds, so it would be best for us to avoid making ALiCE go as fast as possible when using a stepper motor. With all that we know, we determined that the best choice is a brushless DC motor mainly because of its high torque

Table 3.1.5: Comparison of Three Different types of Motors

Motors:	Brushed DC Motor	Brushless DC Motor	Stepper Motor
Torque:	Reaches its maximum torque at	Constantly reaching its maximum torque	Low torque, does not reach its

	certain positions		maximum torque
Efficiency:	High	High	Low
Power Usage:	Moderate	Moderate	High
Weight:	Low	Low	Low
Cost:	Low	Moderate	Low

Motor

After discussing the three types of motors that we plan on using and their pros and cons, we will now talk about three specific choices of the motor that we think are good choices for our design. All the motors have some benefits that make them better compared to the others but they also have some downsides that make it hard to justify using them.

Robotdigg Brushless DC Motor

The first brushless DC motor option we have is the Robotdigg Brushless DC Motor. The motor has a total of 4 poles in the motor. This motor performs at a voltage of 24 and has a rated speed of 3000 revolutions per minute (rpm). Although, twenty-four volts is a lot when you consider that we may either use three of these motors or five of these motors depending on whether we want to do two wheel drive or four wheel drive. What's good about the voltage usage is that it means that because of the high power requirements it provides as a result a higher output, which is good in order to make sure the wheels have no issue moving the entirety of ALiCE. Another thing about us choosing two wheel drive or four wheel drive is that we would need to consider the cost of this motor. It also has a good torque of 0.33 newton-meters.

Robotshop Brushless DC Motor

This motor is a brushless DC motor that aligns pretty well with the requirements we need. IT also has the same amount of voltage as the brushed motor we picked, but there is a big difference between the revolutions per minute (rpm). The no load speed of the brushed dc motor is at 326 rpm, while the no-load speed for the brushless DC motor is at 8000 rpm. Although the rpm is good, that is not what we consider important because we mainly value torque. The torque of this motor is 700 grams-centimeter which is vastly different compared to the brushed DC motor

High Torque Brushless DC Motor

As the name would suggest, this High Torque Brushless DC Motor is considered to have a higher torque than most. With a torque of 500 grams-centimeter, it has the lowest torque

out of all three options. This alone would make it hard for us to choose this motor for our device. It does at least have some speed compared to the first one with 500 rpm, but speed is not our main requirement. For its voltage range of 12-24, it does have some very solid specifications, however, compared to the other options, this motor is not that promising.

Motor Comparison

With all the specifications discussed about these three specific motors, it is a good time to decide which one will be implemented into our design. With the main consideration of the motor being torque, there is a very obvious motor that has way more torque compared to the other two and that is the Robotdigg Brushless DC Motor. Considering voltage, they all use around the same amount of voltage so it does not mean much into our decision. The no-load speed may be beneficial as well, but the priority of the torque outweighs the no-load speed. The reason why torque is so prioritized is so that we are able to traverse the rough terrain that is the sand and or gravel.

Table 3.1.6: Motor Comparison

Motor:	Robotdigg Brushless DC Motor	Robotshop Brushless DC Motor	High Torque Brushless DC Motor
No-Load Speed:	3000 rpm	8000 rpm	5000 rpm
Torque:	0.33 newtons-meter	700 grams-centimeter	500 grams-centimeter
Voltage:	24 volts	24 volts	12-24
Cost (For one):	\$36.00	\$24.85	\$27.99
Rated Current	6.6 amps	2.5 amps	2500 milliamps

Sensor

The sensor that is attached to the rover will act as a failsafe. We want to make sure that ALiCE is safe and will not get in the way of any living being that is currently occupying the beach and for that reason, we will add a second sensor that will be able to detect any object in close range of ALiCE and if it does detect something it will stop the movement of the rover. In order to do this we would need to have a sensor that has a small range, having a sensor with a large range will defeat the purpose of the lidar puck and will also keep causing our rover to shut down. Price will also be in consideration mainly because

in order to detect objects on any side of the rover, it would be best to have 4 small sensors, one on each side, to make sure there are no objects near. Another thing that matters for the sensor is precision and accuracy. It would be very problematic for ALiCE if it is constantly stopping for objects that are not actually in range as well as objects that do not exist. Another problem would be if the sensor keeps detecting the floor because of the potential height difference that can occur with sand. So it is important for our sensors to be precise and accurate. The size should not be an issue as long as it is able to be attached to the 4 sides of the rover which will most likely have a lot of space. The weight itself should not be too much of an issue as well because sensors seem to be very light. Now the two sensors we think that are usable for these tasks are infrared sensors and ultrasonic sensors.

Ultrasonic Sensor

The way ultrasonic sensors work is that it sends out ultrasonic sound waves, and if there is an object or an obstacle, the ultrasonic sound waves will bounce back towards the sensor which will then be able to measure the distance between the sensor and the object. The way it is able to measure the distance is by using time of flight, which has been mentioned and explained in our paper before (**3.1 LiDAR**), but using the time of flight we are able to calculate the distance between the object and the sensor using this formula:

$$d = (\Delta t \times s) / 2$$

Where d is distance, Δt is time elapsed, and s is speed of sound. If we use microseconds for the time of flight, this will give us the distance in centimeters. A problem with the ultrasonic sensor that we need to make note of is the fact that any kind of obstruction, such as dirt, snow, and in our case, sand, will disrupt the sound waves from reaching the sensor. This mainly depends on the height of the sensor and if the wheels will kick up sand towards the sensor. The benefits of using an ultrasonic sensor is that they are able to function properly regardless of light, smoke, dust, and color. This is important in the beach where it can be sunny or dark depending on time and there could be a multitude of colors in a populated beach.

Active and Passive Infrared Sensor

The infrared sensor is another type of proximity sensor, the same as the ultrasonic sensor, which is able to detect objects without having to have physical contact with said object. How the infrared sensor works is that it is able to detect any kind of change in light (that is not visible to the naked eye). It does this by either emitting or detecting infrared radiation from any kind of object/obstacle within their range and if there is any change then there would be an object detected. There are two types of Infrared sensors, active and passive. Passive is only able to detect any infrared radiation from objects but it would not be able to determine the distance from the rover to the object. The use of a passive

infrared sensor would be a bit challenging compared to the other options, but it would end up being doable, it would just take a lot more effort. The other sensor is the active infrared sensor, which sends infrared light out and it also detects the infrared radiation from objects which would allow the distance to be determined from the sensor to the object. There are some issues when it comes to using infrared sensors, the one that is important to realize is that fact that infrared sensors are able to be interfered with by other sources of infrared radiation, such as the sun. This is crucial as ALiCE will be operating on the beach in which there will be nothing but the sun during the first half of the day. If we were to choose the infrared sensor, we would have to come up with a way to prevent the sunlight from interfering with the sensor.

Table 3.1.7: Sensor Comparison

Sensors:	Ultrasonic	Active Infrared	Passive Infrared
Wave Direction:	Travel To and From Sensor	Travel To and From Sensor	From Sensor
Can Determine Distance:	Yes	Yes	No
Range:	Typically Far Range	Typically Small Range	Typically Large Range
Power:	3.3 - 5 Volts	3.0-5.3 Volts	3.3- 5 Volts
Size:	Medium	Small	Small
Price:	Low	Low	Very Low

Choices For Ultrasonic Sensors

With everything discussed and researched about what we desire from sensors, we were able to pick three sensors that we believe to be beneficial to our design. One that is an ultrasonic sensor, one that is an active infrared sensor, and one that is a passive infrared sensor. These sensors have some positives that really add on to ALiCE and make it thrive as well as some negatives that would hinder ALiCE and create more obstacles for us to conquer.

Ultrasonic HC-SR04 Sensor

We believe that the HC-SR04 sensor is a solid choice for the ultrasonic sensor because of its capabilities. The sensor is able to have measurement functionality in the range of 2 centimeters to 400 centimeters which is a good range for what we are looking for. ALiCE only needs this sensor as a failsafe so it just needs to detect objects close to ALiCE which

the HC-SR04 is perfect for. It also has an easy use and setup with just four pins and they are the VCC, Trig, Echo, and GND pins. The price is also very low which is good because we would need one on each side. The benefit of this sensor is the fact that it is able to detect mostly anything without physical contact. It has no issues detecting things regardless of light, dust, and color which is very useful considering that ALiCE will be operating at the beach.

MaxSonar Sensor

The MaxSonar sensor is another type of ultrasonic sensor that we could possibly use for this project. It has a very solid detection range from 20 centimeters to 765 centimeters, which has a higher max detection range than both of the sensors. As good as that is, it is not really necessary for the needs of this ultrasonic sensor. What we need is a sensor that is able to detect things up close because we already have the lidar puck that can detect things from afar. It has 7 pins, GND, V+, SCL, SDA, Status, as well as a temporary default pin that is internally pulled high. One of the 7 pins that were mentioned is not used but it does exist on the component, so we can possibly use it ourselves if it is needed. The main problem of the MaxSonar sensor is that the price of this sensor is \$39.95 for just one

Mouser Electronics Sensor

The Mouser Electronics sensor is the last and final ultrasonic sensor we will consider for our design. This sensor is a simple sensor with no extra details to it besides it just functioning as an ultrasonic sensor. It does not have any pins. It also does not mention anything about its detection range which is concerning because that is definitely one of the most important factors to look for when using a sensor. The main good thing about it is that it has a directivity of 80 degrees which is higher compared to the other two sensors. The price of the sensor is also crucial because it cost \$5.44 for one which is important considering our budget

Sensor Comparison

With all the specifications and requirements for the sensor discussed, it is now time to compare and decide which sensor is the best choice. The biggest deciding factor is the accuracy of the sensors and anything that can be harmful to the accuracy is very relevant. The reason why is because this sensor acts as a fail safe and what good is a fail safe that has a huge chance of not working. With that being said, the problem with the maxsonar sensor is that when there is an object that is in front of the sensor that is below 20 centimeters, the sensor will display it as 20 centimeters. This is crucial because these sensors are only in this design to stop when an object is too close to ALiCE, and if the sensor can not detect it if it's too close, then there is no point in using that sensor. A similar problem with the mouser electronic sensor is that the detection range of the sensor is not displayed, even when looking at the datasheet of the sensor. With all the information considered, we determined that the HC-SR04 is the best choice.

Table 3.1.8: Sensor Comparison

Sensors:	HC-SR04 Sensor	MaxSonar	Mouser Electronics
Detection Range:	2 - 400 centimeters 0.8 - 157.5 inches	20 - 765 centimeters 7.9 - 301.2 inches	Not Listed
Voltage:	5 volts	3.0- 5.5 volts	1.7 - 3.6 volts
Measure Angle:	30°	Not Listed	80°
Operating Temperature:	Not Listed	0° - +65° celsius	-40° - +85° celsius

Power Supply

The power supply for ALiCE is the life force of our robot. The job of the power supply just like in any other object took our robot to last as long as it needs to be. This will decide how effective our robot will be. The less human interaction ALiCE has to receive the better. This makes it to where the people working with or around ALiCE have less to worry about and leaving ALiCE to do their job cleaning up pollution off the beach. ALiCE needs to be a self-sufficient robot that can last for a long time while performing its duties. ALiCE's power supply needs to be an efficient power supply that can draw power quickly and adequately through the system to efficiently run ALiCE. This power supply needs to be robust enough to take care of any leaks if any sand were to get into the ALiCE's main body so the power supply system is.

The first requirement is that the power supply must be extremely power efficient. The reason for this is obvious to keep ALiCE on the job longer without needing help from anyone. We would also want this to be a quick charging factor where it can recharge quickly and disperse energy slowly to keep our robot working for longer. This is why we need to make use of good batteries and voltage regulators to keep our efficiency high on the power supply. We need to make sure we are not draining the battery quickly and wasting energy on wasted resources and quickly turn on and off systems to keep the battery from draining quicker than it should be. This will be decided by the software but will ultimately make a massive difference on the total power drain of our system.

The second requirement is size and weight of the power supply system. The total power supply should be an appropriate size seeing how our design will perform better the longer it can run. However, we would still try to make it as small as possible to leave room for other systems on board ALiCE and the bins for trash and recycling. The next part is the weight of the power system should be as light as possible while still being efficient. If the

power system is too heavy it will put more work on our motors and ultimately cost us more power than needed to keep the ALiCE running.

Battery

Batteries are the way to power the device while it's out on the field. The battery we decide to use will need to be capable of keeping the device out in the field as long as possible while still being efficient as possible. Another important thing about batteries is that there are two different kinds of batteries. The first type of batteries are primary batteries that are intended for one time use only. Secondary batteries on the other hand are meant to be recharged and maintained over long periods of time. For this project we will be using exclusive secondary batteries to make sure the only maintenance to ALiCE is that the battery is charged to use ALiCE once again.

Lead-Acid Batteries

Lead-acid batteries are the most widely used rechargeable batteries used today by demand from the automotive industry. There are two basic types of lead acid batteries which are the flooded and sealed type. Flooded batteries are used for starting, lighting, and ignition on cars. Then there are sealed lead-acid(SLA) batteries which are the type we would use if we were to use them in our project. The discharge voltage of a SLA typically remains constant while discharging and drops quickly when reaching the end. With normal operating conditions the battery's capacity will be stable for most of its useful life and then begin to degrade slowly with permanent loss slowly after enough charges. These batteries also happen to be low cost and have various size formats.

Nickel Cadmium Batteries

Nickel cadmium batteries use nickel oxy-hydrate for the active material of the positive electrode and the negative electrode uses the active material of cadmium. The discharge voltage remains constant throughout the discharge of the battery to a sharp drop off near the end. The batteries are also easily charged by applying controlled current rates. These batteries also suffer from the voltage depression effect also known as the "memory effect." This means if the battery doesn't work if in the wrong condition such as having a lot of partial cycles or overcharging at higher temperature then it could result in the cycle life ending sooner than it should. However, this condition can be fixed just by completely discharging and recharging the batteries. Cadmium is also poisonous resulting in this battery being more controversial.

Nickel Metal Hydride Batteries

Nickel metal hydride batteries have a 170% increase in energy density compared to NiCd's and have the cadmium replaced by an alloy in the cells. This was the early choice for electric vehicles until 2005. They have similar discharge patterns to NiCd's but use a different material for the negative electrode. They also have an estimate of a 50% longer service life with the greater capacity.

Lithium-Based Batteries

Li-ion batteries deliver lightweight battery packs more suitable for smaller devices. These have three times the energy density as nickel based batteries and have three times the thermal voltage. Lithium based batteries have a lower discharge rate at 80% than 95% of the rated capacity for NiCd. Li-ion batteries also have greater fragility due to the nature of lithium. Lithium can not tolerate overcharge or over-discharge and are more extensively damaged by these actions. That is why failsafes are built into most battery packs to prevent this. Lithium batteries also require constant voltage and constant current to charge. Even with all these downsides we are still going to use these batteries for our project because of the size, weight, and power output.

Table 3.1.9: Battery Comparison Part 1

Parameters	Lead-Acid	NiCd	NiMH
Average Cell Voltage (V)	2	1.2	1.2
Internal Resistance	Low	Very Low	Moderate
Self Discharge (%/month)	2%-4%	15%-25%	20-25%
Cycle life (# of charge-discharge cycles until 80%)	500-2000	500-1000	500-800
Overcharge tolerance	High	Medium	Low
Energy by volume (Watt hr/liter)	70-110	100-150	200-350
Energy by weight (Watt hr/kg)	30-45	40-60	60-80

Operating temperatures	-20 to 50 C	0 to 45C	0 to 45C
Maintenance Requirements	3-6 Months topping charge	Full discharge every 90 days	Full discharge every 90 days
Safety Requirements	Thermally Stable	Thermal Stable, Fuse protection	Thermal Stable, Fuse protection
Cost	Low	Medium	Medium

Table 3.1.10: Battery Comparison Part 2

Parameters	Li-ion	Li-Polymer	LiFePO ₄
Average Cell Voltage (V)	3.6	1.8-3.0	3.2-3.3
Internal Resistance	High	High	High
Self Discharge (%/month)	6%-10%	18%-20%	1–3%
Cycle life (The number of charge-discharge cycles until 80%)	1000-1200	300 to 500	1500-2000
Overcharge tolerance	Very low	Very low	Very low
Energy by volume (Watt hr/liter)	200-330	230-410	200
Energy by weight (Watt hr/kg)	120-160	120-210	100
Operating temperatures	0 to 45C	0 to 45C	0 to 45C
Maintenance Requirements	Maintenance Free	Maintenance Free	Maintenance Free
Safety Requirements	Protection Circuit Mandatory	Protection Circuit Mandatory	Protection Circuit Mandatory

Cost	High	High	High
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Power Distribution Board (PDB)

A power distribution board is a board that connects from the battery or power supply to the part that needs the required voltage. To do this the PDB has voltage regulators on the board to control the amount of voltage going through by either stepping down the voltage or stepping up the voltage. In most cases I would say you are stepping down the voltage to either 3V, 5V, or 12V. These boards make it possible to deliver the correct amount of voltage while not taking much space or wasting much energy from the power supply. These are an essential piece to our project and needed to divide the voltage correctly to each part of our system for ALiCE.

Empty board

An empty power distribution board is just how it sounds. It is a power distribution board without anything on the printed circuit board with a few wire connections on the board and empty slots to add whatever pieces. These empty boards usually just have polarity symbols on them and holes for them to attach to other pieces. They also have no voltage limit on the board. This makes these boards a lot more customizable to needs of the project instead of being more general use boards with different voltages ranges. Instead the owner gets to decide which regulators and pieces go on the board and which do not. However, one must have basic knowledge of soldering on pieces to a PCB. They must also have a plan of what pieces they want to add beforehand to make these work. The boards also are generally a lot cheaper compared to premade boards because you are doing all the work to add on the parts needed.

Premade board

The premade boards are also just how they sound, the premade boards you can pick and choose what you need. They are like MCU where there are thousands of options you can pick from that would work for your project and someone has to narrow down the things that are needed or would help improve the project by making it easier or run better. These items that come on these boards are but not limited to on screen display, lc filter, current sensor, 5v and 12v regulator, adjustable voltage regulator usually. The lc filter helps a lot with display outputs and making them much clearer. Once one narrows down their board selection then they just have to solder the connections needed for their project to the board and attach the board to their device and it's as simple as that. The big downside to these boards are there aren't really slots to add more parts if needed and they usually cost marginally more for already having everything put together for the consumer.

Table 3.1.11: PDB Comparison

Parameters	Empty board	Premade board
Ease of use	Low	High
Customizability	High	Low
Flexibility	Low	Medium
Efficiency	High	Medium
Cost	Low	Medium

Voltage Regulators

Voltage regulators are essential due to having varied voltage requirements with all the other systems involved working together. The voltage regulators connect to parts to handle certain loads that require specific line voltage. This ensures that the voltage regulator can constantly support the power requirements of all connected systems. These DC/DC converters need to be able to respond quickly to power changes and demands on the fly. Like for motor controllers that require high currents suddenly. The two main types of voltage regulators are linear voltage regulators and switching voltage regulators.

Linear Voltage Regulator

Linear voltage regulators are the less efficient, less flexible, and larger switching regulators of the two. However, it's also more dependable, easier to design, and more cost effective. Linear voltage regulators can also only be step down voltage regulators. All excess voltage will be dissipated as heat making it a less efficient regulator. There are two forms of linear regulators which are series and shunt regulators. A series regulator works by putting lines in series or in parallel to the lines they are intended to regulate. A shunt regulator works by shorting the PV module and will have a constant short-circuit current across the shunt element. This causes shunt regulators to be less common and limited to systems with less than 20 amps. Both types of regulators use low voltage disconnects to disconnect the load when the battery is low on power.

Switching Voltage Regulator

Switching voltage regulators allow constantly switching the input voltage on and off using a PWM or pulse-width modulation to reach a specific output voltage. Pulse width modulation controllers constantly connect and disconnect the PV module to the battery enabling complete control on the rate of discharge from the battery. Doing this to batteries reduces the risk of overheating the battery and makes better utilization of the batteries discharge requirements. A PWM is also relatively cheap and easy to use on smaller scale systems. Using this PWM on switching voltage regulators we make a modulated signal that when pushed through an inductor-capacitor circuit can power a load continuously. There are multiple different types of switching regulators that allow the output to be a step-down, step-up or both. The common switching voltage regulators are Buck, Boost, and Buck-boost. One big thing to remember is that the ripple voltage in equivalent series resistance of the output capacitors increases while the temperature is lowered.

Table 3.1.12: Voltage Regulator Comparison

Parameters	Linear Voltage Regulator	Switching Voltage Regulator		
Type	N/A	Buck	Boost	Buck-Boost
Ease of use	High	Medium	Medium	Medium
Efficiency	Medium	High	High	High
Voltage output (compared to input)	Step-Down	Step-Down	Step-Up	Step-Up or Step-Down
Heat	Medium	Low	Low	Low
Output Ripple	Low	Low	High	Low
Cost	Low	Medium	Medium	High

PCB

The printed circuit board will be the brains of the operation. This will lay the groundwork for all the connections for all of ALiCE. The printed circuit will need to have the correct

peripherals to connect to everything needed to make ALiCe work. This includes making connections to the sensors, camera, robot arm, motors, power supply, and spectrometer. These connections need to be secure and fast. We need to be able to make use of real time systems for fast reaction times from the PCB. We also need to make a PCB that can receive clean signals without noise from a camera. So preferably a PCB with a filter and a special connector that connects directly to the camera that we plan to use. Then we need to fulfill certain requirements to make the most of our PCB.

The first requirement is the amount of memory total our PCB has. Our PCB shouldn't be worrying about memory issues so we are able to update and add more as we develop the project and add updates to either software or hardware. Then it needs to be able to save video quickly to check whether it has picked up trash or not. Then quickly after delete the video when it decides it doesn't need it anymore. Its needs to be able to do the same with sensor data quickly saving then rewriting over data to quickly adjust in real time. Same with our robot arm it needs to be able to tell our robot arms position at all times where to bring the robot arm for the spectrometer. Then reads the data off the spectrometer to read it to tell whether to recycle the waste or put it in the trash bin. The last and probably the most important uses of memory would be saving and constantly rewriting the lidar data to tell our bot where it should be moving to avoid obstacles. Then we also need a decent amount of memory to save all the code dedicated to all the different cases and situations that ALiCE will get into constantly.

The second requirement is performance of the PCB. The PCB needs to have everything to quickly update and change as quickly as possible to keep all the information as up to date as possible for our real time system. So we need a processor that can quickly do that with an accurate timer to make sure everything is on the same clock. We would also do all the processes as fast as possible so that ALiCE can be as efficient as possible and is able to do as much work as possible before needing a recharge.

MCU vs FPGA

In this project we have an important decision between two great pieces of technology. The two best choices to use for the brains of our project are a microcontroller unit (MCU) or a field-programmable gate array (FPGA). There are pros and cons to both options but we need to decide which one is better for our project. Factors to choose from are processing speed, specialization, cost, and power draw.

FPGAs are more powerful and precise with little to no margin of error and specifically made for the task they are programmed to complete. This has its drawbacks consisting of higher cost, more power consumption, and almost no flexibility. FPGAs are also not really user friendly and have more complex programmable hardware made for industry applications not made for small projects. FPGAs use hardware level languages such as Verilog and VHDL making them harder to learn and use for a causal level. In addition FPGAs need to integrate external parts to make use of simple parts that come pretty commonly on MCUs like digital converters or communication interfaces like UART and

I2C. One advantage to FPGAs is that they are scalable and wouldn't be limited like a MCU in needing more processing power for future upgrades. A disadvantage of FPGAs is that they are less robust than MCUs. This is because they are more sensitive to environmental conditions that can make the system unstable like temperature fluctuation and electromagnetic interference. This means in addition to make room for the FPGA in ALiCE we would also make another enclosure to ensure the stability and proper working conditions for ALiCE. So, overall for FPGA it seems not very straightforward for new users and a very deep knowledge set is required because of the non-standardized nature of the hardware. This would make it extremely hard when designing hardware for our project. In addition, our members would be forced to learn a hardware level programming language they have barely worked in before and would need to use in a way that is nothing close compared to what they have worked on before in it. It would also cause a lot of trouble handling errors with all new skills that would need to be learned while trying to code in hardware level languages.

MCUs usually come with most of their features already on the chip. MCUs also are more often made to be low power devices that could let ALiCE run longer. They are relatively easy to use compared to FPGAs and have a lot of documentation with online resources available from the manufacturers. MCU's have standardized architectures with loads of field data making them proven good tools time and time again. MCUs also come standard with communication interfaces like UART and I2C that we will make the most of on our project and not need to be added like for FPGAs. Most MCUs also come with dedicated IDE's that receive constant support and updates. These IDEs also make use of common high level programming languages like C, Python, and Java. This makes programming errors easier to solve for people who have worked with these programming languages before. Our team all having worked with higher level programming languages makes this a much safer choice for programming letting us use previous knowledge and tools to debug problems with the software.

With all this information in thought our group decides to go with MCUs over FPGAs. It really an easy decision considering all the extra learning that would need to be put in to learn FPGAs. Compared to working with MCUs where the barrier of entry is significantly lower and already being used to working MCUs. In addition we have already worked with high level programming languages throughout our time in the field. MCUs also have built in error handling and are usually more stable products with more robust features that provide more safety that everything will work correctly on our project. Overall, the choice of picking the software and programming language we use to code is too nice an advantage to have plus when selecting hardware just needs to be compatible without adding external parts.

We have also decided that we will need to make use of two MCUs, one to control the program data for the just about everything but the camera and one that controls the camera and sends the minimal amount of data to the main MCU to tell the rest of the system how to respond based of the camera data. So for the MCU controlling the data it will need a lot of storage for holding video data in a good resolution like 1080p. Then the second MCU will be the main brains of the operation taking the data from the robot arm, sensors, spectrometer, and the motors.

Table 3.1.13: MCU vs FPGA Comparison

Parameters	MCU	FPGA
Power Consumption	Low	High
Ease of use	High	Low
Processing power	High	High (could be higher than MCU)
Environmental Robustness	High	Low
Scalability	Low	High
Peripherals	High	Low
Standardization/ Documentation	High	Low
Cost	Medium	High

Robotic Arm

Our method of choice for picking up the trash and debris, is to incorporate a precision, industrial robotic arm from Mecademic Industrial Robotics. The Meca500 is not the most cost efficient arm for the job however, we chose to implement this equipment as we have been granted access from one of the member's employers. The robot connects via ethernet cable, and acts as a slave component, making it unique in its industry, “And unlike most other industrial robots—which are usually complex stand-alone systems—the Meca500 is a plug-and-work automation component. Our robot is a slave component rather than a master, which makes it very easy to integrate via any computer or PLC” (Mecademic, 2023). The Meca500 is an extremely precise and compact device that will really maximize the performance and potential of ALiCE. Its high precision, with a position repeatability of 0.005 mm, ensures that the robotic arm can accurately and reliably pick up even the smallest pieces of trash. This level of precision is essential for the effective operation of ALiCE, as it needs to handle various types of debris with varying shapes and sizes found on the beaches.

We compared using the robotic arm versus sifting technique used in the commercial product available today. We determined our approach went a step above in terms of collecting and sorting the items collected from the environment. Also, because we avoid sifting through the sand, we are actively avoiding accidentally collecting sea-turtle nestings. Which are highly protected due to their endangered species status.

Spectrometer

The spectrometer will determine whether the item collected is recyclable, trash, or possibly a seashell. The spectrometer will measure across the VIS-NIR spectrum for analysis of the material. Measuring in this spectrum will give accurate results in real time. The basic function of a spectrometer is to receive light, break it into its spectral components, digitize the signal as a function of wavelength, and read out its analysis.

Software Research

Framework

In order for the robot to function effectively, it's important for it to be able to handle multiple tasks. Several of these tasks must be able to work in real-time to ensure the accuracy and performance of the robot. A good majority of this code will use open-source libraries to manipulate sensor data because the idea of switching between tasks to achieve the responsiveness for the amount of code that needs to be used is simply not the most proficient way. We will use a programming framework to test and implement different components together.

Yarp is a software framework for developing robot applications. It's a set of tools that will help communicate and integrate between the software modules. It allows developers to build complex systems by connecting components together that can communicate and work seamlessly well together. YARP is free to use and is written in C++; it can be compatible with other languages as well but it requires a compatibility layer. Even though YARP is an open source, it seems to be quite limited which makes it more difficult to find debugging assistance and supporting materials. Their website provides different tutorials with getting started and the libraries it uses.

Another framework is ZeroMQ which is an asynchronous general-purpose messaging library. It supports multiple communicating patterns making it easy to implement messaging scenarios. ZeroMQ is designed to be fast and lightweight with reliable performance. It can establish communication between processes, locally and the internet. ZeroMQ is written in C++ but supports other languages as well. While ZeroMQ is a general-purpose library, it would take some extra time to learn and implement it for the robot.

ROS (Robot Operating System) is another framework that is designed for robotic applications. Like the previous software frameworks, ROS provides set libraries and tools to help build the robot. ROS is open-source, giving us the flexibility to decide how to use ROS as well as the freedom to cater and customize our robot. ROS works well with C, C++, and Python but can also integrate other softwares into the equation. It is compatible for multiple platforms such as macOS, Windows, and Linux. ROS is specifically

designed for robots and is improved by and for developers who contribute to robotic software.

Comparing all three of these frameworks, each one has their pros and cons. All of these provide a library that can support different programming languages and is free to use. Although ZeroMQ is a popular framework, it wouldn't be an option due to the fact that it simply wasn't built for robots alone and would require extra time to accurately apply it. Due to a tight schedule, that would push the project back. YARP and ROS are similar in many ways, however, YARP seems to be more limited in the libraries, sources, and overhead. ROS is specifically designed to build a robot fast and its install is more robust compared to the other two frameworks. For this, ROS would be the best framework to work with.

Mapping and Object Detection

SLAM

A huge part of the robot is knowing where it is in its own environment. ALiCE is specifically designed to map out its location and detect obstacles whether that is landmarks or trash. The robot would need to take in data from the camera and continuously update the map providing the robot with real-time data. Besides knowing its location, the robot must detect what is trash compared to what isn't trash. More specifically, the robot will identify whether the piece of trash is glass, aluminum, or plastic. We can use the camera sensors and LiDAR for mapping and object detection. Slam is a method used for robots to map out locations to localize itself. With the improvements of computer processing speeds and lower-cost sensors, SLAM is being used in a more practical way. SLAM consists of two parts: the front-end processing and the graph optimization which includes the back-end optimization.

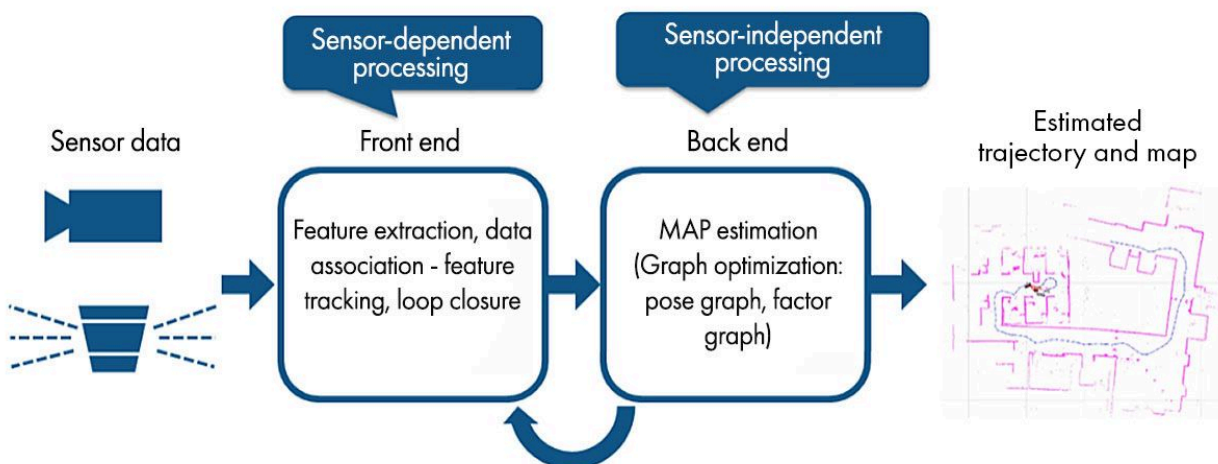


Figure 3.1.2.1: SLAM Processing Flow

How SLAM works is using the sensors, in this case the camera, to scan the room and collect data about the environment. The data is then processed to identify objects or landmarks and the robot will then use the map to determine its own location. The robot will compare its current data to the map and estimate its own position. As the robot roams around, the robot is constantly taking in new data and updating the map.

There are different types of SLAM methods, but for this project, we will implement the lidar SLAM. The lasers provide precise distance measurements and work well in mapping with SLAM algorithms. We can use SLAM with either 2-D or 3-D LiDAR. There are a few different ways to estimate the relative transformation of point clouds such as iterative closest point (ICP) and normal distribution transform (NDT). Using lidar SLAM in ALiCE, the robot will be able to make a map to localize itself and detect objects and landmarks to avoid running into them. SLAM can also be used to remember where trash is located on the beach. While the system is continuously providing real-time updates, this prevents ALiCE from falling over or getting trapped. With SLAM, ALiCE can accurately position the robot arm and effectively pick up the trash.

YOLO

The camera is used to detect objects and act as the ‘eyes’ of the rover. You Only Look Once (YOLO) is a real-time object detection system that is extremely fast and accurate. It can detect objects in pictures and videos in real time making it suitable for an autonomous robot like ALiCE. How it works is that the system divides the image into a $S \times S$ grid and each cell is responsible for detecting the objects within that cell. Each grid itself predicts the coordinates (x,y) and the width (w, h) of the object relative to the whole image. Each grid also predicts the class of the object such as person, car, building, dog etcetera. YOLO will combine the two predictions and determine the final detections. YOLO can be used in ALiCE by detecting objects on the beach. It will use the camera to capture images in real time. It will also help in the navigation system; once the camera picks up an object, ALiCE can move towards the object. YOLO is fast and precise making it ideal for real time applications and its architecture is simple and unified, allowing for easy learning and training.

Software Testing

Testing is a crucial phase in the development of ALiCE, as we must make sure that the robot performs its tasks consistently and effectively in real-world conditions. Our first stage of testing, unit testing, focuses on the individual components of the software and hardware. Each software module we will incorporate in the robot such as the communication protocols, the sensor data processing, and SLAM algorithms will be tested on their own. There are several tools we can use to automate the testing such as PyTest which handles the Python aspects of our software development and Google Test for C++. Ensuring these all work individually before blending them all together is vital in the development of ALiCE to avoid and fix any bugs early before daunting problems occur in the late stages. For example, we can test the Meca500’s physical capabilities to

make sure it meets its specifications by programming predefined movements, and instructions to measure its precision, reach, payload, and repeatability.

Once we test and validate all individual components, our next step in the testing process is to see how well the components work together. We will use incremental integration to test these components in harmony, where we start by integrating the SLAM module with the robotic arm control module, then integrating the rover navigation module, and so on. This will help tremendously in identifying issues at each step.

3.2 Part Selection and Comparison

After researching and carefully considering which pieces of technology we plan on utilizing in our design, we will then decide which parts to implement and satisfy our requirements to achieve our design goals and other important factors.

LiDAR

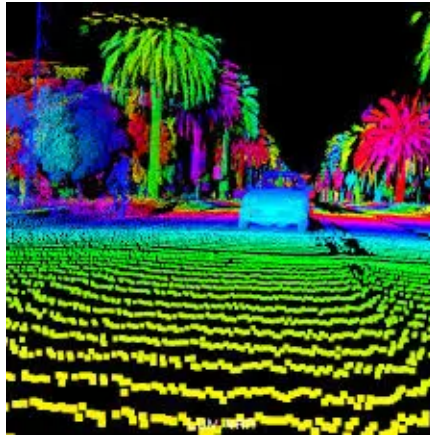


Figure 3.2.1: Luminar LiDAR Point Cloud

To develop a robust robotic system capable of operating in dynamic environments, integrating dynamic sensing is essential to map and transmit information effectively to the central logic unit. This processing requires rapid sampling and processing, which is why we have chosen an embedded sensor solution for this purpose. LiDARs are widely used in autonomous vehicle applications due to their ability to effectively process dynamic environments.

For this module, achieving a 360-degree omnidirectional scan capability with a high sampling rate is crucial. Additionally, it is essential that the scanning range extends up to 6 feet to accommodate environmental variability caused by user interaction or moving objects. After thorough research and consideration, a SLAM LiDAR solution is deemed optimal for our requirements.

Slamtec RPLiDAR

The Slamtec RPLiDAR A1M8 is a cost effective, 360 degree 2D LiDAR scanner, with plug and play capabilities and range radius up to 12m. This LiDAR scanner can be used for ROS educational robots, open source hardware, UAV mapping and obstacle avoidance, synchronous positioning and navigation. RPLiDAR is basically a laser triangulation measurement system that can work in indoor or outdoor applications. This scanner will be used mainly for navigation and obstacle avoidance.

Yahboom EAI X3

The Yahboom EAI X3 is another cost-effective solution, however from information gathered online, reviewers have said this system does not perform well in outdoor applications. The laser triangulation method mainly uses a laser beam to map its environment, the laser is reflected and scattered on the surface of the target, and the reflected laser is converged and imaged by a lens at another angle, and the spot is imaged on a Charge-Coupled Device or CCD, position sensor.

Table 3.2.2: LiDAR Comparison

LiDAR Sensor	Slamtec RPLiDAR	Yahboom EAI X3	Inno Maker LD06
Scan Range	12m	8m	12m
Sampling Frequency	8000 Hz	3000 Hz	4500 Hz
Scan Rate	Up to 10 Hz	Up to 10 Hz	Up to 13 Hz
Distance Resolution	$\leq 0.5\text{mm}$	$\leq 0.5\text{mm}$	$\leq 0.5\text{mm}$
Wavelength	785nm	775nm - 800nm	780nm - 800nm
Cost	~\$100	~\$100	~\$100

Camera

When choosing a camera for this project, we went with the Raspberry Pi Camera for its compatibility with the Raspberry Pi board that we will be using. This camera is designed to work seamlessly with the board having driver support making it easier to set up and better performance. The latest camera offers high resolution which is important for detecting trash and debris on the beach and with different lenses, the camera is suitable for varying lighting and distance conditions on the beach. The camera can be configured using Python or other languages as well which we can tailor to the language we program

the board. The camera is also small enough to avoid any bulkiness or weight to the rover as well as inexpensive, in case we need to order more.

We could consider two other options for this project. The Logitech C920 HD pro Webcam is a popular choice for many reasons. This camera offers a full HD 1080p video giving us clear footage of the beach. The Logitech Webcam is equipped with autofocus and light correction which is useful for beach conditions and is compatible with many operating systems. However, the webcam has a slightly high power consumption and is larger than the Raspberry Pi Camera. The Arducam 8MP IMX219 camera is very compatible with the Raspberry Pi board. It's high resolution and compact size makes it a popular choice. However, this camera has a fixed focus which isn't ideal for the beach conditions as well as on the pricier side.

Table 3.2.3: Camera comparison

Specifications	Raspberry Pi Camera	Logitech C920 Webcam	Arducam 8MP Camera
Resolution	8MP	1080p (2MP)	8MP
Focus Type	Fixed	Autofocus	Fixed
Field View	62.2 degrees	78 degrees	76 degrees
Connection Interface	CSI	USB	CSI/USB
Cost	\$	\$\$	\$\$\$
Suitability with ALiCE	Cost effective, good for fixed-range detection, easy set up	Easy set up, good for versatility	High Resolution

Microcontroller (MCU)

The Microcontroller, or MCU, for our project is single handedly the most important part of our project. The MCU needs to be a safe and stable part of our project that can control ALiCE without worry that it will break due to environmental conditions. Like stated also earlier in our hardware research section we will be making use of two MCUs one for the camera and the another for the rest of the project. Now we will discuss between the five options we decided on which MCUs we will use and why.

MSP-EXP430FR6989

MSP-EXP430FR6989 or MSP430 for short is the first option we discussed is a board made by Texas Instruments. It comes with a 16-bit RISC architecture and up to a 16MHz clock speed. The supply voltage for the MSP430 is from 1.8V to 3.6V and has multiple low power modes depending on what is needed to operate ALiCE with best power efficiency. It comes with a RTC and a crystal oscillating clock. It has a 16-channel 12-bit ADC. It comes with a comparator and five timers. It has direct memory access allowing you to grab memory straight from the registers. It has a 320-segment LCD controller that allows you to display information on the LCD display with useful things such as the battery level. It also comes with 128KB of nonvolatile FRAM for storage. It has a 5V bus from USB and a 3.3V rail from the VBUS in the eZ-FET domain. MSP430 also comes with 83GPIOs pins. Overall is a good choice, the only downside is a little low on processing power and doesn't have much memory.

ESP32 WROOM

The ESP32 WROOM or just ESP32 board is made for ESPRESSIF and is made for network applications and comes with Wi-Fi and Bluetooth features. It has 4 MB of nonvolatile flash memory installed on the device. ESP32 uses less voltage than most MCUs with a minimum of 3V. The minimum current draw is 28mA and peaks at 379mA. Making it a very power efficient option to keep ALiCE running longer. It comes with multiple connection peripherals already on it such as UART, SPI, I2C, PWM, ADC, and DAC. These boards also come with 26 GPIOs pins. This board also comes in at a really low cost compared to every other board. Overall, this is a very good board being power efficient and being powerful enough to still have run all the programs we would need with more memory space.

Raspberry Pi 4 Model B

The Raspberry Pi 4 is probably the most powerful option on the list while also providing the most flexibility. The Raspberry Pi comes with a quad core 64-bit A72 processor running at 1.5GHz. It comes with 4GB of LPDDR4 RAM. It also comes with a built-in hardware decoder called H.265 or HEVC that can do 4k 60fps. Then it has a second one with H.264 that can do 1080p 60fps. It comes with a built-in video chip that supports 3D graphics and has dual HDMI outputs that can display up to 4K 60fps. Then it has multiple upgraded interfaces from the last choices that include 802.11 b/g/n/ac Wireless LAN and Bluetooth 5.0 with BLE. It has 1 SD card for video storage from the camera port that it has. Its direct port is connected to a camera with 2-lane MIPI CSI which makes it a very good choice for the second MCU that we need for our project. It comes with two USB2

ports and two USB3 ports. Then there are 28 GPIOs interfacing pins with multiple interfacing options with, up to 6x UART, up to 6x I2C. Up to 5x SPI. 1x SDIO interface, 1x DPI (Parallel RGB Display), 1x PCM, Up to 2x PWM channels, Up to 3x GPCLK outputs. Overall this makes it a great choice for the second MCU being flexible and being able to take and receive camera data easily will work well and transmit the data to another MCU.

Raspberry Pi Zero 2 W

The Raspberry Pi Zero 2 W is a smaller more cost effective version of the Raspberry Pi 4. However it comes at a lot of costs of the flexibility of the MCU and a less powerful chip. The processor for the Raspberry Pi Zero 2 is a 64-bit Arm Cortex-A53 clocked at 1 GHz. The MCU comes with a microSD card slot and CSI-2 camera connector. Making this another viable option for connecting to the camera with an microSD card to hold all the camera data we need for our program. It also comes with a HAT-compatible 40-pin GPIO header. It has video output through a mini HDMI port. It is also powered through a micro usb port. The operating temperature of the MCU is -20C to 70C.

Rock Pi 4 SE

The Rock Pi 4 SE is an alternative for the Raspberry Pi 4 with very comparable parts. It uses the Arm big.LITTLE technology that has a dual Cortex-A72 with a clock frequency of 1.5 GHz and a quad Cortex®-A53 with a clock frequency of 1.0 GHz. It hosts the Arm Mali T860MP4 GPU for a display chip letting it make use of a hdmi port to display up to 4k 60fps. It uses the same two hardware decoder as the Raspberry Pi 4 H.265/VP9 (HEVC) hardware decoder that can up to do videos up to 4K 60fps and H.264 hardware decoder that can up to do videos up to 1080p 60fps. It also uses a power input of USB C. It comes with a 3.5mm audio jack with a mic. It has two USB2 ports and one USB3 port. It has the same type of camera port as both Raspberry Pi with 2-lane MIPI CSI. It also has 40 interfacing pins that consist of 2 x UART, 2 x SPI bus, 2 x I2C bus – 1 x PCM/I2S, 1 x SPDIF, 1 x PWM, 1 x ADC, 6 x GPIO, 2 x 5V DC power in, 2 x 3.3V power pin.

ARDUINO MKR WAN 1310

The Arduino MKR WAN 1310 runs an ARM cortex-M0 processor running at 48 MHz. The board is powered by 5V by USB. It also has a circuit Operating voltage of 3.3V so it can run at a low power of about the same as an MSP430. This chip also comes with a UART, SPI, and I2C. This chip also came with an internal memory of 256 KB Flash Memory and 2 MB external Flash Memory. It also has 32 KB of SRAM. The clock

speed is 32.768 kHz RTC. Overall this MCU doesn't come with much flexibility but has a lot of good functionality in a small package that is very power efficient.

Robotic Arm - Meca500

The compact size of the Meca500, with a reach of 330 mm and a weight of 4.3 kg, allows it to be easily mounted and maneuvered within the confined spaces of the beach cleanup robot. It is mountable in any direction, and is energy efficient, as it consumes around 30W. The robotic arm's compactness does not compromise its performance; instead, it enables the robot to operate efficiently in the dynamic and often uneven beach environment. The creators of the Meca500, Mecademic, have their own API for programming the robotic arm which is a nice touch in simplifying its implementation. The Meca500 is very expensive and is usually used for lab automation which requires very precise and delicate operations, thus for ALiCE, it is slightly overkill and the other options might be more viable in a cost efficient situation. We are ecstatic to work with such high quality technology and expect great results.

MechArm

An alternative solution, which is considerably pricey, ~\$1200, is the MechArm compact robot arm. This arm has similar payload and movement, however it is slightly smaller and limited in range.

So while we might be killing mosquitoes with a gun using the Meca500, the MechArm from Elephant Robotics, is another suitable choice for the robotic arm on ALiCE. This arm would be our most affordable as well but comes with a few drawbacks. The MechArm is designed to be lightweight and versatile, making it easy to integrate into the robot's framework. Its reach of 270 mm provides a slightly larger working range than the Meca500, which can be beneficial in accessing debris spread over a wider area. The MechArm has a payload capacity of 0.25 kg, which is lower than the other two counterparts we will be looking at. However for lighter loads this could be sufficient as beach litter is usually under 1kg. Two huge benefits with the MechArm is that it has a built-in RaspberryPi which can ease development, and is much more lightweight which can lower its burden on the rover, improving mobility and maneuverability.

UFactory xArm5

The third option which could be used for a much larger rover is Ufactory's xArm5. With a much larger reach at 700mm, this arm can grab from much farther to reach places and before the rover gets too close to the litter. It also boasts a payload of 3kg which is much larger than the other two robots, but finding debris this heavy would be very rare and

basically overkill. These specs also come with a very heavy robotic arm at 11.2kg, almost triple the weight of the Meca500. The xArm5 only has 5 degrees of freedom unlike its counterparts. A part this heavy would cause a lot of problems if our rover is not also much larger than we anticipate. Therefore while this arm seems great and also has raspberry pi compatibility, it is too large for our project.

Robotic Arm Comparison

Below describes all the relevant specifications we can take into consideration, to determine the best suitable choice for ALiCE. The relevant specs we want to focus on are the reach, weight, and position repeatability. They all have compatibility with RaspberryPi so that is not an issue when choosing either option. For control software, the Meca500 has an advantage as it has its own unique API which can simplify programming and won't be as ambiguous when bugs arise as when open-source is used. This is yet another attractive feature the Meca500 has over the others. Although still heavier than the MechArm, the Meca500 used less power which can ease the strict requirements of our power supply and save us money in that aspect. It has the perfect middle ground on reach and payload, not too small and not too large. The xArm 5 is eliminated due to its larger size as our rover will not be able to support that much weight on one component. 11 kilograms is too much and while the reach and payload will be nice, it is not ideal. Another main factor that is taken into consideration is of course, price. Realistically, if we were choosing to purchase any of these three robot arms, they would end up being too pricey to be within our budget. Thankfully, we were able to get the Meca500 loaned to us. While all great options, Mecademic's Meca500 ease of use, reach, compact size and state of the art accuracy and positioning, deem it the winner.

Table 3.2.4: Comparison of Robotic Arms

Specifications	Meca500	MechArm	UFactory xArm 5
Payload (kg)	0.5 (1 max.)	0.25	3
Reach (mm)	330	270	700
Position Repeatability (mm)	0.005	0.5	0.1
Weight (kg)	4.3	1	11.2
Degrees of Freedom (DOF)	6	6	5
Max Speed (mm/s)	1000	500	1000
Power Requirements (V)	24	12	24
Power Consumption (W)	30	60	200
Temperature Range (°C)	0 ~ 40	0 ~ 50	0 ~ 50

Material	Aluminum Alloy	Plastic	Carbon Fiber
Control Software	Mecademic API	Open-source	UFactory Studio
Communication Interface	Ethernet	USB,UART	Ethernet, USB
Raspberry Pi Compatibility	Yes	Yes	Yes
Cost (\$)	\$\$\$	\$	\$\$

Spectrometer

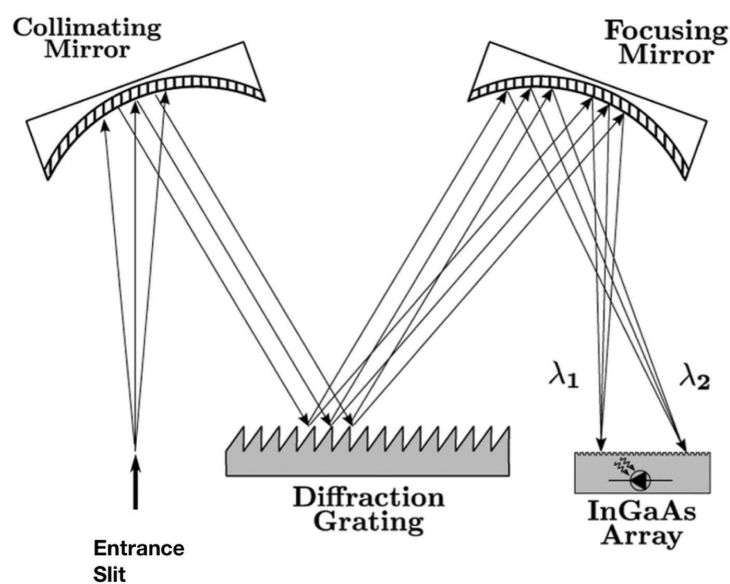


Figure 3.2.5: Spectrometer Drawing

Researching spectrometers involves understanding various types, applications, and specifications relevant to scientific or industrial needs. Spectrometers are instruments that analyze the spectral content of light or other electromagnetic radiation. There are a few approaches or types of spectroscopy like absorption, emission, fluorescence, raman, and laser-induced breakdown spectroscopy. There are various methods through which a spectrometer can collect light. In absorption spectroscopy, light passes through a sample, and the reduction in intensity as it is absorbed reveals specific wavelengths absorbed by the material, aiding in identifying its unique composition. Fluorescence spectroscopy, a

type of emission spectroscopy, involves illuminating a sample with high-energy light to induce fluorescence, wherein the emitted light is analyzed by a spectrometer to identify specific compounds.

Emission spectroscopy encompasses the collection of light emitted from a sample after excitation by an external source such as a laser or electrical discharge. For instance, atomic emission spectroscopy and laser-induced breakdown spectroscopy (LIBS) fall under this category. Raman spectroscopy, meanwhile, involves collecting light scattered after interacting with a sample through inelastic scattering, useful in chemistry for studying molecular and intramolecular bonds.

Optical Component	Function
Measuring System	
Nd:YAG Laser	Emits high energy pulse of 1064nm wavelength on to material
Fiber Optic Cable	Guides light into the spectrometer to be measured
Photo Detector	Used to trigger the spectrometer when IR light is detected
LIBS Spectrometer	
10um Slit	When light passes through narrow slit, it is diffracted into semicircular wavefronts
Collimating Mirror	The collimating mirror then orients the light to planar wavefronts
Diffraction Grating	Disperses or seperates the wavelengths of light to be measured
Focusing Mirror	Focuses the seperated wavelengths on to the detector
Detector	Turns photons to respective electrons and measures intensity at each wavelength
Microprocessor	Computes information from the detector for analyzation

In our project, we focus on LIBS, where a high-powered laser generates plasma on a sample, leading to emission spectroscopy. By analyzing the emitted light from this plasma, we can determine the elemental composition based on the collected spectrum.

The most common spectrometer found in the market is based on Czerny-Turner design. A conventional Czerny-Turner spectrometer achieves high light throughput by dispersing light using a robust first-order diffraction grating. We have opted to design a Czerny-Turner spectrometer due to its widespread use and cost-effectiveness in applications. Such spectrometers can be customized by selecting components that align with project requirements and budgetary considerations.

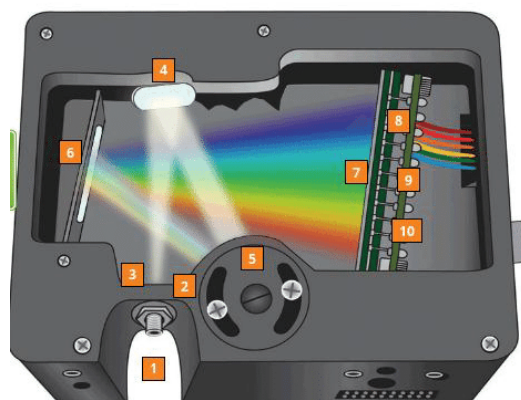


Figure 3.2.6: Ocean Optics USB 4000

Light Collection

The spectrometer will collect emitted light from plasma samples through a Fiber Optic, which will carry the emitted waves through silica material. The fiber optic will meet the 25 μm slit at the entrance of the spectrometer where it will be presented as circular wavefronts.

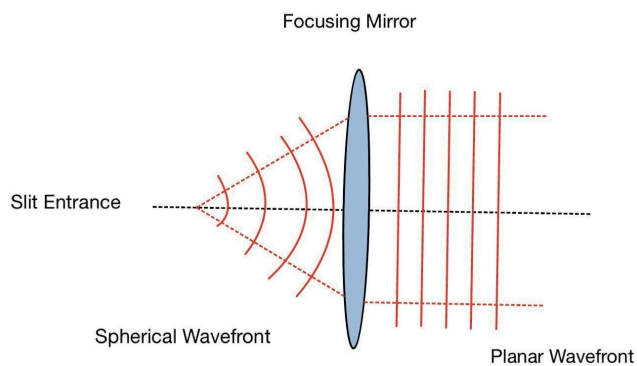


Figure 3.2.7: Light Collection Through Slit

Diffraction Grating

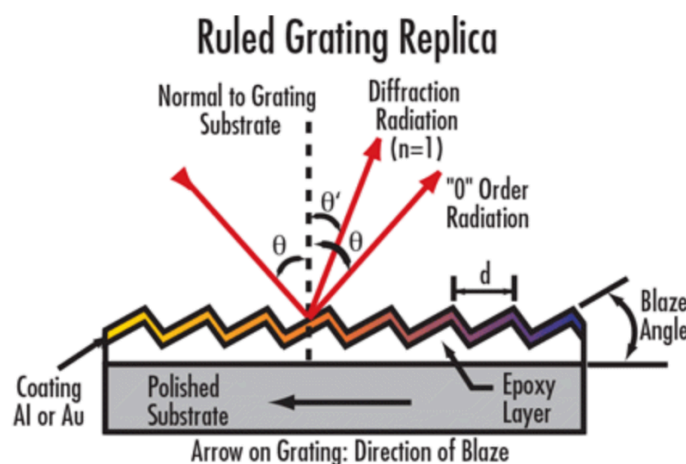


Figure 3.2.8: Diffraction Grating Design

A diffraction grating is an optical component that splits (diffracts) light into its constituent wavelengths, much like a prism does. It consists of a large number of equally spaced parallel slits or rulings, typically etched or deposited on a surface. When light passes through or reflects off a diffraction grating, it undergoes diffraction, which causes the light to spread out into a spectrum of colors. Here's how a diffraction grating works:

Diffraction Principle: When light encounters a diffraction grating, each slit or ruling acts as a source of secondary wavelets. These wavelets interfere with each other constructively and destructively, depending on their path difference, which is related to the wavelength of light.

Dispersion: Different wavelengths of light interfere constructively at different angles, leading to the separation of colors. This dispersion allows diffraction gratings to be used for spectral analysis — breaking down light into its component wavelengths.

Order of Diffraction: The angle at which each color appears depends on the spacing between the slits or rulings and the wavelength of light. Higher-order spectra (where the light is diffracted more than once) also exist and can be observed under certain conditions.

Edmund Optics offers reflective ruled diffraction gratings with claimed efficiencies up to 80%, featuring a bare aluminum coating and blaze wavelength options ranging from 250 to 1600 nm. Meanwhile, Thorlabs provides visible ruled reflective diffraction gratings utilizing an aluminum reflective coating, with efficiencies of 60-80% at the blaze wavelength when measured in the Littrow mounting configuration.

Here is a direct comparison of options and sizes from these leading optical component manufacturers. Both companies were selected for their user-friendly interfaces, clear classification characteristics, and transparent pricing. This comparison focuses on diffraction gratings with either 600 or 1200 grooves/mm, covering wavelength ranges of 200-900 nm or 200-1600 nm, and dimensions of 12.7x12.7 mm or 25x25 mm. A blaze wavelength of 500 nm is chosen as optimal for material identification, as it falls centrally within the visible spectrum.

Figure 3.2.9: Table of Spectrometers

Manufacturer/ Part Number	Edmund Optics PN: 15-763	Edmund Optics PN:43-751	Thorlabs PN:GR13-0605	Thorlabs PN:GR13-1205
Groove Density (Groves/mm)	600	1200	600	1200
Wavelength Range (nm)	350-900	350-900	350-900	350-900
Blaze Wavelength (nm)	500 \pm 25	500 \pm 25	500	500
Dimensions (mm)	12.7 x 12.7	12.7 x 12.7	12.7 x 12.7	12.7 x 12.7
Cost	\$136.00	\$80.00	\$78.11	\$128.29

Toshiba TCD1304 CCD

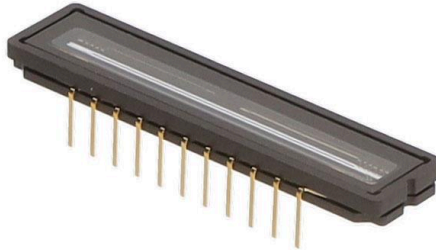


Figure 3.2.10: Toshiba TCD1304

The Toshiba TCD1304 CCD is a prominent charge-coupled device (CCD) sensor known for its high performance in spectroscopy and imaging applications. Featuring a linear array of 3648 pixels, this CCD sensor offers excellent sensitivity and low noise characteristics, making it ideal for capturing precise and detailed spectral data. Its wide spectral response range, typically from ultraviolet to near-infrared wavelengths, enables versatile use in various scientific and industrial fields. The TCD1304 CCD is widely favored for its reliability and accuracy, providing researchers and engineers with a robust tool for spectroscopic analysis, fluorescence measurements, and other high-precision imaging tasks.

Pin Connections (top view)

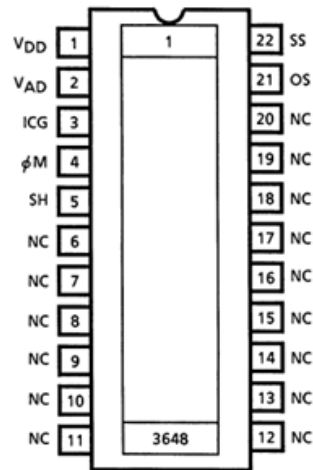


Figure 3.2.11: Toshiba TCD1304 Pinout

The TCD1304DG is a high sensitive and low dark current 3648 elements CCD linear image sensor. The device consists of a sensitivity CCD chip. The TCD1304DG has an electronic shutter function (ICG). Electronic shutter function can always keep output voltage constant that varies with intensity of lights. Features Include:

- Number of Image Sensing Elements: 3648 elements
- Image Sensing Element Size: 8 μ m by 200 μ m on 8 μ m center.
- Photo Sensing Region- High sensitive PN photodiode
- Power Supply Voltage: 3.0 V (min)
- Internal Circuit: CCD drive circuit
- Package: 22 pin CERDIP
- Function: Electronic shutter, Sample and hold circuit

Characteristic	Symbol	Min	Typ.	Max	Unit	Note
Sensitivity	R	110	160	—	V/lx·s	—
Photo response non uniformity	PRNU	—	—	10	%	(Note 2)
Register imbalance	RI	—	—	3	%	(Note 3)
Saturation output voltage	V _{SAT}	450	600	—	mV	(Note 4)
Dark signal voltage	V _{MDK}	—	2	5	mV	(Note 5)
Total transfer efficiency	TTE	92	95	—	%	—
Dynamic range	DR	—	300	—	—	(Note 6)
Saturation exposure	SE	—	0.004	—	lx·s	(Note 7)
DC power dissipation	P _D	—	25	75	mW	—
DC output signal voltage	V _{OS}	1.5	2.5	3.5	V	(Note 8)
Output impedance	Z _O	—	0.5	1.0	k Ω	—
Image lag of electronic shutter	V _{LAGICG}	—	—	10	mV	t _{INT} =100 μ s

Figure 3.2.12: Toshiba TCD1304 Characteristics

Chapter 4: Standards and Constraints

4.1 Standards

Standards in engineering documentation play a critical role in ensuring quality, reliability, safety, compliance, and efficiency throughout the lifecycle of engineering projects and products. Standards establish guidelines that ensure all engineering documentation follows a consistent format, structure, and level of detail. This consistency helps in understanding and using the documentation correctly. A standard is a formal technical document for generally accepted products, processes, procedures, and policies. Standards are not mandatory by law unless adopted as a code or regulation, however they impact various aspects of our life and are an integral part of every design.

Engineering standards provide a common language and format that engineers, designers, manufacturers, and users can understand universally. This facilitates effective communication across different teams and disciplines. Many engineering standards include safety guidelines and regulations that must be followed to ensure that products or systems are safe for use. Adhering to these standards reduces the risk of accidents or failures. Following established standards streamlines the design, manufacturing, and testing processes. Engineers can leverage existing knowledge and best practices, reducing the time and effort required to develop new products or systems.

Five key players in the development of standards include the American National Standards Institute (ANSI), the National Institute of Standards and Technology (NIST), standards developing organizations (SDOs), government bodies, and consortia. ANSI serves as the official coordinator for standards development organizations in the USA, publishing a wide range of standards such as basic guidelines, design specifications, management systems criteria, processing methods, product requirements, and testing

procedures. These standards are crucial in the design and construction of our robot, ensuring compliance with various regulations essential for creating a functional product. Specific standards for robots provide standardized terminology and information, facilitating easier knowledge sharing among stakeholders.

ANSI

ANSI stands for the American National Standards Institute. In the context of engineering, ANSI plays a pivotal role in developing and promoting voluntary consensus standards for a wide range of industries and disciplines within the United States. These standards cover various aspects of engineering, including dimensions, performance criteria, safety guidelines, and testing methods for products and systems. ANSI standards are developed through a consensus-based process that involves stakeholders from industry, government, academia, and consumer groups. They aim to establish uniformity, reliability, and interoperability in engineering practices, ensuring that products are safe, compatible, and effective for their intended use. ANSI standards are widely adopted across industries to facilitate communication, improve efficiency, and meet regulatory requirements, both nationally and internationally.

Robotics and Automation Standards

ANSI/UL 4600

ANSI/UL 4600 is the standard that is used for the standard of safety for the evaluation of autonomous products. It is a standard that we should definitely be following considering that we aim to make ALiCE autonomous. This standard mentions certain item operation safety related issues which we'll go over and explain how it affects our project.

a) Operation of Autonomous items in potentially unstructured environments

In our situation, the beach is possibly considered an unstructured environment, however, the standard claims that we are able to operate in a potentially unstructured environment as long as it is disclaimed. How ALiCE tends to move its way through the rough and unlevelled area of the beach is with the use of wheels that are different from normal ones. The wheels we tend to use allow us to navigate in off-road situations much easier than normal wheels. Also the way it would figure out how to navigate its way through an unstructured environment is with the help of our lidar puck scanning the area and giving back said info to our rover.

b) Operation with potentially inaccurate, incorrect, incomplete, or misleading data provided by sensors

With the use of a lidar puck as our sensor, the lidar puck should be more than capable of giving accurate data that will be provided to our rover. Even if the lidar puck fails to give accurate data, there will be proximity sensors attached to ALiCE that would work as a failsafe.

c) Potential defects and failures of hardware and/or software in the item, data collection functions, data processing functions, communications, engineering support systems, tools, and infrastructure support

Over the span of senior design I and senior design II, we will be working on the hardware and the software for all that was listed. When it comes to the point when our design of ALiCE will be close to completion, we will be testing and checking for any and all types of potential defects and failures of hardware and/or software in order for our design to be considered completed. Not only will we be testing during the final stages of our design, we will also be testing throughout all stages of the design to make sure there is nothing wrong with our design.

- d) Human contributions to potential risk, including occupants, pedestrians, other road users, non-road users, cargo handlers, maintainers and inspectors. This includes act of omission and commission; accidental and malicious physical acts; and human roles in creating as well as mitigating risk

Since the location of ALiCE would only be in a beach environment, there would not be a lot of road users, cargo handlers, maintainers and inspectors. The only human contributions towards risk would mainly be just pedestrians. ALiCE's way of avoiding colliding with humans is with the combined components of the lidar puck and the rover. The lidar puck will determine the position of the human and if it becomes too close it will notify the rover and the rover will then begin to make adjustments in order to avoid colliding with the human or any other kind of occupant.

- e) Lifecycle considerations, including design data collection, engineering data management, tool qualification, design, implementation, testing, other validation, field data collection, operations, maintenance, updates, upgrades, and retirement. Lifecycle considerations also encompass potential changes to the environment which may affect odds, changes in object types, changes in behaviors, etc.

One of the main considerations we have towards ALiCE's lifecycle, is having all our hardware covered to prevent any damage from the weather such as sun, rain, and wind causing the sand to land on and damage our components. It should also protect the hardware from any of the wildlife that could potentially destroy or mess with our hardware. We also have gathered the info we need for all of our components to be able to verify how we should be able to keep all of our components safe and increase the lifecycle expectancy to as long as we can. Some changes to the environment we plan on figuring out how to deal with includes changing tides that could lead to the water reaching ALiCE or the opposite effect in which the distance the water covers decreases.

- f) Ability to use a heterogeneous approach to arguments, including use of diverse standards to support safety (e.g., use of different but acceptable functional safety standards for different item subsystems).

One of our heterogeneous approaches is the approach we use when it comes to our object detection. We have the lidar puck, which is the main way of detecting objects that should be able to map out the area and let our rover know where it should go. Now if something were to happen and the lidar puck did not pick something up that is approaching the rover, we will have proximity sensors installed as a failsafe that when an object is picked up by the sensors, the rover will stop automatically.

Standard for Robotics and Automation: IEEE 1872-2015

IEEE 1872-2015 or Standard Ontologies for Robotics and Automation is a core ontology describing general concepts, relations and axioms of robotics and automation. This standard is intended to be a reference for knowledge representation and reasoning in

robots. Included are general concepts and their definitions, attributes, constraints, and relationships. IEEE 1872-2015 is composed of a core ontology called CORA, proposed by the working group (WG) Ontologies for Robotics and Automation (ORA) and sponsored by the IEEE Robotics and Automation Society. Published on April 10th, 2015, and ANSI approved on August 5th, 2016, the purpose of this standard is to provide both a unified way of representing knowledge and a common set of terms for sharing knowledge across humans, robots, and artificial systems. Some aims include providing methodology, terminology, defining concepts in robots, knowledge representation, and facilitating the transfer of information among robotic systems. This standard is important for our design as we are aiming to build an autonomous robot which will interact with humans. The standard makes it easier for knowledge and information to be shared about robots not only amongst humans but for interactions between robots and humans. The standardized knowledge of robotics and automation allows ideas, designs, and data to be shared amongst large groups without information being lost or confused.

Optical Standards - U.S. Standard MIL-PRF-13830B

This standard describes surface quality by identifying a “scratch” number, any marking or tearing of the surface, followed by a “dig” number, a small rough pit or spot in the surface. This is based on calibration and quality assurance inspection standards widely used in the optical industry. The scratch number is an arbitrary number scale used to describe the brightness of a scratch on the lens, lower numbers being better. It also covers fractures and edge chips on a lens. The purpose is to define the allowable defects in a lens or coating or on the surface of an optical component. Dig numbers are the diameter of a pit or spot, specified by 1/100 mm. An example would be a lens that is rated 80-50, would have a surface dig somewhere on the lens of 0.5 mm in diameter and one with 80-20 would have a dig of 0.2 mm in diameter. The standard will only allow one “dig” of that maximum stated size for every 20 mm of lens diameter. The scratch number is measured by method of comparing to a calibrated sample standard by visual inspection under dark-field illumination conditions. This “by-eye” matching can lead to different evaluators scoring lens either higher or lower depending on what is observed. The evaluator is looking at each lens and matching the brightness of the two surfaces by eye. It is not a measure of the size of the scratch but the visibility of the scratch. The scratch standards as described in “Surface Quality Standards for Optical Elements (scratch and dig) Drawing C7641866” (Revision R as of 2010). The prototype calibration samples are kept at Picatinny Arsenal in New Jersey. They follow the order of (80, 60, 40, 20, 10), there is a pair for each number, one defining the maximum allowable visibility and the other defining the lowest allowable visibility to fit the criteria for each number. The military and its vendors can use these prototypes or working copies calibrated from them. The private sector relies on the working copies calibrated from the original prototypes costing several thousands of dollars, these can vary in quality from maker to maker but are close enough to be used as a standard. For this reason, it is important for a commercial supplier to include a surface quality inspection specification manufacturer name for the optical component being compared.

The ISO (International Organization for Standardization) is a worldwide federation of national standards bodies. They work to prepare international standards through technical committees. Each member represents a different technical interest on the committee, and they work with international organizations, governmental and non-governmental entities. Unlike MIL-PRF-13830B, ISO 10110-7 is a more quantitative method to characterize scratches and digs on an optical element. It specifies surface quality based on the physical sizes and frequency of surface defects. MIL-PRF-13830B, can be a more economical and faster method to characterize surface imperfections but ISO 10110-7 is a more precise method to identify these blemishes if it is required. This method is more time consuming because it requires the use of a microscope with strong enough magnification to identify all sized surface defects. Many measurements are required to image the entire sample and to visualize these requires a small field of view. This standard does not make a difference between scratches and digs, treating both as surface imperfections. It will indicate the allowed number of imperfections and equate a grade number to each optical element defined by the square root of the area of the maximum allowed imperfection. This measurement is known as the dimensionality measure, but ISO also can use the visibility method identical to MIL-PRF-13830B. The benefit is that they can both be used interchangeably and if the need for a high-precision application arises, the use of ISO is there but if application is not as strict, the more expedient and cost effective method of MIL-PRF-13830B can be used.

Laser product Standards (LiDAR)

The industry guidelines related to this project include: General requirements (29 CFR 1910.132), along with the eye and face protection (29 CFR 1910.133) requirements. There are additional voluntary guidelines which are provided by the American National Standards Institute (ANSI). The ANSI guidelines related to the project are: Safe Use of Lasers (Z136.1), Recommended Practice for Laser Safety Measurements for Hazard Evaluation (Z136.4), Safe Use of Lasers in Educational Institutions (Z136.5), Safe Use of Lasers Outdoors (Z136.6). These are some of the safety standards required for operation of a class 4 laser which is the required class to create plasmas for the LIBS system project. These standards will be adhered to to the best ability of the group to ensure the safety of the group members and those who will be around the laser while in operation. Using optical lasers falls under the OSHA standards for laser hazards. The State of Florida does have some regulations and standards for the use and manufacturing of lasers as well. High power lasers (classes 3b and 4) fall under the jurisdiction of the Florida Department of Health in the Bureau of Radiation Control. The Bureau of Radiation Control oversees and registers many different sources of radiation emissions. These include Ionizing Radiation Machines (or X-ray machines), Radioactive Materials, Radiologic Technology, Environmental Radiation Programs, and Laser Radiation. The Florida Department of Health Bureau of Radiation Control has registered over 1700 lasers within the state. This laser will not be used on humans for any medical reason.

Lasers are classified according to their ability to cause harm. This factor, referred to as the accessible emission limits (AEL) is calculated using exposure time, laser wavelength,

laser power, amongst other factors. Non-class 1 laser products may be dangerous, causing eye injuries, skin hazards, and fire hazards due to laser radiation. Classes of lasers include class 1, class 1M, class 1C, class 2, class 2M, class 3, class 3R, class 3B, and class 4. International standard IEC

60825-1 was published May 14th, 2014 and prepared by the IEC technical committee 76: optical radiation safety and laser equipment. IEC 60825-1:2014 is applicable to the safety of laser products emitting laser radiation in the wavelength range 180nm to 1mm. A laser product may consist of a single laser with or without a separate power supply or may incorporate one or more lasers in an optical, electrical, or mechanical system. The objective of IEC 60825-1:2014 is to introduce a classification system for laser and laser products within the wavelength range 180nm – 1mm to both aid in hazard evaluation and determine user control measures. This standard establishes requirements for manufacturers to supply information so the proper precautions can be taken. This information includes warnings of hazards associated with radiation from laser products and how to reduce the possibility of injury. This edition includes updated accessible emission limits for class 1, 1m, 2, 2m, and 3R of pulsed sources.

Communication Standards

Communication standards for digital communication may include the RS-232, RS-422, and RS-485 standards. The LIBS system may use one of these communication standards to communicate with external devices or machines. These standards describe the voltage logic levels and speeds that are expected to be used by devices to communicate with one another. The voltage levels described in this standard indicate the voltages used to indicate a logic high and logic low signal. The speed at which data is transmitted is also listed by the standard. For the LIBS system this will likely be abstracted away via the digital controller, or communication protocol chip. However it is important to be aware of what communication standard is being used in the system. Without understanding the voltage logic levels and communication speeds used in the system, the ability to provide forward compatibility for new devices could be limited. The MCU specifically uses RS-485 for UART communication.

Portable and Rechargeable Battery Standards

When it comes to batteries, there are a lot of standards so it is important to know about which battery we plan on using and what standards apply to that battery. The first thing we should talk about is the standards for the general battery. The table below will talk about specific standards for the general battery that we believe is important to know about

Table 4.1: General Battery Standards

Standards	Description
-----------	-------------

IEC 60050	Vocabulary about electronics and technology relating to batteries
IEC 600086-1	Talks about Primary batteries in general
USNEC Article 480	How to store batteries
ANSI C18.2M	General and specifications about portable rechargeable cells and batteries
UL 2054	Testing for the safety of commercial as well as household battery packs

After talking about the general standards it is best to talk about the standards that relate to the batteries we plan on using. The three main batteries we are considering for now are nickel metal hydride, nickel cadmium, and lithium batteries, so it is important to know about the standards that relate to them. The reason why is that those standards talk about the specific ways of safety operation, electrical requirements, technical specifications, and many more. Written below is a table that talks about the standards for each one.

Table 4.1.2: *Battery Standards*

Batteries:	Nickel Metal Hydride	Nickel Cadmium	Lithium
Standards:	IEC 61436	BS EN 1175-1	BS 2G 239
	IEC 61809	BS EN 2570	BS EN 60086
	IEC61951	BS EN 60285	02/209100
			BS EN 60086

The table above only lists which standards apply to which type of batteries, so we will now talk about the important standard for each one. The three standards that were listed for nickel metal hydride mainly talks about secondary cells and batteries containing alkaline. For nickel cadmium, BS EN 2570 spoke about the technical specifications of the battery which is important to know if we plan on using said battery for our design. For lithium, the BS EN 60086 is very important as it discusses the safety standards for lithium batteries, which is valuable to know about if we plan on including it in our design.

ANSI for Portable Rechargeable Batteries

ANSI C18.2M is divided into two parts, part one covering general information and specifications, and part two, which covers safety standards. Both standards are developed and published by the National Electrical Manufacturers Association (NEMA) while processed and approved for submission to ANSI by the American National Standards Committee. ANSI C18.2M Part 1 is applicable to nickel cadmium, nickel metal hydride and lithium-ion portable rechargeable cells and batteries. This standard contains information addressing battery dimensions, terminals, standard charge methods, polarity, and standardized performance and mechanical tests which the specifications in part two are based on. This standard also specifies the designation for secondary batteries, they must be designated by a number, followed by a letter, then by a sequential number. The first number represents the nominal voltage, the letter represents the type (H: nickel metal hydride, I: lithium ion, or K: nickel cadmium), while the final number is assigned based on the battery's physical dimensions, terminal configurations, and performance variables.

Soldering Standards

The J-STD-001 is a standard that is issued by the Institute for Printed Circuits (IPC). The point of the J-STD-001 standard is to talk about what is established as the best soldering practices. The reason why this standard is important is because it would help us guarantee that the product we design will have the highest quality as well as reliability in specific weather conditions. This is something that we should best follow considering that our design is going to operate in the beach in which it is susceptible to multiple weather conditions, good or bad. There are a few main important requirements for soldering and they are as follows:

1. It is important to keep the area clean to prevent contamination of materials, tools, and surfaces
2. Heating and cooling rates should be the same as the standards from the manufacturer
3. The wire stands should not have any kind of damage and the solder must wet the tinned area of the wire
4. Both the soldering and cleanliness aspects should be inspected before the applying of the coating and stacking
5. Soldering errors should be reworked or scrapped
6. Visual inspection should be performed using automated optical inspection as well as automated x-ray inspection

The picture below is an example of soldering and it would be best for us to make sure that ours follow the correct way in order to give us the best reliability and quality.



Figure 4.1.3: Soldering Examples

4.2 Design Constraints

When it comes to creating a new project or some kind of new design, one of the most important factors that should be taken into consideration even during the starting process is design constraints. It is very relevant for those who are working on the project or design to figure out what constraints they should have, whether its economic, environmental, social, political, ethical, health and safety, manufacturability, etc. The more we are aware of their constraints, the easier it is for us to come up with a plan that meets the constraints we have. What is written below in the sections is the multiple design constraints that tie in to our project, and how we plan on addressing the constraint.

Time Constraint

The main constraint that we as a group realized was none other than the time constraint. In the beginning of this class we came up with a good amount of ideas but the main reason why most of our ideas were scrapped was because we believed it would not be realistic for us to achieve that idea in the amount of time we were given. Once we settled on an idea that we believed was achievable (ALiCE), the first thing we discussed as a group was what would be the best way for us to space out the time we have in order to make our design a reality. We came to the conclusion essentially very similar to how senior design I and senior design II are set up, in which we would spend most of our time in senior design I to research and come up with a plan on how to design and implement ALiCE and then during senior design II, we would then begin designing ALiCE, then

start testing each individual hardware component to see if they are functional, combine all working hardware components to where we planned on having them, and then lastly, begin testing ALiCE and making adjustments based on said test. We also believe that it is best for us to get started on the design phase as soon as possible so if we have enough time, it would be in our best interest to start designing during senior design I to give us better odds of completing ALiCE.

There is one more time constraint that relates more to ALiCE than us as a group. The time constraint is none other than the battery life. There are a lot of components in play that require charge in order to function, so it would be best for us to have a battery that is capable of giving ALiCE a decent enough operation time for ALiCE to have an effect on the environment. It would not be wise to have a battery that is only capable of keeping ALiCE up for 30 minutes or less because the beach would barely end up getting clean if we have to keep charging the robot every 30 minutes.

Economic Constraint

During the course of senior design I, it was heavily suggested for groups to have a sponsor to help provide money, ideas, or both for the groups, unfortunately for us we were not able to secure a sponsor. What that means for us is that we are limited in our budget. The reason for that is because all parts and components that we would need for ALiCE, we ourselves would have to pay for it (unless we are borrowing or we already own it). This would mean that we would have to do more extensive research on all the parts and components we need before we actually purchase it. We can not afford the mistake of purchasing expensive items that we may not end up using or may not end up working out. The main thing we need to take into consideration is that we are 5 college students and most of us are only working part time jobs so we do not have excess money to be spending. Luckily for us we were able to borrow the robotic arm from mecademic robotics or else we would have to come up with a cheaper alternative.

Ethical Constraint

Since ALiCE's purpose is to help better the ecosystem of the beaches, it makes sense for our design to have some ethical constraints. One main constraint is the safety of all living things, primarily humans and wildlife. Ensuring that ALiCE does not pose any threat to the beachgoers and wildlife in its operational area is paramount. To achieve this, we have integrated a lidar puck that continuously monitors ALiCE's surroundings. The lidar puck sends real-time information to the rover, enabling ALiCE to navigate and move out of harm's way when an obstacle is detected. In the unlikely event of a lidar puck failure, we have additional proximity sensors installed on the robot. These sensors act as a secondary safety mechanism, detecting objects in ALiCE's path and automatically stopping the rover to prevent any collisions.

Beyond safety, another critical ethical constraint involves respecting the privacy of people on the beach. While our robot is equipped with a camera, we have taken measures to ensure that it does not record or capture images of individuals without their consent. The camera's sole purpose is to distinguish between trash and non-trash objects, aiding in

ALiCE's primary function of beach cleanup. This approach ensures that the privacy of beachgoers is maintained while allowing ALiCE to perform its environmental duties effectively. Ethical considerations also encompass the data handling practices of ALiCE. Any data collected by the robot, whether it pertains to the types and locations of trash or the robot's operational parameters, is managed with strict adherence to data protection regulations. We ensure that no personal or sensitive information is gathered, stored, or processed by ALiCE, reinforcing our commitment to ethical data practices.

Additionally, our commitment to ethical design extends to minimizing the environmental impact of ALiCE itself. We are dedicated to using environmentally friendly materials and ensuring that ALiCE's operation does not contribute to pollution or ecological disruption. This includes designing the robot to be energy efficient and exploring the use of sustainable power sources, such as solar panels, to reduce its carbon footprint.

Environmental Constraint

Environmental constraint is an important constraint to use because the location our design desires to operate in is on the beach. Since we live in Florida in which it is always very sunny and rains very often, this constraint is something we need to be sure that we can have as much control on it as we possibly can. The sun and the rain as well as the wind can cause some problems for ALiCE. If it's too hot it can possibly melt some of the components as well as overheat the battery, causing it to operate in less time than usual. During the rain it can damage the components and it can also make the components short circuit. The wind is not that significant, but it can carry the sand and end up placing sand inside or components which can lead to our components possibly worsening over time. The solution we have for the weather is enclosing the pcb and the battery so that they can not be exposed to the weather. As for the robotic arm, since it needs to pick up the trash, the only cover we can provide for it is a roof so it can at least lessen the risk of the weather. The camera and the lidar puck will be on top of the roof so those two components would be at the highest risk of the weather, but as long as we are not constantly putting ALiCE out in bad conditions, those components should be fine.

Chapter 5: Comparison of ChatGPT and Other LLMs

5.1 Introduction

This chapter evaluates the pros and cons of ChatGPT in the context of our ALiCE (Autonomous Litter Collection Equipment) project. We will examine how AI can contribute to the development of ALiCE, highlighting both its benefits and limitations. Additionally, we will provide case studies to illustrate the practical applications and challenges of using AI for this project.

5.2 Pros of AI Language Models for ALiCE

Artificial Intelligent tools, such as ChatGPT and Gemini, are incredibly helpful in the design and development of ALiCE. AI helps lay out the skeleton of the project in which we can use and build upon. We can use AI in assisting us in ideas of improving ALiCE and using it to troubleshoot our problems. We can use ChatGPT to generate design concepts, explain coding algorithms, and organize our workflow so that we can meet deadlines and focus on implementing and testing ALiCE.

Design and Development Support

AI language tools are incredibly valuable in supplementing the design and developmental phases of the project. We utilize them as idea generators to bridge the gaps in our design and identify enhancements for ALiCE. When provided with clear instructions, goals, and constraints, ChatGPT can outline the foundation for the robot, offering us a framework to build upon. Here, we evaluate the pros and cons of artificial intelligence, exploring their effectiveness and limitations in the realm of engineering.

It is important to be aware of the limitations of AI tools and know when to use it and when it is not as accurate. Since AI tools pull from everything on the internet, it is a random generated source that we cannot rely on. These AI tools are also simplified algorithms that cannot perform more complex mathematical equations which would need to be completed by hand.

Case Study 1: “What are good lenses to use for a spectrometer?”

As referenced in the Appendix Case Study 1, ChatGPT provides multiple lens options that are general recommendations. It fails to target options that we could potentially use or consider in this project specifically. ChatGPT gives a brief overview of each lens and what it is used for. We can use it as our base of choosing some options but we would need to do additional research to gain more information about these lenses and see which one fits in our design as well as our budget.

Comparing Gemini’s results with ChatGPT, Gemini focuses on two specific lenses providing more information including the description and how each lens would work with different wavelengths of the spectrometer. In addition, Gemini provides specific examples of lenses that can be used in spectrometers with pictures and diagrams. Gemini showcases general options so additional research would need to be completed to decide which lens to use. Please reference Case Study 1 in Appendix B.

Case Study 2: “What microcontroller is more compatible with the raspberry pi 4?”

Just like our first case study, ChatGPT gave the most compatible microcontrollers from a general view. It lacks the capability to know the full extent of our project to provide the most compatible microcontroller with a Raspberry Pi for our project. ChatGPT gave useful tips and information as to include a “Key Considerations” section when choosing a microcontroller. However, we still can’t rely on ChatGPT to choose a microcontroller since it only provides a brief overview of each one.

Something that Gemini does that ChatGPT does not is include outer sources into the results. In the search results, Gemini provides suggestions to consider when choosing a

microcontroller and two examples. For example, Gemini recommends the Raspberry Pi Pico and describes “it is also programmable in C++ and MicroPython” (Gemini, 2024) and includes the website link that the AI tool pulled it from, “Google Search found similar content like this:...” (Gemini, 2024). The link will take you to the direct page which is super useful to view the entire article to do additional research.

Case Study 3: Raspberry Pi 4

For this case study, we asked Gemini to provide a description of a Raspberry Pi 4. It gave a brief overview of the microcontroller. It also provided a couple links to purchase the Raspberry Pi which ChatGPT generally doesn’t provide. Here, I would need to ask Gemini more specific questions to get a more concrete understanding, as well as, doing more outside research. Below is ChatGPT’s response.

Like Gemini, ChatGPT gives an overview of the Raspberry Pi using similar phrases. However, unlike Gemini, ChatGPT asks a question to the user if there is something more specific we would like to know giving it a more humanistic quality than Gemini. Here, we would need to ask ChatGPT more questions as well as search on Google to get a strong idea of what we are working with.

Programming Assistance

ChatGPT is an excellent resource for writing skeleton code and debugging the navigation system and robotic arm movements in our project. By leveraging the AI’s advanced programming capabilities, we can significantly reduce development time and receive valuable troubleshooting assistance. These AI tools not only help us optimize time complexity but also suggest efficient algorithms that are best suited to execute the tasks at hand. Additionally, ChatGPT can provide insights into best practices and coding techniques, further enhancing the overall quality and robustness of our project.

Case Study 4: “How can I program the meca500 robot arm to pick up objects with a raspberry pi?”

We can see how the AI model can create a step-by-step guide on how to potentially set up the robotic arm and any other advice on what we will need to move forward. (Check Appendix–B) It also provides a skeleton of code that we can follow and adjust to what works. This can expedite the programming phases tremendously and aid in potential excruciating debugging. However, we must take this information with a grain of salt as it could be inaccurate and unhelpful, thus, when working with these components, it is imperative to read the respective manuals. We cannot simply rely on AI to code the robot, there must be outside knowledge to fully be able to code the specific tasks the robot needs to perform.

5.3 Cons of AI Language Models for ALiCE

Despite the benefits of using AI, there are some downsides when using tools like ChatGPT and Gemini. It's important to note that this is a machine generated platform and we cannot fully rely on the accuracy of the information that these tools present to us. Additionally, these AI languages lack the understanding and creativity that we as human beings inhabit which leads to the tool not fully understanding what we are asking for. In addition, with more of these AI tools available to us, a question of ethical standards arise. Even though we use these tools to help with the backbone of our project, it's important that we must cite the sources as well.

Accuracy

A big limitation in using AI language models is that mathematical computations and complex calculations are usually incorrect and inconsistent. ChatGPT warns users at the bottom of the webpage, " ChatGPT can make mistakes. Check important info." This is a very accurate statement and we must be cautious when we are working with sensitive info that requires accuracy. It can also create false information about existing products or topics. For example, when asking about the specifications of certain parts suitable for our project, the data ChatGPT provides might not only be outdated, but wrong and fabricated as it copies the specs from another product. There are user manuals and datasheets dedicated to these parts on their respective sites that we must use. Usually when AI language models write code, there are many bugs associated with it. This can actually cause more harm than good sometimes as it can lead programmers on the wrong path if they assume that ChatGPT or other AI is reliable.

Ethical Concerns

The use of AI language models such as ChatGPT in our project or any other project, raises some ethical concerns that should be considered and addressed. As AI technology improves, it becomes much easier to transition our workload to the language models. However, this reliance on ChatGPT can inadvertently reduce human expertise and judgment in the project, as over-reliance on AI might lead to undervaluing human skills and critical thinking needed for innovative and ethical engineering. There should be a healthy balance between AI influence and human input. Another issue that may arise when relying on AI is lack of accountability and transparency. When we use AI generated suggestions for our project, it can become difficult to trace those decisions and hold whoever is responsible for those important project details accountable. AI should only be a supplementary tool and is not a member of the project. Transparency should be required whenever the use of ChatGPT or other models is involved, and maintaining clear documentation is essential in mitigating these ethical concerns.

Chapter 10 Administrative Content

10.1 Budget

Although there are no external sponsors for this project, the group was able to source a substantial amount of supplies for the design build through donations and “on loan” from one of the team members’ employers. The Mecademic Meca500 Industrial Robot Arm was an essential component that will allow the team to retain capital and focus on sourcing less expensive parts. In addition, the team will have access to 3D printing and a small machine shop for custom brackets/fixtures. The table below details the critical components necessary to have a successful design. For the remainder of the items that aren’t donated, the group will be dividing the cost of parts between the 5 members. This will help gain experience in finding cost-effective, off the shelf solutions throughout the design process. The group has agreed to set the budget to \$500, this will cover the supplies listed below with some cash flow to cover unforeseen expenses.

Table 10.1: Preliminary Design Budget

Sub-System	Budget	On Loan
Robotic Arm	\$15,000	Yes
Motors/wheels (Donor)	Donation	No
PCB/Electrical	\$200	No
LiDAR Puck	\$77	No
Raspberry Pi Camera	\$84	No
Prox Sensors	\$15	No
Enclosure	Donation	No
Battery/Power Supply	Donation	No
Misc wiring/connectors	Donation	No
Spectrometer Build	\$150	No
	Sub Total =	\$526

10.3 Distribution of Worktable

Below is a table that outlines each specific task that is expected from each group member in which it ensures a clear division of responsibilities. There are integration meetings to ensure that each section flows seemingly together and test the system as a whole.

Table 10.3: *Distribution of Worktable*

Computer Engineering	Responsibility	Tasks
Mary Bartlinski & Andre Reveles	Program Robot Arm	Program the robotic Arm: write a programming algorithm that will allow the arm to pick up trash and move
		Integrate the Camera: Collaborate with Mario so that the arm's movements align with the camera detections
		Simulate and Test: Simulate the program in a controlled environment and test on the beach
CREOL: Photonics	Responsibility	Tasks
Mario Puesan	Camera Vision and LiDAR and Spectrometer	Image Processing Algorithm: Develop and implement an algorithm that processes camera images and object detection
		Integrate the Arm: Work with Andre and Mary to ensure that the camera works simultaneously with the robotic arm
		Test: Test the camera in various lighting and different beach conditions
		Trash differentiation algorithm: create and test an algorithm that is able to use the spectrometer to split up the trash into different types
Computer Engineering	Responsibility	Tasks
Luiz Hernandez	Program the Self-Driving Car	Car Selection: Research and select parts for the base of the robot.
		Navigation System: Develop an algorithm that will allow the car to self drive on different surfaces and detect objects, making sure that it interacts with the camera and arm
		Testing: Test the car in different beach conditions making sure it's well structured

Electrical Engineering	Responsibility	Tasks
Sean Waddell	Supply Power to Robot and PCB design	Power System Design: Design a system that will allow power to flow throughout the whole robot selecting batteries and circuits that provides sufficient and efficient power to provide the most efficient battery life and performance
		PCB design: Design a PCB that will match our test microcontroller and have all the peripheral, memory, and other specified requirements.
		Safety and Testing: Implement safety features to prevent overheating and exhaustion as well as ensuring no water damage to the system. Test in different temperatures.

10.4 Milestones

Below are two tables that tell the meeting and event times that are required to create good time management between our group members and give us plenty of time for each step of the process. These milestones will lead us down the right path to success for our project. The first table will describe the time spread out for making the project idea and paper. The second table will describe making the prototype for the project.

Table 10.4: Project Initialization Milestone

Project Design				
Start Date	Planned Date	End Date	Task	Description
5/14/24	5/14/24	5/16/24	Recruitment	Members recruited: Mario Puesan (PSE), Mary Bartlinski (CPE), Andre Reveles (CPE), Luiz Hernandez (CPE), Sean Waddell (EE)
5/16/24	5/25/24	5/27/24	Brainstorming and Decision	Talking over zoom and deciding from everyone presented projects which one to do
5/16/24	5/30/24	5/31/24	Divide and	First 10 pages of our final

			Conquer Paper	document
5/16/24	7/4/24	7/5/24	60-Page Paper	60 pages made for our final draft of the paper
5/16/24	7/22/24	7/23/24	Final Paper	150 pages for the final draft of our project in Senior Design 1

Table 10.4.2: Project Prototyping Milestone

Project Prototyping				
Start Date	Planned Date	End Date	Task	Description
8/21/24	TBD	TBD	BOM	Making a BOM based of the parts we need with room to grow incase we need more or less for the project
8/21/24	TBD	TBD	System Design	Designing the system together with all the parts connected and first look at what the final design will accurately look like
TBD	TBD	TBD	PCB Design	Design a PCB to fulfill the requirements of our test PCB with all the required specifications needed to run our project
TBD	TBD	TBD	PCB Testing	Testing the PCB out to make sure it works as well or better than our test Microcontroller for our project
TBD	TBD	TBD	Prototype Completion	The completion of our Prototype and the end of Senior Design 2

Various tasks overlap as expected due to how the project is done with previous work being important to future work and some tasks are TBD. These milestone tables are a guideline for reference to make a successful project.

Appendix–A:

References:

https://www.researchgate.net/publication/224225487_Rechargeable_Batteries_and_Their_Management

<https://www.mathworks.com/discovery/slam.html>

https://www.yarp.it/latest/#yarp_learning

[Meca500 Robot Arm | Mecademic Robotics](#)

Appendix–B:

ChatGPT Case Study

Case Study 1: “What are good lenses to use for a spectrometer?”

“Choosing the right lenses for a spectrometer depends on several factors, including the specific application, wavelength range, resolution, and cost. Here are some general recommendations for good lenses to use in a spectrometer:

1. Achromatic Lenses

- **Description:** Achromatic lenses are designed to limit the effects of chromatic and spherical aberration.
- **Advantages:** They provide better focusing of different wavelengths (colors) of light, making them ideal for applications requiring high precision across a range of wavelengths.
- **Use Case:** Suitable for UV, visible, and near-infrared spectrometry.

2. Aspheric Lenses

- **Description:** Aspheric lenses have a more complex surface profile that reduces spherical aberrations.
- **Advantages:** They can improve resolution and focus light more accurately than traditional spherical lenses.
- **Use Case:** Beneficial in applications where high precision and minimal optical distortion are required.

3. Plano-Convex Lenses

- **Description:** These lenses have one flat surface and one convex surface.
- **Advantages:** They are simpler and less expensive while providing good focusing properties.
- **Use Case:** Commonly used in basic spectrometry setups, particularly where cost is a concern.

4. Biconvex Lenses

- **Description:** These lenses are convex on both sides.
- **Advantages:** They provide better performance than plano-convex lenses in applications where the object and image distances are equal or nearly equal.
- **Use Case:** Useful in compact spectrometers and other optical instruments where space is limited.

5. Fresnel Lenses

- **Description:** Fresnel lenses are flat lenses that use a series of concentric rings to focus light.
- **Advantages:** They are lightweight and can focus light similar to a much thicker lens.
- **Use Case:** Good for portable and handheld spectrometers where weight and size are critical factors.

6. Cylindrical Lenses

- **Description:** These lenses focus light into a line instead of a point.
- **Advantages:** Useful for applications that require focusing light along one dimension, such as slit imaging in a spectrometer.
- **Use Case:** Often used in spectrometers that require high sensitivity and precision in one dimension.

Material Considerations

- **Fused Silica/Quartz:** Excellent for UV and visible light due to its high transmission and low absorption.
- **BK7 Glass:** Common and economical, suitable for visible and near-infrared applications.
- **Calcium Fluoride (CaF₂):** Ideal for UV, visible, and infrared applications due to its wide transmission range and low birefringence.

Coating Considerations

- **Anti-Reflective (AR) Coatings:** Reduce reflection losses and improve transmission efficiency.
- **UV Coatings:** Enhance performance in ultraviolet spectrometry.
- **Infrared Coatings:** Optimize performance in the infrared spectrum.

Selecting the right lenses for a spectrometer involves balancing performance requirements with cost considerations. Achromatic and aspheric lenses are excellent for high-precision applications, while plano-convex and biconvex lenses offer good performance at a lower cost. Fresnel and cylindrical lenses provide unique benefits for specific use cases. Additionally, material and coating choices are crucial to optimize lens performance for the desired wavelength range.” (OpenAI 4.0, 2024)

“There are two main types of lenses used in spectrometers: collimating lenses and focusing lenses.

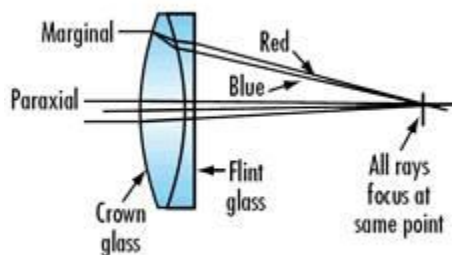
- Collimating lenses are used to collect light from the source and collimate it into a parallel beam. This is important because the diffraction grating, which separates the light into its constituent wavelengths, works best with parallel light.
- Focusing lenses are used to focus the collimated light onto the detector. The detector measures the intensity of the light at each wavelength, which is used to create a spectrum.

The specific type of lens that is best for a particular spectrometer will depend on the wavelength range of the spectrometer and the desired resolution. Here are some general guidelines:

- For spectrometers that operate in the visible and near-infrared (NIR) range, achromat lenses are a good choice. Achromat lenses are designed to minimize chromatic aberration, which is the tendency of a lens to focus different wavelengths of light at different distances.
- For spectrometers that operate in the ultraviolet (UV) range, quartz lenses are a good choice.
pen_spark
Quartz lenses transmit UV light well, while glass lenses absorb UV light.
- For high-resolution spectrometers, aspheric lenses are a good choice. Aspheric lenses have a more complex shape than traditional spherical lenses, which can help to reduce aberrations and improve image quality.

Here are some examples of specific lenses that can be used in spectrometers:

- **Achromat lenses:** These are a good general-purpose lens for spectrometers that operate in the visible and NIR range. You can find achromat lenses from various retailers.



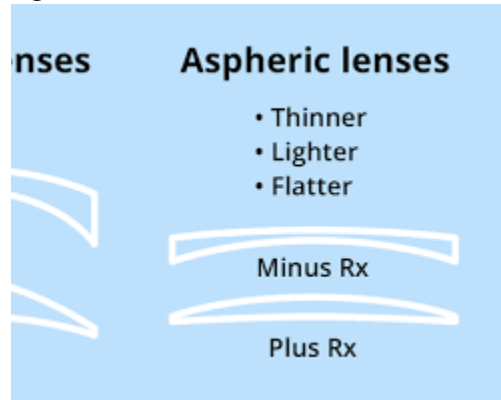
Achromat lenses

- **Quartz lenses:** These are necessary for spectrometers that operate in the UV range. You can find quartz lenses from various retailers.



Quartz lenses

- **Aspheric lenses:** These are used in high-resolution spectrometers. You can find aspheric lenses from various retailers.



Aspheric lenses

It is important to note that these are just general guidelines. The best way to determine the best type of lens for a particular spectrometer is to consult with the manufacturer of the spectrometer.

(Gemini 2024)

Case Study 2: “What microcontroller is more compatible with the raspberry pi 4?”

“The Raspberry Pi 4 is a powerful single-board computer that can interface with a variety of microcontrollers to extend its capabilities. Here are some microcontrollers that are particularly compatible and commonly used with the Raspberry Pi 4:

1. Arduino

- **Arduino Uno, Nano, Mega, etc.**
 - **Compatibility:** Easily interfaces with the Raspberry Pi via GPIO pins or USB.
 - **Advantages:** Large community support, extensive libraries, and well-documented examples.

- **Use Case:** Ideal for prototyping, sensor integration, and control applications.

2. ESP8266 and ESP32

- **ESP8266 (NodeMCU), ESP32**
 - **Compatibility:** Can communicate with the Raspberry Pi via Wi-Fi, serial communication, or GPIO.
 - **Advantages:** Built-in Wi-Fi and Bluetooth (ESP32), powerful and low-cost.
 - **Use Case:** Great for IoT applications, wireless communication, and edge processing.

3. Microchip PIC Microcontrollers

- **PIC16, PIC18, etc.**
 - **Compatibility:** Interfaces via serial communication (UART, SPI, I2C).
 - **Advantages:** Wide range of options, reliable and robust for industrial applications.
 - **Use Case:** Suitable for embedded systems, control applications, and automation.

4. STM32

- **STM32F0, STM32F1, STM32F4, etc.**
 - **Compatibility:** Can interface via various communication protocols (UART, SPI, I2C).
 - **Advantages:** High performance, extensive peripheral support, and scalability.
 - **Use Case:** Ideal for complex applications requiring high processing power and peripheral integration.

5. ATtiny Series

- **ATtiny85, ATtiny84, etc.**
 - **Compatibility:** Can interface via serial communication (I2C, SPI).
 - **Advantages:** Very small form factor, low power consumption.
 - **Use Case:** Suitable for small, low-power applications, such as simple sensors or actuators.

6. RP2040

- **Raspberry Pi Pico**
 - **Compatibility:** Native support from Raspberry Pi Foundation, easy to interface via GPIO and USB.
 - **Advantages:** Dual-core ARM Cortex-M0+ processor, programmable in MicroPython and C/C++.

- **Use Case:** Perfect for projects requiring tight integration with the Raspberry Pi ecosystem, educational purposes, and prototyping.

Key Considerations

When choosing a microcontroller to pair with the Raspberry Pi 4, consider the following factors:

- **Communication Interface:** Ensure the microcontroller can communicate via a protocol supported by the Raspberry Pi (e.g., UART, SPI, I2C).
- **Power Requirements:** Verify that the Raspberry Pi can supply the necessary power to the microcontroller or if additional power sources are needed.
- **Software and Libraries:** Check for available libraries and examples that facilitate integration.
- **Performance and Features:** Match the microcontroller's capabilities to the requirements of your project.

For ease of integration and community support, **Arduino** and **Raspberry Pi Pico (RP2040)** are excellent choices. For IoT and wireless projects, **ESP8266** and **ESP32** provide robust solutions. For high-performance applications, **STM32** microcontrollers are well-suited. Each of these options can be effectively paired with the Raspberry Pi 4 to extend its functionality and enable a wide range of projects.” (OpenAI 4.0, 2024)

“The Raspberry Pi itself is a single-board computer (SBC) with a central processing unit (CPU). It already has processing power and doesn't necessarily need another microcontroller for basic tasks.

However, if you want to add some specific functionality to your Raspberry Pi 4, here are some factors to consider when choosing a microcontroller:

- **Functionality:** What specific task do you want the microcontroller to handle? Microcontrollers are good for low-power tasks that don't require a lot of processing power, such as reading sensors, controlling LEDs, or communicating with other devices.
- **Communication Interface:** How will the Raspberry Pi communicate with the microcontroller? Some common communication interfaces include SPI, I2C, and UART. Make sure the microcontroller you choose has a compatible communication interface.
- **Development Environment:** What programming language and development environment are you comfortable with? Some microcontrollers are easier to develop for than others.

Here are two examples of microcontrollers that are compatible with the Raspberry Pi 4:

- **Raspberry Pi Pico:** The Raspberry Pi Pico is a low-cost microcontroller board that is based on the RP2040 microcontroller chip. The RP2040 chip is a dual-core ARM Cortex-M0+ processor that runs at up to 133MHz. The Raspberry Pi Pico

has a variety of built-in features, including SPI, I2C, UART, and ADC. It is also programmable in C++ and MicroPython.

- **Arduino Uno:** The Arduino Uno is a popular microcontroller board that is based on the ATmega328P microcontroller chip. The ATmega328P is an 8-bit AVR microcontroller that runs at 16MHz. The Arduino Uno has a variety of built-in features, including SPI, I2C, and UART. It is also programmable in Arduino C, which is a variant of C++.

These are just two examples, and there are many other microcontrollers that are compatible with the Raspberry Pi 4. The best microcontroller for you will depend on your specific needs. (Gemini, 2024)

Case Study 3: Raspberry Pi 4

“The Raspberry Pi 4 is a powerful single-board computer that can be used for a wide variety of applications. It is a popular choice for hobbyists, educators, and professionals alike. The Raspberry Pi 4 is the latest iteration of the Raspberry Pi series and offers significant improvements in processor speed, multimedia performance, memory, and connectivity compared to prior models.” (Gemini, 2024)



Figure 5.2.1 Case study #4 by Gemini, Google AI

“The Raspberry Pi 4 is a popular single-board computer developed by the Raspberry Pi Foundation. It's known for its versatility and affordability, making it suitable for various projects ranging from hobbyist electronics to educational uses and even some small-scale server applications. Is there something specific you're interested in or need help with regarding the Raspberry Pi 4?” (OpenAI 4.0, 2024)

Study Case 4: “How can I program the meca500 robot arm to pick up objects with a raspberry pi?”

“Programming the Meca500 robot arm to pick up objects using a Raspberry Pi involves several steps, including setting up the Raspberry Pi, communicating with the Meca500, and writing the control code. Here’s a step-by-step guide to get you started:”

1. Setting Up the Raspberry Pi

- **Install Raspbian:** Ensure your Raspberry Pi has the latest version of Raspbian installed.
- **Connect to the Internet:** Ensure your Raspberry Pi is connected to the internet for downloading necessary packages and updates.

Update Packages: Run the following commands to update your system:

```
sudo apt-get update
sudo apt-get upgrade
```

2. Install Required Software

Python: Ensure Python is installed. It is pre-installed on Raspbian, but you can update it using:

```
sudo apt-get install python3
```

PIP: Install pip for managing Python packages:

```
sudo apt-get install python3-pip
```

Mecademic Robot Library: You need the Mecademic robot library for Python. You can install it via pip:

```
pip3 install mecademicpy
```

3. Connect to the Meca500 Robot

- **Ethernet Connection:** Connect the Meca500 robot to your Raspberry Pi via an Ethernet cable. Assign a static IP address to your Raspberry Pi in the same subnet as the robot arm.
- **Robot IP Address:** Note the IP address of the Meca500 robot.

4. Write the Control Code

Create a Python script to control the Meca500 robot arm. Below is an example code to pick up an object:

```
import mecademicpy.robot as mecademic

# Define robot IP address
robot_ip = '192.168.0.100' # Replace with the actual IP
address of your Meca500

# Initialize the robot
robot = mecademic.MecademicRobot(robot_ip)
```

```
# Connect to the robot
robot.Connect()
robot.ActivateRobot()
robot.Home()

# Function to pick up an object
def pick_object():
    # Move to the pick position (replace with your
    coordinates)
    # Close the gripper
    # Move to a safe position
```

5. Running the Code

- Save the script as pick_object.py.

Run the script using the following command:

```
python3 pick_object.py
```

Additional Considerations

- **Calibration:** Ensure that the Meca500 is properly calibrated and the coordinates for picking objects are accurate.
- **Error Handling:** Add error handling in your code to manage exceptions and ensure safe operation.
- **Safety:** Ensure that the workspace is clear and the robot operates within safe parameters to prevent damage or injury.

(OpenAI 4.0, 2024).