ALiCS- Autonomous Litter Collection & Sorting

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***Abstract* — Beaches are riddled with new trash every day, ranging from plastic cups, beer bottles, and soda cans. ALiCS is an innovative engineering project aimed at cleaning these beach environments. This robot is equipped with a robotic arm, sensors, and a spectrometer, enabling it to detect, collect, and sort litter autonomously. This project combines custom software, machine learning, and environmental monitoring to deliver an effective solution for managing beach litter while minimizing manual intervention. ALiCS is designed to contribute significantly to beach conservation efforts through automation.**

***Index Terms* — Autonomous Robots, Brushless DC Motors, Image Analysis, Vehicle Driving, Spectrometry**

I. INTRODUCTION

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. ALiCS (Autonomous Litter Collection & Sorting) is designed to tackle beach litter by using an autonomous robot equipped with sensors, a robotic arm, a VIS-NIR Spectrometer, and a PCB control system. This robot navigates different terrains while avoiding obstacles and uses camera vision to detect trash, which the robotic arm then collects and places in designated bins. The spectrometer identifies recyclable materials, and the power system is built for efficiency and sustainability, housed within a protective enclosure.

The project's goals include collecting various types of debris, navigating the beach while avoiding obstacles, accurately identifying recyclable and non-recyclable items, and operating with minimal training. Advanced goals involve integrating machine learning, adding metal detection, developing a swappable battery system, incorporating solar panels, and enabling remote troubleshooting. Objectives focus on camera vision and machine learning for navigation, efficient trash collection, safety systems, and a robust enclosure design to withstand environmental elements.

Overall, ALiCS aims to inspire innovative environmental solutions by leveraging current technologies and applying creative development approaches.

II. SYSTEM COMPONENTS

The ALiCS robot combines multiple components, each serving a unique role in achieving our goal of autonomous beach cleanup. These components enable ALiCS to function autonomously, navigate beach environments, detect trash, and sort the waste efficiently.

A. Meca500 Robotic Arm

ALiCS is equipped with a Meca500 robotic arm from Mecademic Industrial Robotics, chosen for its precision and compactness, essential for the precise operations in outdoor conditions. The Meca500 is a compact, highly precise robotic arm with a position repeatability of 0.005 mm, ensuring it can accurately pick up small debris of various shapes and sizes. The arm's compact reach of 330 mm and weight of 4.3 kg enable easy mounting and operation in confined spaces, essential for maneuvering in beach environments. Mecademic's custom API further simplifies programming and implementation.

B. LewanSoul Mechanical Claw

The LewanSoul Mechanical Claw is an excellent choice for ALiCS due to its robust design, precision, and adaptability. Its sturdy metal construction provides durability, which is essential for handling various types of debris on beach terrains. The claw's high-torque servo motor allows it to grip objects securely, ensuring that items like cans, bottles, and other trash are firmly held and accurately placed in designated bins. Additionally, the claw's compact and lightweight build makes it suitable for ALiCS, as it minimizes weight on the robotic arm, reducing energy consumption and enhancing maneuverability. The claw's versatile design also allows for easy customization, making it possible to adapt the grip for different object sizes or shapes.

C. RaspberryPi 4 Microcontroller

The Raspberry Pi 4 stands out as one of the most powerful and flexible options available for the project. It features a quad-core 64-bit A72 processor running at 1.5GHz and includes 4GB of LPDDR4 RAM, ensuring robust processing capabilities. The raspberry pi comes with connectivity ports and is equipped with a built-in hardware decoder. The Raspberry Pi is a strong choice for ALiCE due to its substantial memory capacity and built-in camera port, enabling easy and efficient integration into the system. The board also offers extensive interfacing options with multiple pins and ports. These features make the Raspberry Pi 4 ideal as the second microcontroller unit (MCU) in our project. Its flexibility in handling camera data, transmitting information, and interfacing with other systems ensures that it meets our project's requirements effectively.

D. RaspberryPi Camera

A RaspberryPi camera module, trained using computer vision models, is used to detect common litter items like plastic bottles, cans, and glass bottles. Integrated with the robotic arm, this system will allow ALiCS to identify and target waste effectively. The Raspberry Pi Camera has seamless compatibility with the Raspberry Pi board and offers built-in driver support, making setup straightforward and ensuring optimal performance. Its high resolution is crucial for accurately detecting trash and debris on the beach and can adapt to varying lighting and distance conditions. Configurable in Python or other programming languages, it integrates well with the language chosen for the board's programming. The Raspberry Pi Camera is also lightweight and compact, minimizing added bulk or weight to the rover, and it's cost-effective, making replacements or additional units affordable.

E. RPLiDAR A1M8

For our autonomous design, we chose LiDAR as the primary navigation tool, supported by other sensors for redundancy. While cameras capture images to process environmental data, LiDAR uses pulsed laser beams to create 3D point clouds with precise distance measurements. LiDAR (Light Detection and Ranging) emits laser pulses to map environments in 3D. It calculates distance by measuring the time it takes for a laser pulse to travel to a target and return, creating a point cloud of data with attributes like intensity and reflectivity. This technique is highly effective, even in varying light conditions.

Time of Flight (ToF) is key for measuring distances in LiDAR. It calculates the time a light pulse takes to return after hitting an object. Direct ToF uses short light pulses for high resolution, while indirect ToF uses continuous modulated light. The formula

$$d = \frac{\Delta t \times c}{2} \tag{7}$$

(where c is the speed of light) determines distance. This results in detailed 3D maps that help ALiCS navigate accurately and detect obstacles efficiently.

G. VEVOR Beach Balloon Wheels

The main purpose of the wheels is to be able to drive and navigate through the sand of the beach. For that reason, we need wheels that have very good off-roading capabilities so that there are no issues with traversing through the sand. Another important factor was the size of the wheel because it is best to keep some distance from the ground to the base of our design so that way no sand can potentially kick up and land on the base and possibly damage our components. Putting all these factors into consideration, the VEVOR beach balloon wheels are the best choice. First of all, these beach balloon wheels were specifically made to help traverse on the beach, secondly they have a diameter of thirteen inches which is enough to keep the base off the ground, and lastly it has a decent price of about $120 for all four wheels.

H. 57BLF03 Brushless DC Motor

In order to move our device, we will need motors that are capable of rotating the wheels. With that in mind, the few factors that were considered for this motor choice was energy consumption, price, and torque. Torque is important because if the torque is not high enough, then the motor will not be able to spin the wheels to get the design moving, so for that reason, we desire a high torque. It is important for us to think about energy consumption for the fact that there will be four motors, so our power distribution needs to be able to supply enough power to all four motors without draining our power supply. The last factor to consider is of course, price, it is important for our small budget to consider that we will be purchasing four motors so if the prices were lower it would be more beneficial. When it came to the decision for the type of motor, we chose the brushless DC motor as opposed to the brushed DC motor and the stepper motor. The power usage for the three motors were around the same so that factor was not too important and the only difference in cost is that the brushless DC motor was a bit pricier compared to the other two. The reason why we settled on the brushless DC motor even with the price difference is because of the torque. The brushless DC motors are constantly reaching its maximum torque while the other two options do not reach maximum torque as often. When choosing the brushless DC motor options, the voltage was not an important factor to consider mainly because they were close in range from 12-24 volts. The main two things that were considered was once again price and torque. With that being said, we settled on the 57BLF03 brushless DC motor because it had high torque and only a slightly higher price compared to the other options that were looked at.

I. MP6541A Motor Driver

When it comes to using brushless DC motors, you need motor drivers to operate said motors. What motor drivers do is that they are able to take the voltage and current that the motor needs, and distribute it to the three phases of the brushless DC motor, this will allow us to write code to the motor drivers that can make the motors go forwards or backwards as well as adjusting the speed of the motors. When it comes to making the decision of which motor driver to purchase, there are three main factors. The first factor was the price, but most of the motor drivers ended up with very similar prices. The other two factors were the voltage and current limits of the motor driver. The voltage and current limit has to be higher than the voltage and current needed to power the motor, which was 24 volts and 6.6 amps. With those factors taken into consideration, we went with the MP6541A motor driver that can handle up to 40 volts and 8 amps which is more than enough for what we need. We will, of course, need four drivers, one for each motor. The motor drivers will be connected to the esp32 board, the power distribution board, and the motors.

J. HC-SR04 Ultrasonic Sensor

When thinking about our design, we decided that we should have a failsafe that stops ALiCS in place if something were to come too close to the object (besides the trash), so we decided that a sensor would be the best option. There were three types of sensors we looked at, ultrasonic sensors, passive infrared sensors, and active infrared sensors. The most important factor that was considered was close distance detection, the sensor should be able to tell how close the object is to it so that way we know when to stop the vehicle. The passive infrared sensor is only able to have waves travel from the sensor, meaning that it can not determine distance, so we decided not to use it. The other two options, active infrared sensors and ultrasonic sensors, both had the requirements we needed as well as similar voltages and prices, so we ended up choosing ultrasonic sensors due to familiarity with those types of sensors. Looking through the choices we considered for the ultrasonic sensors, the main requirement we are still looking for is the detection range, we only care for objects that are close to ALiCS because we already have different ways of detecting objects that are far away. With that in mind, we chose the HC-SR04 sensor for the fact that it has a detection range of 0.8 - 157.5 inches which meets our requirements while the other choices did not have a similar detection range.

III. PCB DESIGN

The ALiCS robot has multiple crucial roles that the PCBs need to fulfill to make the system fully run with expectations of our goals. This design will make it possible to have a centralized MCU for our system. These real time systems will have to be able to work properly without help from a user to make our robot fully autonomous. This system will also control our power in our robot. To make sure everything is stable and running properly. Our ALiCS design has three main PCB designs, the MCU board, which is the esp32 along with all its GPIO pins needed, the motor driver board, which has all the connections needed for four motor drivers to spin the motors, and the power distribution board which provides enough voltage to every component within our design.

A. MCU board

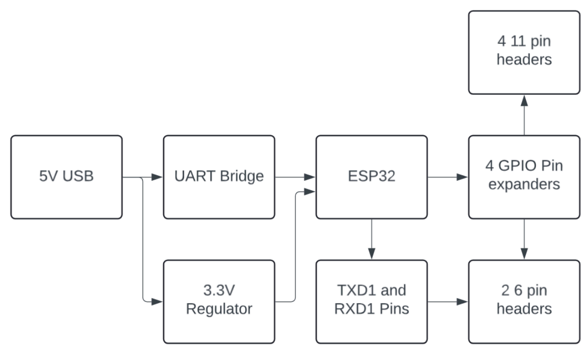

Fig 2: ESP32 Block Diagram

Our MCU board is a ESP32 WROOM and uses a 5V USB for power. This board is gonna be the main MCU that controls most of the systems on ALiCS including the driving and sensor controls. Now looking at the figure above we will go into details about what we will use the multiple amount of GPIO pin expanders for and what each of the pins from these expanders are for. First we need the GPIO pin expanders to communicate with the motor drivers because each motor driver requires an 11 pin header for itself. Then we have the two 6 pin headers which 8 of those pins are gonna be used for the ultrasonic sensors. Then another two pins will be used for communication with the spectrometer. Then the last two pins will be connected directly from the MCU which are the RXD1 and TXD1 used to communicate with the Raspberry Pi 4.

B. Power Distribution board

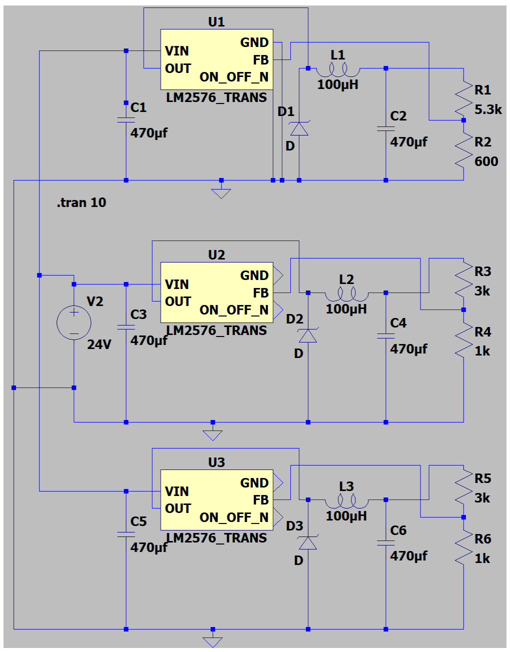

Fig 3: Voltage Regulator Circuit

The Figure above shows the circuit for our voltage regulators from our battery. The battery we are using for our system is two 12V batteries in series with 35Ah. So we are connecting this 24V battery to a 24V external regulator to keep a clean 24V throughout the system then going into this circuit above to be distributed throughout the system. The first voltage regulator on the top produces a 12V output we will use for our spectrometer light. The two outputs on the bottom both produce 5V however the voltage regulators limit us to 3A per a regulator so we need to use two of them to supply power correctly throughout the entire system. For the first 5V output we will be using it on our ultrasonic sensors and Vref on the Motor board. The next 5V will go to a USB to power our Raspberry Pi 4. We will also make use of the regulated 24V to power our Robot arm, spectrometer, and Motors for ALiCS.

C. Motor board

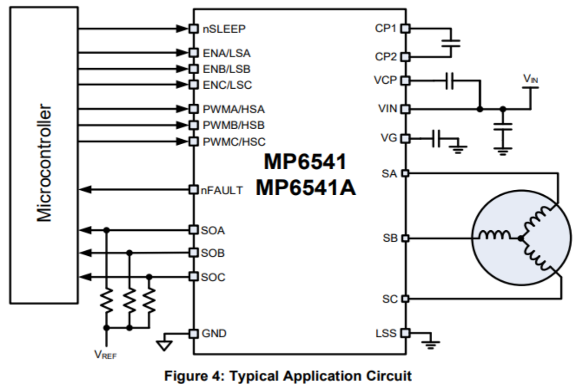

Fig 4: Motor Driver Circuit

The Motor board is the second board of our PCB design. This board is equipped with 4 motor drivers based on the figure above. This shows what each pin for the 11 pin header connects to on the motor driver from the ESP32. However on our motor driver board there are two extra pins making it a 13 pin header that connects the motor driver. These extra two pins are for Vin and for Vref. Then looking at the figure again you can see that SA, SB, and SC are the output pins that will control the motor from this motor driver.

IV. HARDWARE DESIGN

A. Spectrometer

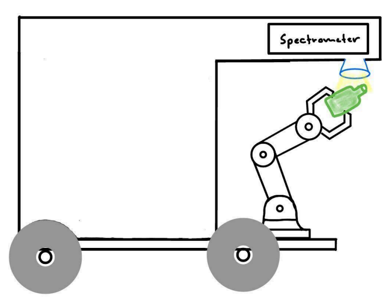

Figure 1: ALiCS spectrometer measuring sample.

ALiCS will be fitted with a spectrometer to analyze collected materials and determine their recyclability. Spectrometry refers to analyzing specific light spectra to identify material compositions. Our chosen spectrometer is based on the Czerny-Turner design, which features a reflective diffraction grating and two concave mirrors. The first, the collimating mirror, aligns the incoming light beam to interact uniformly with the grating surface. The focusing mirror then directs the dispersed light onto the image sensor. The Czerny-Turner configuration is known for being compact and versatile, delivering a compressed spectral field and effective coma correction for a specific wavelength. While it may have spherical aberration and astigmatism across wavelengths, it remains a reliable design for high-quality spectrographic analysis in compact spaces like ALiCS. In Figure 2, angles $\phi 1$ and $\phi 2$ are the diffraction angles of the two edge wavelengths after passing through the diffraction grating; they intersect the focusing mirror at *A* and *B*. $\sigma 1$, and $\sigma 2$ are the angles between the reflected light of the two edge wavelengths on the focusing mirror and the horizontal line. Finally, they gather on points *C* and *D* of the linear CCD. Using the diffraction grating formula,

$$d*\sin\theta = n\lambda \tag{1}$$

Where *d* is the grating constant, diffraction angle ϕ_1 and ϕ_2 can be calculated as:

$$d*(\sin(\alpha) + \sin(\phi_1)) = n\lambda_1 \tag{2}$$

$$d*(\sin(\alpha) + \sin(\phi_2)) = n\lambda_2 \tag{3}$$

Setting the diffraction order equal to one (n=1) and minimizing size (length) of the focusing mirror to reflect the two edge wavelengths according to the geometrical structure:

$$AB = x_2 * [\tan(\alpha + \phi_1) - \tan(\alpha + \phi_2)] \tag{4}$$

After reflection from the focusing mirror, the horizontal angle of the diffracted rays is changed by 2*θ as given below.

$$\sigma = \alpha + \phi - 2*\theta \tag{5}$$

The size of the image is calculated using the geometrical structure:

$$CD = AB - x_3 * [\tan(\sigma_2) - \tan(\sigma_1)] \tag{6}$$

Equation 6 shows the minimum length of the CCD detector surface. Based on the original configuration and using the equations (1- 6), all the necessary parameters to design the spectrometer can be determined.

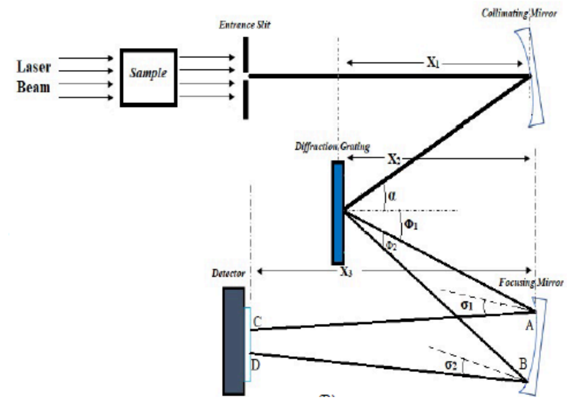

Fig. 2: Analysis of Spectrometer Imaging Plane

B. 3D Printing

During prototyping, we found leveraging 3D printing became a very essential tool in our design. 3D printing is often faster and more affordable than traditional prototyping methods, allowing us to quickly create and refine custom parts as we test different versions. Although our group didn't have much CAD experience we were able to self teach and spend over 100 hours learning, designing, and revising 3D printed parts to help bring our ideas together. This proved to be very cost efficient and allowed us to have rapid iterations in just a few short hours.

C. Enclosure

Since ALiCS will spend most, if not all, of its time collecting debris from the beach, we had to take the elements of the environment into consideration. The beach environment can have a significant impact on commercial products due to the combination of salt, sand, humidity, sunlight, and high temperatures. We implemented protective components to help mitigate these elements and incorporated specific design elements and materials to resist wear, corrosion, and damage.

For construction of our prototype, we decided to use 25mm Aluminum Extrusion due to its durability and modularity. Aluminum extrusions typically come with a modular design (e.g., T-slot profiles), allowing our group to easily assemble and reconfigure the structure by adjusting the components, adding brackets, or making structural modifications. This modularity is ideal for iterating on design and testing different configurations without the need for specialized tools. The aluminum is also very light in weight which will help preserve battery life. Lastly, aluminum extrusions thus provide a versatile, durable, and efficient solution, enabling easier design changes and better structural integrity, making them especially suitable for ALiCS prototyping.

D. Rover

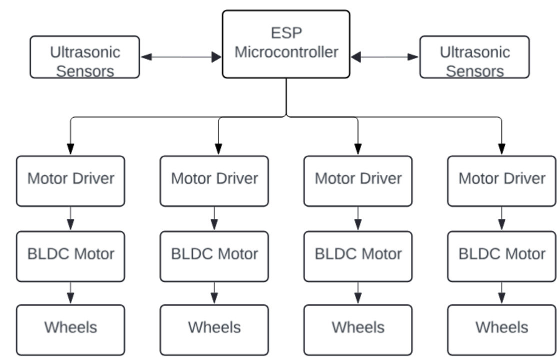

Fig 2. Diagram of the Rover Driver

Figure 2 depicts the hardware design of the components that allow ALiCS to traverse the beach environment safely. The ESP32 will be the brain that will communicate with the motor drivers and the ultrasonic sensors. The ultrasonic sensors will act as a fail safe to keep the rover from colliding with obstacles or humans. This is a safety protocol we felt was necessary while operating in public environments.

V. SOFTWARE ARCHITECTURE

The ALiCS robot integrates various components, each playing a crucial role in enabling autonomous beach cleanup. To achieve optimal accuracy and performance, these components must seamlessly interact and perform multiple tasks in real-time. The majority of the codebase will leverage open-source libraries to efficiently handle data manipulation. Below is a diagram of the Software concept.

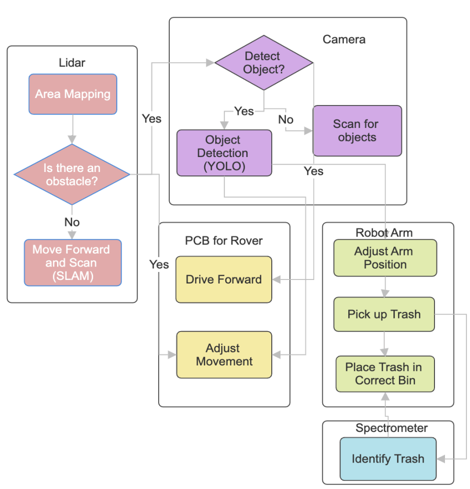

Fig 3: Software Diagram

A. ROS

ROS (Robot Operating System) is a comprehensive framework designed specifically for robotic applications, offering a robust set of libraries and tools for building and managing robots. As an open-source platform, ROS provides the flexibility to tailor its use and customize the robot's functionality to meet specific needs. It supports programming languages like C, C++, and Python, while also allowing integration with other software solutions. ROS is compatible with multiple operating systems, including macOS, Windows, and Linux, making it highly versatile. Developed and continuously improved by a community of developers, ROS is purpose-built for robotics. For ALiCS, we will utilize ROS to seamlessly integrate key components, including the robotic arm, claw, and LiDAR puck.

B. SLAM

A critical part of ALiCS is its ability to map its environment and detect obstacles. ALiCS uses camera and LiDAR sensors to continuously gather and update real-time data, allowing it to identify landmarks and distinguish trash from non-trash, including glass, aluminum, and plastic. SLAM (Simultaneous Localization and Mapping) enables ALiCS to build a map and localize itself within it. This method uses front-end data processing and back-end graph optimization. By using sensors to scan and gather environmental data, ALiCS identifies landmarks and estimates its position by comparing current data to the map. Lidar-based SLAM, known for precise distance measurements, will be implemented for effective mapping. Algorithms like iterative closest point (ICP) help refine positioning, allowing ALiCS to navigate smoothly, detect obstacles, and remember trash locations while ensuring stability and accurate arm positioning for debris collection.

C. YOLO

The camera serves as the 'eyes' of the ALiCS rover, detecting objects in real-time. You Only Look Once (YOLO) is a fast and accurate object detection system, ideal for ALiCS. YOLO frames detection as a single task, processing image pixels to object coordinates and class probabilities. It divides the image into an S x S grid, with each cell predicting object coordinates, size, and class. Detections are refined using Non-Max Suppression (NMS) to remove overlaps and low-confidence results.

YOLO's advantages include high-speed processing suitable for real-time use, direct training on full images, and a high recall rate for detecting true positives. For ALiCS, YOLO will enable object detection on the beach, helping differentiate trash from obstacles and aiding navigation by capturing images, processing video feeds, and guiding the rover's movement in real time. Implementation involves creating a dataset of trash and beach images, training YOLO, and integrating it with the camera for real-time detection. YOLO's simplicity and unified design make it ideal for this purpose.

D. A Algorithm – Global Pathing*

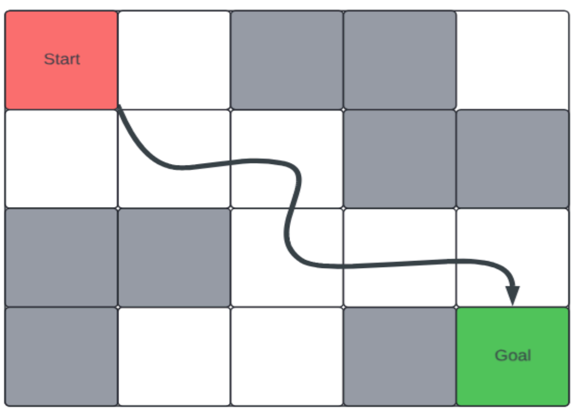

Fig. 4: A Model of A* algorithm

We chose the A* Algorithm for ALiCS because it excels in finding the most efficient path while navigating complex environments. A* creates a 2D grid map, enabling the robot to detect and avoid obstacles while finding the optimal route to its target, which in ALiCS's case is debris collection on the beach. Unlike simpler algorithms, A* combines the benefits of path cost and estimated distance, ensuring that ALiCS can quickly and accurately determine the best path to the goal while considering real-time obstacles. This feature is essential for ALiCS to navigate unpredictable beach terrains, making it a reliable choice for autonomous pathfinding and trash collection.

E. Arduino IDE

When it comes to writing code into the esp32, we will be using the Arduino IDE along with its esp32 packages. The main use of the arduino IDE is for the motors, there will be code written in the IDE to set up and connect the motors, as well as make them rotate. The code will also include the ultrasonic sensors, in which if an object is too close to the sensors, the motors will then stop spinning.

F. Software Class Diagram

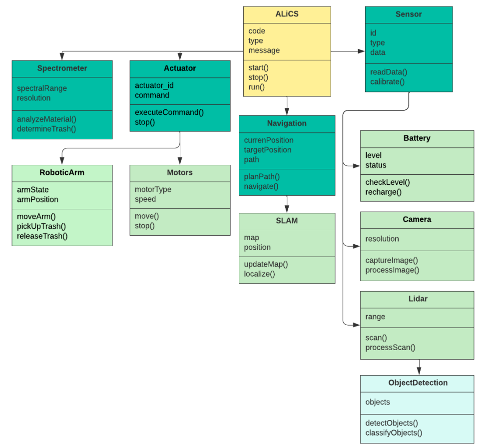

Fig. 5: Software Class Diagram

The class hierarchy begins with ALiCS as the parent class, or base class for all components involved. The Spectrometer class inherits from ALiCS and handles analysis of the objects to classify whether they are trash or not. This class can work hand in hand with the robotic arm class as it must detect if it's trash before collecting and storing the object. The Actuator class stems from the parent class as well and handles all actuators the robot contains, in this case the Meca500 arm and the motors. The robotic arm will perform trash collection as necessary, and the motors will control the movement of the rover as well as the speed. The Navigation class is responsible for the path planning and following, which stems into the SLAM class that is responsible for simultaneous localization and mapping, including map updates. The Sensor class contains all sensors used in the project, including the battery sensors which determine if ALiCS has low battery and needs a recharge, the Camera and Lidarclasses implement specific methods for their specific functionalities, and finally ObjectDetection, which handles the detection and classification of the objects located in the rover's environment. This diagram shows the inheritance relationships, key methods, and attributes of the classes involved in the ALiCS software.

VI. Conclusion

The Autonomous Litter Collection System (ALiCS) demonstrates an innovative approach to environmental cleanup through robotic technology. Specifically designed for beach environments, ALiCS integrates object detection, power distribution, material analysis, and precise control mechanisms to find, collect, and sort trash. The combination of an ESP-32-controlled navigation system with LiDAR mapping, ultrasonic sensors for obstacle avoidance, and a robotic arm equipped with an object-identifying camera, allows ALiCS to operate independently and efficiently. This project exhibits a scalable solution for environmental preservation, further emphasizing the potential of robotics in helping our societies.

VII. ACKNOWLEDGEMENT

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VIII. BIOGRAPHY

Mary Bartlinski is a Senior who intends to graduate Fall of 2024 with a degree in Computer Engineering BSCpE. She will begin an internship with the Office of Naval Research in November and will work with the Naval Air Warfare Training Center in Orlando. She is excited for what the future holds for her, whether that is going back for her masters or a full-time position.

Andre Reveles is a Senior at the University of Central Florida who intends to graduate Spring of 2025 with a Bachelors of Science in Computer Engineering and a minor in Finance. He is currently an intern and will begin his full time position as an engineer at MtronPTI in January of 2025. He is eager to leverage this project experience into future engineering endeavors.

Sean Waddell is a Senior who intends to graduate Fall of 2024 with a bachelor's degree in Electrical Engineering. Hoping to pursue a career in PCB designing and manufacturing. Planning to use the PCB designs on this project for experience into his future career.

Luis Hernandez is a senior at the University of Central Florida who intends to graduate with a degree in Computer Engineering in Fall 2024. He will begin to search for jobs related to his degree and is eager to learn.

Mario Puesan is a Senior who intends to graduate with his Bachelors of Science in Photonics Science Engineering from University of Central Florida in Fall 2024. Mario is currently Advanced Manufacturing Engineer at Luminar Technologies, where he plans on continuing his employment after graduation.

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