**Cover Page

EEL4914: Senior Design 1 - Summer 2020

Automated Rescue Vehicle (A.R.V.)

Group Number: 7
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Executive Summary

Stranded at sea. For some it is a fantastic adventure, for others it is their greatest fear. Disasters at sea prove to be the most daunting challenges for rescue parties, so much that a branch of the U.S. military has dedicated teams and equipment for this task. What comes to mind is a US Coast Guard diver jumping from a helicopter and emerging with a rescued voyager, tied together to a crane cable, but in order to achieve this dramatic image of relief, rescue teams must first locate what amounts to a needle in an incomprehensibly big haystack.

The ocean tragically claims the lives of 2,000 seavoyagers every year. Commercial fishing and shipping are considered among the most dangerous jobs in the world. There are also tens of millions of smaller, private vessels that take to the seas for fishing, recreation, and business. This makes for a web of traffic that is far less regulated than air or land travel. This web, and the harsh conditions constantly seen in all oceans produce a navigation challenge that takes years of experience to overcome and decades to master.

Topwater waves can reach heights exceeding 70 feet, and extreme wind and rain must always be considered in sea travel. Ocean weather alone can tell many cautionary tales, but disaster also strikes with equipment malfunction. Rudders or propellers can be damaged, or an iceberg could be hit. This leaves passengers and crew members either in the water, or in emergency life vessels, ill equipped for extended survival at sea.

The ocean is in constant motion. The only reference point rescue teams have is the last recorded GPS signal of the vessel prior to disaster. From this clue, it is a matter of sharp eyes and luck to locate survivors that may have drifted miles from the location of the shipwreck. It is here that the A.R.V. steps in to offer assistance. It will be an addition to a rescue tool box consisting of teams on the water, in the air, and on land providing communication and guidance. The object detection will look for persons, debris, or airborne flares and give a degree of certainty that what it is seeing is of interest to the rescue team. Under the operating conditions we intend to implement the A.R.V. in, every set of eyes, human or not, counts.

The journey of this project will be governed by certain industry standards and design constraints, which will be outlined throughout this report. The report will set quantitative goals for all aspects of the A.R.V., from battery life to environment capabilities and size restrictions. It will provide a detailed record of the component selection process, and research into relevant technologies, related projects and helpful resources. The report will explore the logic of the code requirements, as well as Machine Learning, Object Detection, and Image Processing concepts. Above all else and as with any engineering project, safety

will govern decision making to the highest degree. The A.R.V. will respond to disasters, and will not be designed in a manner to risk another disaster if a malfunction occurs. As an independently funded project, cost will be in heavy consideration with the selection of each component.

Motivation

Mankind has made its most significant advancements by satisfying our need to explore what we do not understand. Our *curiosity* has allowed us to discover amazing new technologies and physical understanding, hence the namesake of one of the greatest exploration projects in human history. From wooden ships crossing oceans to metal rockets crossing solar systems, it has never been satisfactory to not know and simply conjure a guess. Our need to learn will continue to propel us to an enlightened future, however it will also continue to expose us to new and potentially dangerous environments.

Water is one of the great unknowns to mankind. It is the one place that humans venture where we are entirely unequipped for survival. As depth increases, light fades, and the world below becomes more strange and unobserved. In water lies foreign creatures and unknown hazards. There are many ways a person could be left to survive in the ocean: left behind on a scuba trip, falling overboard, or a shipwreck. Finding someone lost at sea is an arduous and unfortunately often hopeless endeavour. Authorities like the Coast Guard and other search parties need any help to tip the scales in their favor, and we are in the age of technology providing that help.

It is the directive of this project to provide a lightweight, portable solution to this problem. We will build a system that actively seeks and analyzes objects in water in an effort to identify subjects that would interest search parties at sea. It will implement image processing and object detection with the use of LIDAR and conventional camera technology. There will be a layer of autonomous decision making to allow an extra set of eyes (the operator) to scan the water while the system assists in the effort.

Background

Large scale sea travel has existed for the past 5,000 years. Ships at sea have evolved in role from simply trade vessels to also military, police, and recreation. At any given moment, there are around 50,000 merchant ships alone at sea. This modern marvel is an unfortunate opportunity for disaster to strike. In this case of disaster, there are often scores of small boats and helicopters that are deployed to locate shipwrecks, survivors, and debris. This can also apply to plane crashes over large bodies of water. The core function of this project is to provide machine assistance to the search effort by detecting objects of interest and alerting the user upon discovery.

The past ten years have seen a huge surge in devices that provide air exploration to any user. The “drone” is a weekend hobby, essential tool for law enforcement, and even a weapon. While the aerial drone market floods, there are few options for similar underwater exploration. The term underwater exploration typically conjures thoughts of miniature submarines visiting the Titanic and pirate wrecks, but what about a system to collect the most essential readings of a body of water? These readings are its depth, temperature, and contents, and will be the core functions of this project.

Requirements Specifications

Requirements for the entire system will be split into three levels. The first will be the system operating as a whole. Level 1 will state requirements for the controller and boat operating together. The second level of requirements will be directed toward how the boat should operate. The third level of requirements specifies how the controller shall operate.

Level 1

* **Note:** Within this section of Level 1 requirements, “The System” will refer to the combination of the rescue vessel and its remote controller with data display.

- The system as a whole shall be lightweight and easily portable
    - Weight Limit: 15lbs
    - Dimensions: 18in x 8in
    - Autonomous
- The system price shall not exceed $600
- The system shall have a battery life to sustain ample exploration.
    - Minimum Time of Operation: 8 minutes
- The system shall be rechargeable
    - Possible Solar Battery
- The system shall be able to work in different environments or bodies of water, i.e, pool, lake, etc.
- The system shall be waterproof
    - IP68+ rating
- The system shall be able to withstand reasonable shock from impacts with possible obstacles (stumps, waves, etc)
- The System shall be able to receive and transfer video, depth data, values to the remote control display wirelessly.
- The system shall use 433Mhz RF modules or 2.4Ghz RF modules

- The System shall be able to communicate and transmit data back and forth within a specific range
    - Control Range: TBD
    - Depth Sensor Data Transfer: Range - TBD
    - Live Camera Feed Data Transfer: Range -TBD

Level 2

* **Note:** Within this section of Level 2 requirements, “The System” will refer to the exploration vessel.

- The System shall be able to maintain buoyancy with the addition of analysis equipment.
- The System shall maintain aero and hydrodynamics with the addition of data recording equipment.
    - Display this with cone navigation
- The System shall be able to navigate waters with a depth resolution of 8mm
- The System shall be able to undergo various speeds up to TBD without affecting efficiency.
- The System shall be a low power system with maximum operating voltage of 12V
- The motor in the System shall have a maximum power of 8000rpm
- The motor shall be driven by an 11.1V Lithium Polymer battery
    - Possible Solar Battery
- The System shall be able to maintain data transfer efficiency while moving
    - Depth readings shall have accurate measurements while the vessel is in movement.
- The power system and circuitry shall have leakage protection and be completely sealed for waterproofing.
- The receiver and transceiver (RF Modules) shall have a data transfer range minimum of 10 meters
- The system shall have various voltage regulators outputting a voltage range of 3.6-15V for microcontroller, TBD for depth sensor, and 3.3-5V for camera.
- The output current for voltage regulators shall not exceed TBD amps.
- The Depth sensor in the system shall be able to record depth values within the specified range of 1in - 50feet
- The camera shall be able to transmit live video feed to the remote control display
- The System shall be able to identify distinguishable objects and recognize with a high percentage.
- Minimum percentage for correct identification shall be 70%

Level 3

*** Note:** Within this section of Level 3 requirements, “The System” will refer to the remote controller with data display.

- The System shall have a maximum weight of 5lbs to prevent user fatigue
- The System shall have maximum dimensions of 10x10 inches
- The System display shall maintain a frame rate of TBD
- The System shall have a display suitable for users of all eyesight abilities
    - Minimum screen size 4x4 inches
- The System shall transmit control data quickly to maintain fluid control on a body of water
    - Transfer rate TBD
- The System shall have a battery life indicator function
    - Possible alarm for low battery
    - Percentage or visual indicator ie three bars
    - Backup battery so the vessel is never stranded (move to level 1 most likely)
- The System shall be water resistant in case of rain or splash from the body of water
- The System shall have a warning when the vessel is approaching its shallow water limit
- The System shall be user friendly
    - Minimal controls: power and steer
- The system shall maintain controls of the display
    - Brightness range TBD

Table 1. Engineering-Marketing Trade Off Matrix

			Marketing Requirement			
			Ease of Use	**High Performance & Resolution**	**Range Usability**	**Versatility**
			+	+	+	-
Engineering Requirements	**Weight (15lbs)**	-	↓	⇈	↑	↓
	Object Detection Range (10m)	+	⇊	⇈	⇈	↓
	Data Transfer Range (40m)	+	↓	↑	⇈	↓
	Power (7 minute run time, <12V supply)	-	↓	⇈	↑	
	Cost ($600)	-	↑	⇈	↑	↑

↑ = Positive Correlation
⇈ = Strong Positive Correlation
+ = Positive Impact Requirement

↓ = Negative Correlation
⇊ = Strong Negative Correlation
- = Negative Impact Requirement

Estimated Project Budget and Financing

- Our project will be self funded with an initial budget of 600 USD. We are exploring 3rd party funding to subsidise this but it is unlikely in our current crisis.
- Below is an initial list of parts needed and a table of estimated costs.

Table 2. Estimated Item Cost (Implementation #1)

Item	Cost
Raspberry Pi	$40.00
Flytec HQ2011 RC boat (and remote)	$69.33
Eachine TX02 NTSC Super Mini camera	$18.89
Bullet Skimmer Transducer depth finder	$39.99
Jumpers	$7.49
Pimoroni HyperPixel	$49.95
Battery pack	$2.00
Resistors x100	$10.00
Capacitors x50	$8.50
Inductors x50	$36.00
RF 433MHz Module	$4.95
Pcb Assembly	$23.90
Regulators x10	$18.20
Transmitter and Receiver	$4.95
LiDAR	$39.90
Total	**$381.46**

- In the case that we choose to design our own RC boat and only purchase the hull pre-made.

Estimated Additional Costs

Table 3. Additional Items (Implementation #2)

Item	Cost
Hull	$34.99
35T Motor	$25.99
Venom Group Venom 7.2V 3000mAh 6 Cell NiMH Battery	$22.99
Double Sides Brushless ESC	$16.39
Rudder	$7.40
Propeller	$6.58
Driveshaft	$6.87
Servo	$2.57
Venom Group Venom 7.2V 3000mAh 6 Cell NiMH Battery	$26.51
Total (New Total)	**$150.29 ($531.75)**

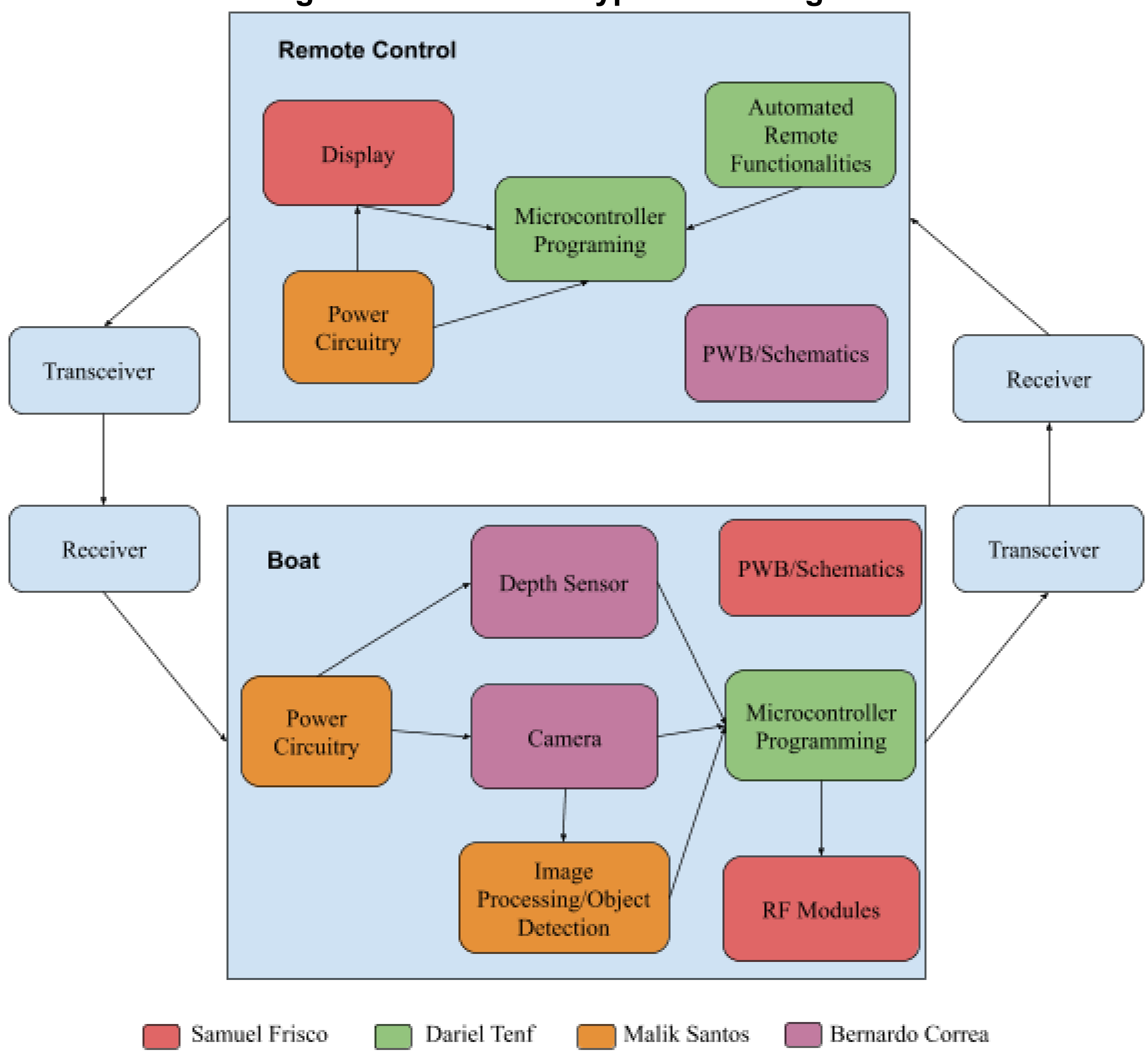
Initial Project Milestone for both semesters (Red indicates UCF-imposed deadlines)

5/29 – Divide and Conquer due
6/5 – Divide and Conquer V2 due
6/25 – Theoretical Project Design "relatively" finalized (We will have a strong idea of all, if not most, of the parts we need to build and complete the project, and we may begin ordering parts.)
7/3 – 60-Page Senior Design Draft due
7/8 – Parts acquired, Production Process begins
7/17 – 100-Page Report Submission due
7/22 – Final Document completed, Review and Finalization begins
7/26 – Final Document finalized
7/28 – Final Document due
8/5 – Depth-Sensing Boat 25% Completed

8/24 – Fall Semester Begins
8/31 – Depth-Sensing Boat Completed, Testing and Optimization begins, Consider adding additional features if all is going as planned
9/31 – All features finalized
11/10 – Testing and Optimization Completed, Project Finalized

Block Diagram

Figure 2. Initial Prototype Block Diagram



Block Status

Power Circuitry - Research and Purchase - Researching operating voltage ranges and circuit protection for both feature and basic operation components. Also battery material options and brushed vs brushless motors. All research is being done with the goal of a single power source.

RF Modules

Research and Purchase- Finding and tuning equipment to correct frequencies.
PWB/Schematics - Research, Design and Purchase- Designing schematic digitally and then ordering the result.
Display - Research and Purchase- Installing display inside of the remote with a shared power source.
Depth Sensor - Research and Purchase - Investigate different types of sensors such as sonar for depth measurements. Research quality and resolution of part.
Temperature Sensor - Research and Purchase - Investigate different types of sensors and mounting options, as well as accuracy and the units that will be reported.
Camera - Research and Purchase - Investigate different cameras based on cost, quality, resolution, and wireless transmission
Microcontroller Programming - Research - Finding optimal coding language to use for the software design aspect of the project.
Remote Functionalities - Research - Finding how to produce the software specifically required for the different features we desire for the control of the boat.

Related Projects

Arduino GPS Drone RC Boat

The Arduino GPS Drone RC Boat is a GPS-controlled, camera-equipped RC boat, as pictured below, with an Arduino Mega and 433 MHz remote. It's a drone boat controlled by an Arduino Mega. Like our project, it's designed to be capable of navigating a body of water autonomously. The control is transmitted via 433 MHz serial transceiver modules, the software is written in C#, and the navigation is controlled by GPS.

This project is similar to ours with regards to the automation and the camera capabilities, but our project takes the idea further. The Automated Rescue Vehicle will utilize the camera mounted on it as a means to search and locate desired objects via image processing, which as stated previously, can have great benefits in search and rescue missions out at sea. While the GPS control would likely improve our project, we've chosen to create a basic search algorithm to not dedicate too many resources to the driving pattern of the project, and instead, put those resources to the more demanding parts of the project such as the vehicle automation and the image processing.

Figure #: Arduino GPS Drone RC Boat

Overall, here is the side-by-side comparison of the two projects in terms of features:

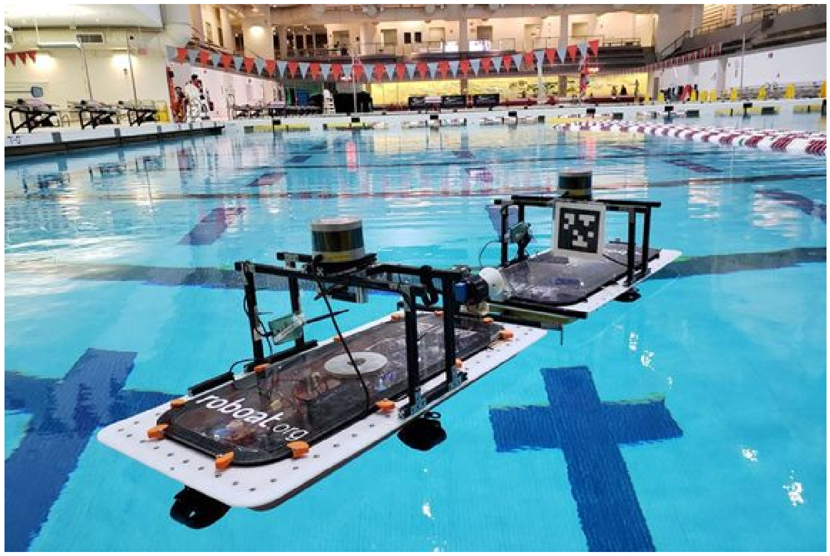
Table #:

	Arduino GPS Drone RC Boat	**Automated Rescue Vehicle**
Vehicle Automation	Yes	Yes
Camera	Yes	Yes
GPS Control	Yes	No
Image Processing	No	Yes
Data Collection Tools	No	Yes

Roboat

The Roboat is a collaboration project between the Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute) and the Massachusetts Institute of Technology (MIT) that began in 2016 and is scheduled to be completed in 2021. Rather than a simple autonomous boat, the goal of the project is to make a fleet of autonomous vessels that are capable of moving people and goods through the creation of portable infrastructure, most notably bridges. As seen in the image above, the individual vessels coordinate with each other autonomously to link together to create a chain of two boats as shown below. As of now, prototypes are being tested in the canals of Amsterdam.

Figure #: Two Roboats linking together



On a larger scale, several of the Roboats would all link together to create a large bridge as shown in the image below. The image below is just a sample drawing of what the technology would look on a large scale. There are also other sample images online displaying what the device would look like when transporting goods and people.

Table #: Sample image of Roboats linking to form a bridge

Objectively, this project is much more intricate than the Autonomous Rescue Vehicle, and understandably so, as this is a five-year project. The Roboat takes boat autonomy to the next level, and even utilizes neural networks to realize image processing to recognize objects in the canal environment. On their official website, “roboat.org”, the Roboat applies the following techniques in its operation:

- Inertial Navigation System
- Image Processing
- Motion Planning with Obstacle Avoidance
- Predictive Trajectory Tracking
- Route Planning
- Latching
- Multi-vessel Coordination
- Environmental Monitoring

SeaCharger

Figure #: SeaCharger sailing at sea

The SeaCharger is a project by Damon McMillan, Troy Arbuckle, Matt Stowell, and JT Zemp to make “the first unmanned surface vehicle (USV) to cross an ocean on solar power alone.” In other words, a solar-powered autonomous boat. While the project is currently retired, before it's retirement, the SeaCharger managed to complete a voyage from California all the way to Hawaii. The SeaCharger was then set to sail for New Zealand and managed to get within 300 miles of the shore before the rudder died and the boat was unable to go any further. The SeaCharger began as a hobbyist project and is mainly built using hobby-grade/homemade components.

For a boat made of simply hobbyist components to be designed in such a way where the vessel is able to make it within 300 miles of New Zealand's shore from California is an amazing feat. The project took 30 months to complete and overall, the project was partially a success. After the rudder had gotten damaged 300 miles from the New Zealand shore. The SeaCharger was eventually recovered and spent the next six months in the New Zealand Maritime Museum.

As what we have planned for the Automated Rescue Vehicle, the SeaCharger is capable of switching between autonomous navigation and radio control. The SeaCharger is much sturdier than what we have planned for the A.R.V. as we don't plan on designing it to traverse the ocean. We will have it navigate calm bodies of water just as a proof of concept. Also, the A.R.V. will likely not be solar-powered.

Research and Investigations

What is Digital Image Processing?

Digital image processing is the use of a computer to process digital images using algorithms. For the Automated Rescue Vehicle, we would need to apply digital image processing, so the camera can process images and recognize when a desired object is in its view. What's challenging about this is that the CPU can't simply record an image of a desired object and be able to consistently recognize it. The desired object could be found in unfamiliar positions and/or conditions in which despite being the desired object, the CPU won't know due to being unable to match what's on camera to what's recorded as the desired object in memory.

In order to tackle this issue, digital image processing is a practical application of the following concepts:

- Statistical Classification
    - Statistical classification is the problem of classifying a new observation into a specific sub-population of a set of sub-populations. As there are typically a finite set of sub-populations and, in the real world, it's rare that any two observations would be identical, it's even rarer that an observation falls perfectly into a subpopulation. What this means is that statistics becomes increasingly important in order to find what sub-population in the set an observation matches the most.
    - Given its nature, statistical classification is an example of pattern recognition, where new observations need to be classed based on which sub-population's patterns the new observation most accurately fits under. An algorithm responsible for implementing classification is called a classifier, and it maps input data to a subpopulation.

- Feature Extraction:
    - Sub-populations are identified by their features. Features are derived values from an initial set of measured data, which is intended to be non-redundant and informative. Feature extraction is the process of taking a set of measured data and transforming it into a reduced set of features. This set of features is known as a feature vector. In the case of the Automated Rescue Vehicle, the input data would be the images from the camera. Features need to be extracted to find if an image contains a desired object. With images, generally, features are extracted from shapes.
- Signal Processing:
    - Signal processing is the science of analyzing, synthesizing, sampling, encoding, decoding, enhancing, transporting, archiving, and basically manipulating signals in some way. A signal is any physical quantity that varies with time, space, or any other independent variables. For image processing in the Automated Rescue Vehicle, we apply signal processing when we take an image (signal) and extrapolate data from it. Essentially, image processing is a subcategory of signal processing.
- Pattern Recognition:
    - Pattern recognition refers to the automated recognition of similarities and patterns within sets of data. It is the basis of statistical classification as the recognition of patterns is essential to the proper classification of a piece of data into its respective category.
    - In modern times, pattern recognition is also closely associated with machine learning as the computer needs to be able to produce more rigid boundaries between subpopulations to more accurately classify new data. It is common that pattern recognition systems are fed “training” data to be able to recognize desired patterns. This is known as supervised learning. Supervised learning is most likely the method that we will use once we properly incorporate image processing into the Automated Rescue Vehicle in order to establish pattern recognition to identify desired objects.
- 3D Projection:
    - A 3D projection is a mapping of points in a three-dimensional space onto a two-dimensional plane. Although there are several different types and methods of projection. The most relevant method of projection for image processing on the Automated Rescue Vehicle will likely be perspective projection.
    - It’s unrealistic that a desired object be sought by the A.R.V. would be present on the water in the same or even similar positions as what’s already been registered by the CPU. As a result, perspective

projection provides a method to facilitate the CPU recognizing a desired object from different perspectives.

What is Machine Learning?

Machine learning is a subdiscipline of artificial intelligence focused on the study of computer algorithms that automatically become more proficient through experience. This learning process allows computers to discover how to perform certain tasks without being explicitly programmed to perform said actions. This has very practical applications when attempting to have a computer perform complex tasks where it would be increasingly difficult for a human to manually create the proper algorithm to complete the tasks. The programmer instead allows the computer to develop its own algorithm by labelling desired outputs as “valid,” which prompts the computer to more efficiently produce valid outputs. Approaches to machine learning are broadly divided into three categories.

These categories are as follows:

- Supervised Learning:
  - In supervised learning, a “teacher” feeds the computer a set of example inputs with their respective expected outputs with motive to establish a general behavior for the computer to map inputs to desired outputs.
- Unsupervised Learning:
  - Unsupervised learning is understandably opposite to supervised learning where instead of being fed inputs with their expected outputs to create a mapping, the computer is left to find its own patterns with the inputs to create a structure. This often leads the computer to find hidden patterns in the data that would have otherwise gone unseen by humans.
- Reinforcement Learning:
  - For reinforcement learning, the computer program is placed in a dynamic environment in which it is to accomplish a certain goal. The computer program’s progress towards completing said task in the given problem space is provided as feedback, and the program attempts to maximize the progress in hopes to complete the task. An example would be having a program play a game with the objective of beating it, and as it keeps playing, it gets more and more proficient at playing the game.

What is Vehicle Automation?

Vehicle automation is the use of artificial intelligence to assist in the operation of a vehicle. For this project, we are primarily concerned with navigation autonomy, so the Automated Rescue Vehicle (A.R.V.) may traverse a body of water and independently search for a given object. There are six levels to categorize autonomy in vehicles. These levels are as follows:

- Level 0 – No Automation
- Level 1 – Driver Assistance: In specific circumstances, the vehicle can independently control either steering OR speed to provide assistance to the operator.
- Level 2 – Partial Automation: In specific circumstances, the vehicle can independently control both steering AND speed to provide assistance to the operator.
- Level 3 – Conditional Automation: The vehicle is capable of taking command of both the steering and the speed independently under normal environmental conditions with an operator's oversight.
- Level 4 – High Automation: The vehicle is capable of completing a trip independently under normal environmental conditions without the oversight of an operator.
- Level 5 – Full Autonomy: The vehicle is capable of autonomously completing a trip in any environmental conditions presented to it.

With the information just presented, the A.R.V. would likely be classified as a level 3 autonomous vehicle (conditional automation) as the A.R.V. is to be able to traverse and search a body of water to find an object independently, but if needed, will be able to switch to human control to navigate the water.

ROS

ROS stands for Robot Operating System. It is a flexible framework designed by Open Robotics used for writing software for robots and has a wide assortment of libraries and resources to simplify the process of devising robust behavior for robots. Throughout our research, as well as some previous experience, we've found that ROS has a lot of open-source materials for us to incorporate into the more difficult software aspects of the Automated Rescue Vehicle (A.R.V.). These materials include joystick drivers, camera drivers, image processing libraries/packages, and navigation libraries/packages. ROS' main supported libraries are C++ (roscpp) and Python (rospy).

C++

C++ is a programming language created as an extension of the C programming language. Unlike C, C++ is object-oriented, similar to Java. Object-oriented programming is a programming paradigm centered around the idea of values in memory known as "objects." Objects include data structures, functions, methods, and variables. For class-based object-oriented languages, such as C++ and

Java, an object is an instance of a class, which can be a combination of the previously mentioned pieces of data (functions, data structures, variables).

Despite C++'s similarity to Java, C++ is almost identical to C syntactically and is widely known as a superset of C. Most C code would easily compile correctly in C++, except for a few exceptions, as C++ introduces many new keywords that aren't present in standard C. If they were to be used in C code as identifiers, the C code would not compile correctly in C++. C++ is widely used and compatible with both ROS and MOOS-IvP, making it very attractive to consider using for designing the software for the Automated Rescue Vehicle.

Python

Python is a high-level, general-purpose programming language that supports several programming paradigms. This includes procedural, object-oriented, and functional programming. Python uses a significant amount of whitespace to encourage and emphasize code readability and assist in writing logical code that can be easily understood. Python has a very comprehensive standard library and is often considered very user-friendly to beginners due to its very organized nature. Unlike several other programming languages, blocks of code are not bounded by curly braces, rather with indentation. Also, semicolons are optional to end a line of code as newline characters provide the same functionality. Although it is incompatible with MOOS-IvP, Python is compatible with ROS, and its simplicity makes it very attractive as it can ease the learning curve of those in the group that aren't so proficient with coding.

MOOS-IvP

MOOS-IvP stands for Mission Oriented Operating Suite – Interval Programming, which is an open-source set of C++ modules that, while it can be used for all robotic platforms, specialize in providing autonomy for marine vehicles. MOOS seems to have a lot more open-source material on autonomy that we can use for the A.R.V., but lacks any resources on the additional functionalities that must be implemented.

PID Controller

In order for the boat to autonomously traverse a body of water, it's highly recommended, if not necessary, to implement a PID controller for the speed and the course of the boat. A PID controller, known as a proportional-integral-derivative controller, is a control loop mechanism within a control system that uses feedback to ensure that a system maintains steady-state and can quickly and efficiently return to steady-state should the system encounter any noise, which is almost guaranteed to happen in the real world. A PID controller has three separate components, each with their own responsibility in eliminating error. The three components are as follows:

- P – the P in PID stands for proportional, and this component acts somewhat as a first responder when there's an error in a control system. If an error is large, the P component of the controller will have a proportionally large control output which is constant. In most cases, the P component alone results in a constant error between the desired steady-state value and the actual output, which is why it's not used exclusively.
- I – the I in PID stands for integral. This component has a slower response than the P component and works to completely eliminate any residual error that still exists in the system over a period of time. It accomplishes this by introducing a control effect due to the cumulative value of the error over a period of time. This nullifies the P components shortcomings of leaving a constant error after its response.
- D – the D in PID stands for derivative. This component is different from the previous two components in the aspect that the D component has no bearing on the actual output of the system, rather it's a controller for the output's rate of change. With just a P component and an I component in a controller (otherwise known as a PI controller), the system can potentially exhibit oscillatory and unpredictable behavior in a noisy system. The reason for this is that the noise in the system can cause a large and sudden spike in the output of the system, which would result in an equally as sudden spike towards steady-state from the PI controller. The D component reduces the rate of change, so that these spikes don't occur so suddenly, so that the other components within the controller can take action on the system before the error becomes drastically large, and when the P and I components do take action, the system's output doesn't spike back to steady-state, rather gently drops to steady-state. This results in much less oscillatory behavior, and a much better control system.

Together, each of these components are crucial in applying accurate and optimal automatic control.

Sensors

Depth finder

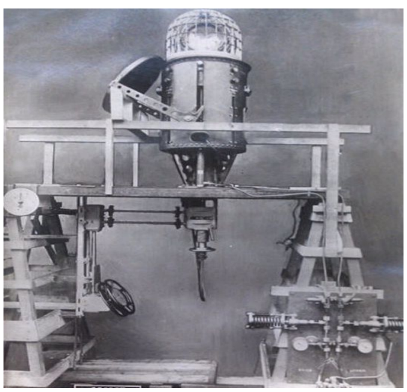
Goals

To measure and record the distance in meters from the bottom of the hull to the bottom of the body of water. This information will then be transmitted to the display.

Technology

Depth finding technology was first used in 1915 during world war 1. This invention at the time was used to detect submarines underwater by sending a strong acoustic pulse. This pulse is sent by a transceiver in intensity measured in decibels (dB). This is the dominant unit in all underwater acoustics. These sound waves are pulsed down at two intensity ratios of Distance 1 and Distance 2, using decibels as the unit you would be utilizing the logarithmic base 10 and expressing the ratio as 10 log Distance 1/Distance 2 dB. This pulse is sent from the transceiver to the object taking into account transmission loss caused by attenuation and sound spreading. This acoustic pulse then reflects off the object and once again taking into account transmission losses, the signal is then collected by a receiver and its values calculated. Using the general globally accepted reference intensity of one micro pascal you are able to express absolute intensities. Decibels of Change=20xlog(distance 1/distance 2) will then give you the distance.

Figure #&#: sonar technology 1942 2020

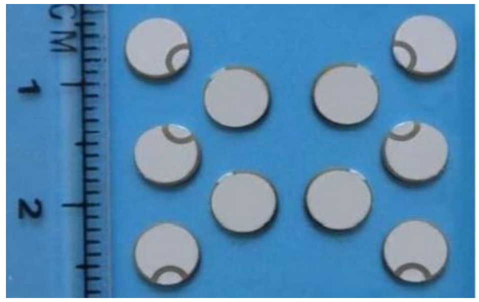


These technologies have continued to improve and we have seen these technologies shrink from bulky large submarine systems to miniature hand held ultrasonic range finders. We will be using a smaller transducer for our particular project, however this is proof of concept for what could be a larger scale. Range finders now can reach past 1000 yards in length, so with a larger budget or frame work this could be implemented easily into a realistic full rescue design project using this particular technology.

SM111 Transducer

The sensors employed for our project will be a piezo ceramic disc bought and manufactured by STEMiNC. We chose this for multiple reasons, firstly the size was very attractive. The disc registers at 6.35mm X 0.7mm making it a logical and ample choice

Figure #: SM111 Transducer



for this particular project because of its smaller nature. It also has the need to connect to a small motorized RC boat. The sensors will be connected to a frame so that we will be able to mount the transducers securely facing downward toward the bottom of the water's surface.

Table #: Data Sheet for the SM111

Piezo Material:	SM111
Part Number:	SMD10T3R111
Dimensions:	10mm diameter x 3mm thickness
Resonant frequency fr:	215 KHz±5 KHz
Electromechanical coupling coefficient Kp:	≥60%
Resonant impedance Zm:	≤9 Ω
Static capacitance Cs:	310pF±15%@1kHz
Test Condition	23±3 °C 40~70% R.H.
fr, Zm, Kp =>	Radial mode vibration
Cs =>	LCR meter at 1KHz 1Vrms

The transducer will be duplexed for our specific purpose. Meaning it will receive the signal from our oscillator and the amplitude from our power supply and send this acoustic pulse toward the bottom of the water. The pulse will reflect and then return and the same transducer will receive the signal and relay the information back to the microcontroller.

Duplexing is a very common procedure in antennas, transducers ect. It allows the system to send a pulse signal switch off and receive the reflected signal then switch on and send another over and over again all within milliseconds if eachother. This can be done without too much work and it reduces the need to have a separate antenna to receive all the information which would both add to costs and the overall weight of our project.

Each specific transducer will have its own data table and needs for optimal efficiency. Two of the largest of these is the power supply and oscillator of our system that will be connected to the sensor. Each sensor will have a resonance frequency, this is the frequency at which it will perform its best. While it still may work at different frequencies that are close to it, you will have your best results the closer you are. We also need to be able to power the and supply the pulse power needed for the amplitude of the signal.

Piezoelectric elements work under the basic principle that when you apply a current to them they will bend and flex causing vibrations, these vibrations if applied with an oscillating signal will cause the element to vibrate at your resonance frequency sending the needed transmission.

The velocity of the wave length can be described by this equation, where v is the velocity of the wave length, lambda is the distance of the wave length and f is the resonance frequency. As seen below the multiplication of the distance of the wave and resonance frequency give you the velocity of the wave.

$$v = \lambda f$$

The resonance frequency of our sensor which is 215 KHz is non negotiable because the part has one required resonance frequency. However we can choose the velocity that we want by choosing the distance of the wave. Because the frequency can be looked at as a constant we can then change the velocity by altering the distance of the wave through our oscilloscope device that we will design.

Table #: Data Sheet for the Piezoelectric Material

Electromechanical coupling coefficient	Unit	Symbol	SM111
N/A	N/A	K_p	0.58
N/A	N/A	Kt	0.45
N/A	N/A	K_{31}	0.34
Frequency constant	Hz ● m	Np	2200
N/A	Hz ● m	Nt	2070
N/A	Hz ● m	N_{31}	1680
Piezoelectric constant	$\times 10^{-12}$m/v	d_{33}	320
N/A	$\times 10^{-12}$m/v	d_{31}	-140
N/A	$\times 10^{-3}$Vm/n	g_{33}	25
N/A	$\times 10^{-3}$Vm/n	g_{31}	-11.0
Elastic Constant	$\times 10^{10}$N/m^2	Y_{33}	7.3
N/A	$\times 10^{10}$N/m^2	Y_{11}	8.6
Mechanical Quality Factor	N/A	Q_m	1800
Dielectric Constant	@1KHz	$_eT_{33/e\ 0}$	1400
Dissipation Factor	%@1KHz	tan δ	0.4
Curie Temperature	°C	T_c	320
Density	g/cm^3	p	7.9

Compare and Contrast

Several different sensors were considered for this particular and in this section we will review each of these and discuss the disadvantages and advantages of all of them so we can confirm we made the correct choice and explain why we chose each specifically.

SM111 Piezo Transducer.

The SM111is a piezoelectric material that when a current is sent through it bends and flexes causing a vibration that when matched with an oscillation produces a signal that can be sent and also received from the same device. The SM111 has more than enough distance capability for our project, the max distance is dependent on our power source design however research shows achieving up to 15 ft is very simple which is more than enough distance for our needs. Its small compact size makes it ideal for our boat as well as to waterproof it.

It uses acoustics to read the distance which is a feature we were looking for and is easily compatible with our desired microcontroller. The piezo offers a touch of simplicity in that we have to do the connections manually, program the device, power it and provide it with an oscillator for its frequency. This was an attractive feature for us since we wanted to build some of these components to gain a true deeper understanding of the engineering involved. The price of the equipment is also the cheapest out of our options making this the most desired of the group.

Table #: Data table for SM111 Comparison

Parameters/Features	Parameter Values
Distance max	256 cm
Distance Min	2 cm
Used Before	No
Size	10mm diameter x 3mm thickness
Measurement technology	Acoustic / Sonar
Capable of underwater usage	Yes
Price	$9.95
Compatible with Raspberry Pi	Yes

PARALLAX 28015 - Sensor Board, PING, Ultrasonic Distance Sensor

The PARALLAX 28015 is your basic ultrasonic range finder for any of your small microcontroller projects. The distance was a bit shorter than we were looking for maxing out at around 9 ft. This device also used acoustics which was what we were looking for and our group has experience using these before in previous projects. Its connections to a raspberry Pi are simple because of its 3 pin header. However the option is more expensive than its competitors costing $29.99 for just one, but the biggest con to this equipment is its inability to waterproof it in our current system. Because it is larger and has a direct connection to our microcontroller via the 3 pin header, it would be impossible to mount on the bottom of our boat with some sort of encapsulation to keep it dry. While a viable option for dry conditions it didn't have the versatility of placement we needed.

Table#: Data table for PARALLAX 28015 Comparison

PARALLAX 28015	Parameter Values
Distance max	3 m
Distance Min	2 cm
Used Before	Yes
Size	22 mm H x 46 mm W x 16 mm D
Measurement technology	Acoustic / Sonar
Capable of underwater usage	No
Price	$29.99
Compatible with Raspberry Pi	Yes

Sharp GP2Y0A21YK0F IR Range Sensor

The GP2Y0A21YK0F IR range finder is the only other option we looked at that isn't an acoustic application, this range finder uses infrared to measure the distance. The infrared range finders calculate the distance from something using triangulation. Triangulation works by sending a beam of inferedd and detecting the reflected beam's angle, with the knowledge of the angle of the reflected beam the distance can be found. This range finder has a CCD (charge coupled device) which computes and corresponding value and sends this information to your microcontroller.

The GP2Y0A21YK0F IR range finder has a max distance of only 80 cm, this is expected because generally inferred technology has a very precise measurement but is never used to measure very far. The size is favorable to our project as well as the price is only $9.95 which is as low as the piezoelectric however, we've never used this technology before so learning curve would be high, the ability to waterproof the system mounted under our boat while it might be possible it would prove difficult as well as the limited measuring range would a be a issue for what we wanted to do.

Table #: Data table for Sharp GP2Y0A21YK0F IR Range Sensor Comparison

Distance max	**80 cm**
Distance Min	10 cm
Used Before	No
Size	4 cm L x 1.5 cm TH x 1 cm W
Measurement technology	Infrared
Capable of underwater usage	Yes
Price	$9.95
Compatible with Raspberry Pi	Yes

Connections

The piezo SM111 we concluded should be controlled by a raspberry Pi microcontroller. (For details on raspberry Pi see section 2.2.2) The details of the raspberry Pi, its specs data and full connections are covered in detail in a future section. In this section we are simply covering the specific requirements and connection from the raspberry Pi to our transducer Piezo material.

Raspberry Pis can produce audio simply attaching a HDMI monitor with built in speakers or attaching amplified speakers to its audio port. However this is not the route we opted for because this is not compact, it's not light weight and it also is not energy efficient. The ability to be energy efficient is important because the hardware to prove large amounts of power wouldn't fit in our small boat.

The Piezoelectric would be soldered with simple jumper wires to their surface on the correct positive and negative terminals as depicted by the semi circles. Each jumper would need to be cut and stripped to make a firm connection to the material. Once these connections have been made take the opposite ends of your jumpers and connect them to your raspberry Pi. The red jumper should be connected to the raspberry Pi pin GPIO 22, the black jumper needs to be connected to ground so simply find one of many ground pins on the raspberry Pi and connect the black jumper there.

Waterproofing

One of the bigger issues we had with our harmonic sensor is that it needs to be mounted on the bottom of the boat as illustrated in image ().... To do this we were not able to use certain traditional TI ultrasonic range finders that we have used before in our education. It became clear we needed a smaller sensor that we could encapsulate in a material to keep it from getting wet, however this provided more issues. If we encapsulate our SM111 (see section 1.2) the harmonics would have to go through two different impedance and densities. This would disrupt the signal and create reflections in the signal.

Reflections in a signal is when along whatever medium you are in part of the power of the signal is reflected back toward the transmitter thus not traveling all the way to the point it is meant to bounce off of before returning. This creates error in the reading and less accuracy for our system. To avoid this scenario you want you medium or load impedance to be the same as your transmitter and receiver impedance. This creates continuity along the entirety of the system keeping the results tight and accurate. For our specific system the load impedance is the water that we are sending the signal through and the receiver impedance is our transducers encapsulation.

Acoustic impedance is the density of a medium multiplied by the velocity of the wave moving through that medium.

Density (**kg/m³**) × Velocity(**V/s**)= Acoustic Impedance (**kg/m²×s)**

Finding a material that matched the acoustic impedance that could be used to waterproof the transducer was required. The specific gravity or density of this product is 1 the same as waters. This allows us to seal the transducer in this poxy while not disturbing the sound wave with reflections. VytaFlex is a two part liquid epoxy sold in the north Orlando area by Smooth-ON. We will be able to solder our connections to our transceiver then submerge it into the liquid epoxy, the epoxy will then solidify into a solid rubberish consinsty so that we can mount and seal this to the bottom of our boat pointing down toward the floor of our body of water

Table#: VytaFlex 20 Technical Overview

A:B Mix Ratio by Volume	**1:1 pbv**
A:B Mix Ratio by Weight	1:1 pbw
Mixed Viscosity	1,000 cps
Specific Gravity (Density)	1.00
Specific Volume	27.7
Color	Clear Amber
Shore A Hardness	20A
Tensile Strength	200psi
100% Modulus	50
Elongation at Break %	1,000%
Die C Tear Strength	60 pli

RC Boat
URUAV 2011-5 Generation

Many things were in consideration in the purchasing of our vessel. Our boat will be purchased as a pre assembled RC boat to avoid any hassle with assembly. It also needs to have a deeper hull and so that we can have room for the addition of parts. The hull needs to be waterproof so that it can hold our additional PCB, raspberry Pi and power sources. Also the length and width of the boat need to be larger than your average RC boat for balance. If you mounted our camera and sensors on some of the smaller models you could easily tip or off balance the frame causing the boat to sink.

Another consideration is speed, while we dont need this to go incredibly fast we need the initial speed to be higher than our goal. This is because we will be adding weight to the boat with our camera sensors etc, which will inevitably lower the speed of our vessel.

Finding the exact versatility was finally achieved in the Flytec 2011-5.

Figure #: Flytec 2011-5

The Flytec 2011-5 satisfied all our needs as mentioned above. We are able to purchase this boat full functional and ready to drive eliminating the hassle of building a working RC boat for our project. As seen in the picture there are a series of screws that connect the top and bottom half of the hull, between these two sections is a rubber seal that goes around the circumference of the boat.

This creates an ease of access to the interior of our boat without having to compromise the waterproofing of our vessel. This boat's hull measures at 20 cm height and 50 cm in length, this is much larger than your typical RC boat on the market which provides the needed room for our added circuitry and sensors.

All data offered by the company is recorded in the table below.

Table #: Specs for the Flytec 2011-5

Product item	**Flytec 2011-5**
Product material	ABS Plastic & Electronic Parts
Product color	Black
Control time	2 - 24 hours
Charge time	10 - 12 hours
Product size	50 L * 27 W * 20 H Cm
Load capacity	1.5 kg
Max speed	5.4 KM/h
Product weight	2020g
Control distance	500m
Battery	7.4V 5200mAh
Controller battery	1.5 V AA x 4
Load capacity	1.5 kg

The battery and servo card are located inside this sealed hull already and we will simply work around these in the abundant room that is provided to add our extra circuitry. The boat measures a width of 27 cm which is also much wider than the speed boat RC models you typically find for purchase, this will add for extra stability we will require once we offset the natural buoyancy of the boat with our cameras and sensors. In the scenario that we may need additional room for circuitry or if we wanted to mount a camera on the backside of the boat we could easily remove the compartments on the rear of the vessel. After removing this we could add a mount for the camera or a box for extra circuitry.

One of the more unique features of this boat is its speed, as noted in the data sheet it travels at a max speed of 5.4 km/h but this is with a load up to 1.5 kg. Because we have no intention of keeping the deployable carriers on the back of the boat this means we will still have that max speed once we attach our extra circuit boards, cameras and sensors. These add ons will weigh much less than the max load provided showing us we will still have plenty of speed for our boat after the additions.

Other notable qualities of the product is the astounding range it has for its connections and communications having a 500 m range. It also has a fairly long battery life at 2 hours of constant use, while it can still be fully charged overnight.

Microcontrollers

Component Selection

Overview

A microcontroller is a small computer system on a single integrated circuit (IC) chip, that performs a task. They are also known as MCUs. They contain one or more CPUs, memory, and programmable in/output peripherals, and are essential to any project that will take an action when given commands of varying forms. The microcontroller will be the heart of our project design and function.

One of its central functions will be to facilitate communication between the remote controller and the boat. This will include commands for movement, information relay from sensors, and data transmission. (redundant?) The goals of object detection and video transmission significantly increase the performance requirements of the microcontroller for the A.R.V. system. We will consider (considered?) three MCU platforms: the Texas Instruments MSP430, the Raspberry Pi, and the STM32F4 series based on the ARM Cortex M4 chip.

Texas Instruments MSP430 Series

The first MCU in consideration is the TI MSP430. It is in fact a large family of microcontrollers that vary in many ways. The first identifier in the part number distinguishes memory types: **F -** flash (most popular), **C -** masked ROM, **FR -** FRAM, **G -** flash value line, and **L -** RAM only. Additional letters indicate special functionalities such as. The next digits indicate the generation and model within the generation, followed by digits indicating the amount of memory the specific model has.

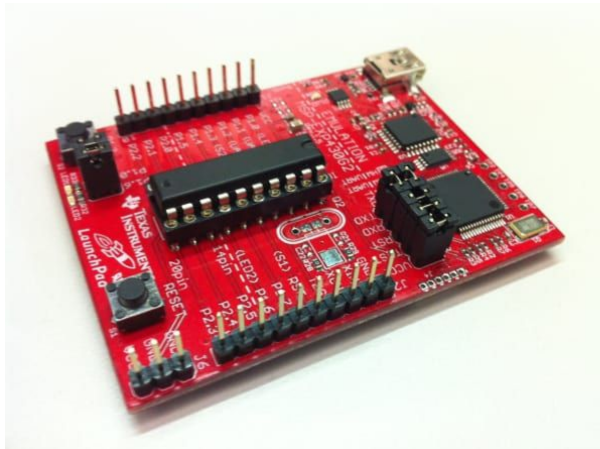
There are also suffixes for various options from expanded temperature ranges to automotive qualifications. In short, the MSP430 family tree has many branches. It is a familiar and very capable platform - built around a 16-bit CPU with low power consumption as a core function. Its operating voltage is between 1.8 and 3.6 Volts, with memory capacities of up to 512KB of flash memory and 66 KB of Random Access Memory (RAM).

The MSP430 also integrates Ferroelectric RAM (FRAM). This "...is a memory technology that combines the non-volatility of flash and the flexibility and low power of S[static]RAM." (cite TI's website?) There are six low power modes that can disable undesired clocks and even the CPU, boasting wake up times under 1 microsecond, and current draw capabilities under 1 microamp. These features could be useful as the A.R.V. lies in wait for a disaster to respond to.

Table #: MSP430 Data

Feature/Specification	**TI MSP430 Family**
Input Voltage	1.8V - 3.6V
Power Consumption	230 μA at 1MHz, 2.2V (Five Power Saving Modes)
Clock Frequency	16 MHz (up to 25MHz)
Memory	0.5KB - 512KB
RAM	0.125KB - 66KB
I/O Pins	4 - 100
Architecture	16-bit RISC
Dimensions	1.75 x 1.85 inches
Weight	4.8 Ounces
Cost	$25.00

Figure #: MSP430 Microcontroller



Raspberry Pi

The next microcontroller in consideration is the Raspberry Pi, although it is much closer to a computer than a microcontroller. The Pi was created with the goal of educating young people in the basics of programming. It is quite powerful, stretching the actual definition of a microcontroller. It is capable of plugging directly to a monitor or TV and runs as a Linux computer, however it also has general purpose in/output (GPIO) pins that allow for the control of external components.

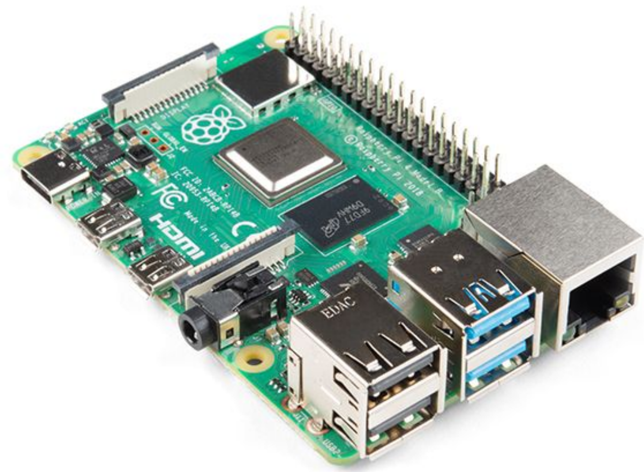
The first Pi model had a single core 700 Mhz CPU and 256 MB of RAM. The latest model, the Pi 4, is available with a quad-core, 64 bit 1.5 Ghz CPU and up to 8 GB of RAM. Standard features of the Pi not found in most microcontrollers are a GPU, HDMI, multiple USB ports (2.0 and 3.0), Wi-Fi, and high RAM.

Raspberry Pi takes a step forward from the MSP430 because it has been implemented in many machine learning applications, which is necessary for object detection (a core function of this project). While the Raspberry Pi boasts the ability to run operating systems and even media, the MSP430 takes a lead in hardware control applications, as well as significant advantage in power consumption. The Raspberry Pi 4 averages 2.85 Watts when idle, which could quickly drain a small battery that an RC boat could accommodate. This is a huge consideration for this project, and will call for an independent power supply for the board.

Despite these concerns, the capabilities of the Pi are attractive for the considerable software requirements of a project based on machine learning, image processing, and object detection. The Pi also has a vast array of proprietary accessories that will build towards the goals of the A.R.V. project.

Integrating these components will be far easier than acclimating foreign parts to the Pi environment.

Figure #: Raspberry Pi 4 Microcontroller



Connections

The Raspberry Pi 4 Model B has a 40 pin GPIO header. There are 28 BCM2711 GPIOs available and are also backwards compatible to previous Pi boards. BCM2711 is a designation for the Broadcom chip used in the Pi 4 Model B.

Power Options

The Raspberry Pi has three main power supply options. The first is 5V DC via the USB-C connector. The next option is 5V DC via the GPIO header. The final option separates the Pi from the other boards and is Power Over Ethernet (POE) ability. POE allows for power to be provided and data transmitted via a single cable.

Display Options

There are multiple display ports on the Pi board. There is not a single standard HDMI port, but two micro HDMI ports. This allows the board to support dual monitors out of the box.

The table below illustrates all of the raspberry pi 4 features and parameters

Table #: Raspberry Pi 4 Data

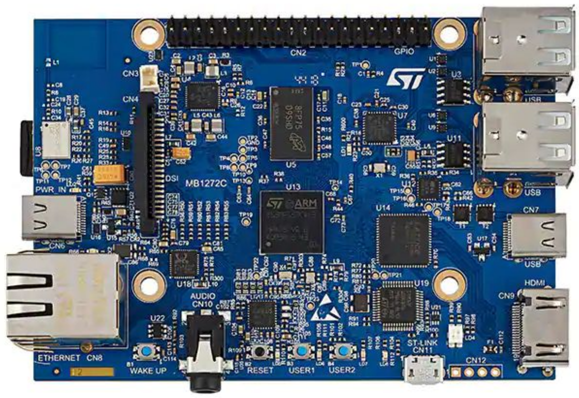
Feature/Specification	Raspberry Pi 4
Input Voltage	5.1V via USB-C
Power Consumption	3.4 Watts (Idle)
Clock Frequency	1.5 GHz
RAM	2GB - 4GB
I/O Pins	40
Architecture	64-bit
Dimensions	2.2 x 3.35 inches
Weight	1.5 ounces
Cost	1GB - $30.00 2GB - $35.00 4GB - $55.00

STM32 Series

The final microcontroller in consideration is the STM32 family of 32 bit microcontrollers, which implement the ARM Cortex-M4 processor. Flagship features of these boards are digital signal processing, in addition to low power/low voltage operation. The Cortex M4 is an extremely fast chip in the world of microcontrollers (verify competing speeds).

The STM32 is capable of 120 Mhz clock speeds, up to 2 MB of flash memory and 640 Kbytes of SRAM. Let's take a deeper look into the memory features. The flash memory on the STM32 is split into two banks. This allows for reading from one bank while writing to the other.

Figure #: STM32 Series Microcontroller



The STM32F469 model includes 384 KB of RAM with 64KB of this being designated as Core Coupled Memory (CCM). This memory is placed in very close proximity of the CPU to allow for even faster access times. Considering the requirements of the A.R.V. the STM32 shines among the three MCUs in consideration. The 32 bit data bus puts that of the 16 bit MSP430 to shame. However, there is little support for this line of MCUs, and fewer resources (opposed to the Pi) that expand on its practical capabilities. It is highly capable in partnering with Tensorflow, a potential code library that will be researched later in the report.

Table #: STM32 Data

Feature/Specification	STM32 Series
Input Voltage	3.3V
Power Consumption	-----
Clock Frequency	84 MHz -180 MHz
Memory	128KB - 2056KB
RAM	32KB - 384KB
I/O Pins	114
Architecture	32 Bit
Dimensions	3.27 x 2.26 inches
Weight	----
Cost	$69.00

Live Video Capture
Component Selection

Camera

The main functionality of the rescue vehicle or ARV, is to be able to process live video for object detection. In order to properly select a viable camera for this system, many parameters must be chosen to ultimately decide what camera should be used. The most important parameter under consideration is video resolution. This is important for object detection as lower resolution can decrease the efficiency of detecting the correct object.

Connector and transmission types from the camera to the microcontroller is also important. Transmitting video from a transceiver to a receiver (from a camera to the Raspberry Pi) or using a wired connection are also under consideration. Other parameters include but are not limited to compatibility and level of difficulties for connection to the Raspberry Pi microcontroller and board, weight, input voltage, frequency and power.

Eachine TX06 FPV Camera

The first camera option under consideration is a small FPV camera that is typically used on drones for live video capture. Using an FPV camera would require a transceiver and receiver for transmitting the video over radio frequency channel. Antennas will also be required for purchasing.

Pros:
There are several pros for choosing this product. It is very light weight and has low power transmitting at 25mW. The product already comes with a transceiver at 5.8GHz with 6 bands and 48 channels. Hence, there would be no need for ordering separate parts for transmitting the video. Input voltage has a reasonable range of 3.3V - 5.5V so an additional regulator is most likely not required for operating the camera/transceiver. This product is already low in cost and with the additional transceiver and antenna features, this choice would help in cost reduction.

Cons:
The camera has a moderate resolution of 700TVL or 700p. This could be a possible problem for object detection during image processing due to low quality video. The product may require a battery pack or another voltage regulator needed for turn on. Even if we already have a voltage regulator that provides sufficient voltage, we would require an additional signal line for operation.

Specifications and features can be seen in the table below

Table #: Eachine TX06 FPV Camera Specifications and Features

Feature/Specification	Eachine TX06
Operating Voltage	3.3V - 5.5V
Resolution	700p/700TVL
Weight	2.8g
Transmitting Frequency	5.8GHz 6 bands, 48 Channels
Power/Current Rating	25mW/280A (Typical)
Cost	$16.05

Raspberry Pi Camera Module v2

This camera option has perfect compatibility with all Raspberry Pi boards and also uses a wired connection to the Raspberry Pi. Using this module is widely preferred when transmitting video to a raspberry pi as it can easily be used in OpenCV based applications. The camera can capture high-definition video and still images and uses a wired flex cable to transmit data to the microcontroller. The cable is also included in the price of the module.

Pros:
This camera offers very good camera resolution at a maximum of 1080p or 1080TVL. This high-definition video capability is perfect for object detection capabilities which can help maximize efficiency ratings for detection of the correct object. The module is compatible with Raspberry Pi and extremely easy to install. It is widely used in OpenCV based applications for image processing and is lightweight.

Cons:
The module is more expensive than the Eachine TX06 FPV Camera and uses a wired flex cable for transmitting video to the microcontroller. Hence, parts such as the transceiver, receiver and antenna could be needed for sending video to a

display since they don't come with the product. The wired connection and short flex cable that connects to the board could pose problems with waterproofing as it will be difficult to keep all the wiring away from water. It will also pose problems with camera placement on the boat because the flex cable limits the camera's distance to the Raspberry Pi.

Specifications and features can be seen in the table below:

Table #: Raspberry Pi Camera Module v2 Specifications and Features

Feature/Specification	Camera Module v2
Operating Voltage	Regulated by Raspberry Pi Board
Resolution	1080p/1080TVL (high-definition)
Pixel	8 megapixel 3280 x 2464
Weight	3g
Data Transmission	Wired
Connector Type	CSI/Flex Cable
Power/Current Rating	Regulated by Raspberry Pi Board
Cost	$29.95

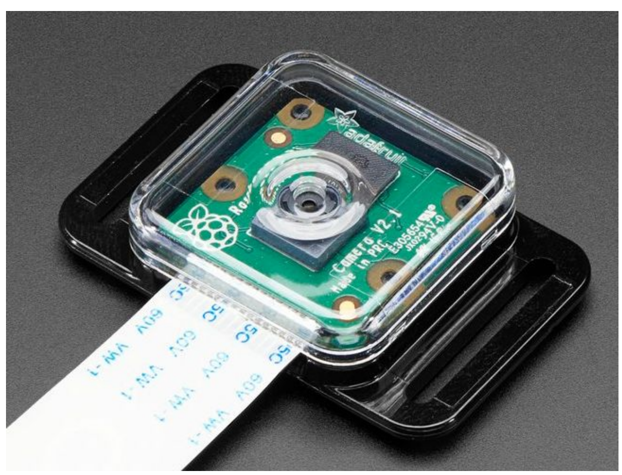
The final choice for our camera option is the Raspberry Pi Camera Module v2. This option showed multiple benefits compared to the mini FPV Camera. The resolution of the Pi module is high-definition and hence gives the benefit for a higher efficiency at object detection. The rescue vehicle will be able to detect a person in the water with more accuracy. Although the cost is high and the camera must be connected to the Pi board by a flex cable, the positives far outway the negatives. The flex cable should not pose a problem as bothe the board and the camera can be waterproof through a plastic casing. The waterproof casing will be explained in a later section.

Figure #: Camera Module and Raspberry Pi Board connected through flex cable

WaterProof Casing for Camera Module

The water proof casing is specifically built for the raspberry pi camera and is another reason why this camera module was chosen. The casing is cheap and provides an easy way for mounting the camera on the rescue vehicle. The flex cable is easily connected through the casing as is shown in the figure below. The cost for the waterproof casing is $2.95 and is sold by a third party Adafruit.

Figure #: Waterproof casing for camera module



Wireless Live Video Streaming

Video Streaming to a Display

In order to take advantage of the functionalities of the rescue vehicle and the live video that is captured and processed by the Raspberry Pi for object detection, it is necessary to display that processed video for it to be analyzed. This process here on out will be called video streaming. The processed video shall be streamed wirelessly to a display of our choosing which will be chosen in a later section.

It is obvious that sending the video data to a display through a wired connection is impossible due to the system being in the water. However, sending the processed video to a display is possible through various wireless methods. The method chosen is specific to the motherboard and camera module that was chosen for our rescue vehicle. Hence, since the Raspberry Pi board and Camera Module were both chosen for our vehicle, then methods for a wireless stream shall be specific to the Pi board. The process and method will be explained in the upcoming sections.

Display/Monitor Options

A display will be needed to view the video on the rescue vehicle. Since the Raspberry Pi will be processing the video for detection of a person in the water, it is important to have a display for the dispatcher to view when a person has been found. There are various options of displays to choose from and these will all need to be considered when designing the full system. To begin the selection of a display, we will take a look at a regular LCD display monitor.

Five Inch 40-pin 800x480 TFT Display

To begin with, this display is a non touch screen device. This was chosen for a lower cost alternative and because there is no need for touch functionalities. This display is sold by third party company Adafruit and contains a 40 pin connector and cable that is perfectly suitable for Raspberry Pi boards. The resolution of the display is set to be 800x480 and contains an LED backlight which will be more than enough resolution for viewing purposes. We must also pay attention to how video will be streamed to this display as the method difficulties will be a supporting factor for choosing the perfect display option. This display screen costs $29.95.

Choosing this display will require the purchase of a second Raspberry Pi because the display only has a 40 pin flex cable connection and does not have a built in receiver for receiving video wirelessly. Hence this will negatively impact the cost requirement for our system. Also, sending video from one Raspberry Pi to another is very tedious and unnecessary as it is possible to stream video using the original Raspberry Pi board. As a positive view, having a secondary board connected to a display allows for a better way to send sensor data along with the video. It can also be used to communicate to the Raspberry Pi that is on the rescue vehicle allowing for a larger range of usability.

Iphone/ Android/ PC Display

A more convenient option for a display to stream video is an Iphone or any device that can connect to a network such as an android or a laptop. These devices are more convenient to use as display monitors because it is more user friendly and would provide no additional cost for building our system.

The iphone already has excellent display quality and resolution. However, one trade off when compared to a computer is that the iphone can display one screen at a time. This could possibly pose a problem when trying to watch the live video stream and record the sensor data at the same time. This would require two pages to be displayed simultaneously. Using a laptop would fix this problem as two pages can easily be viewed at the same time on a laptop screen.

With the tradeoffs mentioned above, it is an easy decision to include a laptop that all 4 team members already own to use as a display. It is easy to carry around and can display multiple pages and data simultaneously compared to an iphone display. It will cut costs immensely as there is no need to purchase the five inch TFT LED Display. The LED display would require extra purchases to be made since we would need a second raspberry pi. This is unnecessary and would negatively impact our goal to make the overall system to be inexpensive and efficient at the same time.

Bluetooth Connection

Bluetooth technology is a form of wireless technology that uses short-range radio frequencies to allow any two devices with the technology to communicate with one another. It’s known as an electronics standard, so manufacturers typically abide by specific requirements to meet industry standards. These industry standards are called the Bluetooth Core Specification and are overseen and regularly updated by the Bluetooth Special Interest Group (SIG).

Bluetooth operates at frequencies between 2.402 and 2.480 GHz with a 2 MHz wide guard band at the bottom end and a 3.5 MHz wide guard band at the top. It transmits radio signals by method of frequency-hopping spread spectrum (FHSS). With FHSS, Bluetooth divides transmitted data into packets and transmits each packet through a designated channel. Normally, Bluetooth has 79 unique channels with each channel having a bandwidth of 1 MHz. It typically achieves 1600 hops per second while using a variation of FHSS called adaptive frequency-hopping (AFH).

AFH is extremely effective at increasing resistance to radio frequency interferences by avoiding the crowded frequencies in the hopping sequence. This is great when dealing with static interference within specific frequencies within the range as all the channels afflicted with the said interference would be labelled as “bad” channels. This allows Bluetooth to avoid the bad channels in the hopping sequence. The instances when this wouldn’t be effective is if the frequency range was being afflicted by dynamic interferences in the system. If the “good” and “bad” channels within the frequency are constantly changing, then AFH won’t be effective at avoiding the interference in the system.

The minimum transmission range of a given Bluetooth device is typically less than 10 meters (33 ft), but there isn’t a definitive upper limit for range, although larger distances negatively impacts data transfer rate as well as the power consumption. The ranges of Bluetooth devices are divided by classes. These classes are as follows:

Table #: Ranges of Bluetooth Devices by Class

Class	**Maximum Permitted Power**		**Average Range (m)**
	(mW)	**(dBm)**	
1	100	20	~100
1.5	10	10	~20
2	2.5	4	~10
3	1	0	~1
4	0.5	-3	~0.5

UART

UART stands for Universal Asynchronous Receiver/Transmitter. It’s a computer hardware device, typically part of an integrated circuit, responsible for asynchronous serial communication that utilizes configurable data formats and transmission speeds. There are commonly one or more UART peripherals integrated into microcontrollers.

The UART deconstructs bytes of data and transmits the individual bits sequentially. Once at the destination, the UART that received the data reconstructs the bits into complete bytes. This is done as it allows UART devices to communicate via serial transmission, which uses only a single wire rather than parallel transmission, which uses multiple wires. UART devices utilize shift registers to convert between serial and parallel forms, and this ultimately results in the UART being less costly. Communication can be either simplex, half-duplex, or full duplex.

Wi-Fi

WiFi is a set of wireless network protocols based on the IEEE 802.11 family of standards, which is most known for its common practice use for local area device networking and for internet access. Wi-Fi stations use data packets, which are blocks of data, to communicate with each other. These packets are individually sent and received over radio via carrier waves, which is a modulated waveform with the purpose of conveying information.

Wi-Fi uses different techniques, depending on the version, to send these carrier waves. The most recent version of Wi-Fi, Wi-Fi 6, uses orthogonal frequency-division multiplexing (OFDM). OFDM is a type of digital transmission that uses multiple carriers that are on slightly different frequencies within the channel as a method of encoding data.

Wi-Fi channels are half-duplex, which means that two devices connected through a Wi-Fi channel can both communicate with each other, but not at the same time. If multiple networks attempt to use a channel simultaneously, the channel will be time-shared, meaning that the networks will take turns using the channel for an allotted amount of time. When two stations attempt to transmit simultaneously, that is known as a collision. In the event of a collision, the transmitted data becomes corrupted, and the stations are required to re-transmit. This reduces throughput, and in some instances, by a significant amount. To prevent such an event, carrier sense multiple access with collision avoidance (CSMA/CA) is used, which is a scheme that is used to handle how computers share a channel. It makes attempts to avoid collisions by having nodes begin transmission only when the channel is detected as “idle”. Once idle, nodes transmit all of their packet data at once. While there are still chances where collisions may occur, this does reduce the possibility by a good margin.

Wi-Fi stations are programmed with a globally unique address known as a MAC address. MAC addresses are 48 bits in length and are used so that both the destination and source of all data packets can be specified and traced. Wi-Fi establishes connections using the destination and source addresses. When a device receives a transmission, it uses the destination address to determine if the transmission was meant to be sent to that device. If the aforementioned device's address does not match that of the transmission's destination address, the network interface most likely does not accept the packet as it was likely meant to be sent to another Wi-Fi station.

The operational range of Wi-Fi depends on several different factors such as frequency band, transmitter power output, receiver sensitivity, antenna gain, antenna type as well as modulation technique, but overall, Wi-Fi is capable of achieving far greater distances than Bluetooth. In general, longer distances means that the speed of transmission is reduced. For Wi-Fi signals, line-of-sight is best for communication between devices, but not necessary.

Wi-Fi transmitters are low power devices. While the maximum power that a Wi-Fi device can transmit is regulated at a local level, the European Union limits the maximum power to 20 dBm or 100 mW. While Wi-Fi is still considered to take up relatively little power, it should be noted that due to Bluetooth's shorter propagation range, Bluetooth's power consumption is lower.

Streaming on VLC Media Player

Choosing a display option for streaming is only the first part of live video streaming. The second portion misunderstanding which platform to use for streaming the processed video. VLC Media Player is compatible with both the iphone and a laptop. It would be impossible to use it on the TFT LED Display, which is another reason why that option was not chosen. Step for streaming on VLC with the Raspberry Pi can be seen below:

<u>Streaming Configuration</u>

1. The most important step is to ensure that the camera module is configured and enabled using the Raspberry Pi Software Configuration Tool. This can be accessed by "sudo raspi-config"
2. Without VLC player installed on the raspberry pi, it will not know where to send the video because VLC media player must be connected on both platforms. Hence VLC Media player is installed using "sudo apt-get install vlc"

3. Once VLC is installed, the video can be streamed by writing various commands to specify the width, height frames per second, and destination that the video is going to. Http must be specified in the code and the video must be flipped due to mirroring effect.
4. Lastly, it is important to know the IP address of the raspberry pi which can be found using “iconfig”. The IP address of the raspberry pi is automatically set to dynamic, which means the IP address will change after every reboot. For more efficient use, the IP can be changed to static though methods that will be discussed in a future section.
5. Finally, VLC Media Player can be opened on either the Iphone or on a laptop. The stream can be seen by opening a network stream in the settings and filling out the IP address of the Raspberry Pi on the command window. The destination number that was established in the code must be written as well.

Streaming on Browser (http)

Streaming on a browser window is simple and is very similar to streaming on VLC. A positive of this method of streaming is that when streaming to a browser, a video window and sensor data can both be displayed on the same window. This makes it easier to view sensor data while watching the stream at the same time. Using this method can also benefit the video that is displayed as controls can be set up for the camera. Brightness settings, contrast and pictures can be taken while the video is streaming live. Steps for streaming on a browser can be seen below:

Streaming Configuration

1. The same process of enabling the camera module must be done in this method. Github must be downloaded in order to run OpenCV code and scripts from github. A github clone must be done to copy the code install.
2. Once the install is complete on the raspberry Pi, all that's left to do is open up the video stream on the browser. This can be done by typing in the IP address of the Raspberry Pi on the url followed by the port number used and the subfolder.

Streaming on the Browser has much more potential for multiple data being displayed on a single page. This method poses various controls that can be used to adjust the video quality on the rescue vehicle compared to using the VLC media player which has no control options. The controls that are possible with this method include shut down and reboot of the Pi board, taking a time-lapse of full HD resolution videos and saving them and time stamping. Image resolution and frame rate can be adjusted for video quality.

Static IP address vs. Dynamic IP address

In order to remotely connect to the raspberry Pi board through any wireless method, the IP address of the Pi will be needed. Hence, it is important to understand the difference between Dynamic and Static IP addresses. A dynamic IP address means that the address can change at any time. When connecting remotely to the Raspberry Pi, it will be repetitive and inefficient to update the IP address every time the address changes or everytime the board is turned on. Hence, we must consider changing the settings from dynamic to static.

A static IP address does not change. Hence, we can assign a permanent address on the network to the Raspberry Pi. This process is rather simple and can be viewed in the section below.

Setting Up a Static IP Address

Assuming that Raspbian has already been installed and is running on our system, the first step is to connect the Raspberry Pi to a network that we will be using. Once connected the current IP address assigned to the board must be obtained as well as the Broadcast Range Number and the Subnet Mask. These values can all be obtained through the “ifconfig” command only when connected to a network. Next the following code must be run to gather information on the network router “sudo route -n”. This will give us the Gateway number and the Destination number needed to set up a static IP address.

Finally, we must open the configuration file for network settings by running the code “sudo nano /etc/network/interfaces”. This allows us to change the line of code that reads “dhcp” (Dynamic IP) and change it to “static”. Under this same line of code we can now write our chosen IP address followed by the netmask network number, broadcasting range, and gateway number that was previously recorded. Running “sudo reboot” will then restart the Raspberry Pi with the new Static IP address.

Standards and Design Constraints

This section will outline the importance of design constraints and design standards. Various constraints and standards that relate to our Autonomous Rescue Vehicle design will be explored.

Related Standards

Standards are documents, forms, or any type of description of a certain product that establishes clear outlines and features for a product or service. Standards are one of the most important applications in any product whether a company is selling it or a single designer is building it. Applying standards to products help guarantee that they are safe to use, effective, compatible, and most of all environmentally friendly or unfriendly. Standardization is usually released from national or international organizations such as the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC).

It is important to understand that there are many other associations all over the word dedicated to the creation of such standards. Some regulations and standards even come down to specific companies. There exists standards and regulations for every type of product or service, from screws and nails to air planes and cars. Hence, the reason for the plethora of committees. For our design project, the Autonomous Rescue Vehicle, standards will be gathered through two organizations. The American National Standards Institute (ANSI) and IEEE Standards Association. For our design project, most standards will come from IEEE and will be used to ensure all safety and regulations are up to date in our design.

IEEE-1679.1-2017 Characterization and Evaluation of Lithium Based Batteries

For the purpose of our design, this standard will be focused primarily on the Lithium Ion Polymer Battery or LiPo. Lithium Ion Polymer is a lithium-ion cell contained in a soft pouch where the electrolyte is gelled by using a polymer additive. When charging lithium ion batteries it is important to charge them specifically with the matched charging device. For safe operation of a LiPo, it is important to only use the charger that is provided with the battery system.

LiPo batteries are always sealed for the prevention of moisture contact from the atmosphere. There should be no effect from any environmental variables such as salt from the ocean, water spray, or rain. Hence, it's important to prevent any destruction to the concealment of the battery. The battery must be placed in any application with proper care so that continuous vibration, thermal cycling, and shock will not cause damage to it. In section 5.10.1 of the related standard, constant monitoring is required for any lithium based battery.

It is also important to understand over-discharge and overcharge. Over-Discharge occurs in a battery when the cell voltage falls below a critical value limitation. This allows for the copper from the negative foil of the battery to dissolve into the electrolyte. Once the battery is recharged the copper comes out of the solution and creates tiny shorts causing the battery to not function. hence , it is important to understand the type of application the battery will be used for.

Some applications allow for operation with a minimum battery voltage. If this continues for a prolonged period without the battery being discharged, then over discharge will occur. Overcharging a battery is the result of the voltage being significantly higher than the recommended operating condition. It is important to follow charging rate limits to prevent cell damage and catastrophic failure.

Before using lithium based batteries in any application, the user should be responsible for knowing all potential safety hazards and issues. Abuse tolerances help eliminate discrepancies on how to handle LiPo batteries. Abuse testing includes electrical abuse, environmental abuse, and mechanical abuse. These tolerances help determine the risk of surrounding equipment in the application inorder to prevent any injuries or equipment damages.

Lastly, it is important to know specific fire codes for lithium based batteries in case of a damaged battery or a catastrophic event. Both the International Fire Code (IFC) and National Fire Protection (NFPA) have specific requirements for lithium batteries. Disposal of batteries and regulations are required to be followed and is regulated for environmental control. Lithium based batteries cannot be disposed of in household waste because of the organic chemicals in the electrolyte. It is also dangerous to throw them away in unknown waste because these batteries contain active materials and can cause shorts and fires.

Battery Standard Design Impact

The battery standard discussed in the earlier section significantly impacts how we properly handle and use the LiPo battery for our design project. The Lithium Ion Polymer battery is the main component of the entire system. WIthout this battery, the motors of the boat will not function and the main goal of the system will not be reached. Hence, it is important to follow the guidelines that were established in the IEE Lithium battery standard. Over-discharge and overcharge impacts our design application by setting a higher limit voltage for the system to function. If we allow for operation of the vehicle for a prolonged time with the battery under critical voltage values, then we can run into the possibility of shorts and failures.

Since the battery is already sealed and lithium based battery standards state that they are safe from environmental effects, there is no reason to limit the conditions that the vehicle can operate in. However, abuse tolerances from the battery standards will affect the location and placement of the battery in our system. Precautions must be taken to prevent the battery from constant vibrations, shocks, or any shorts from touching other equipment in the system.

IEEE-12207-2017- Software Development Standard

Software development and software systems have continuously increased in complexity throughout time and continues to progress. As a result, new challenges exist in creating an approach for tackling the softwares architectural design. This standard helps integrate all disciplines and groups to achieve a functional software design that meets the needs of the application.

This standard will pose comprehensive sets of procedures to follow in order to provide a structural and workable environment for developing the software. For our design project, this standard will be useful in writing software that processes video ford object detection and autonomous vehicle movement. Creating a structured software application that has a high efficiency is important for our design as the rescue vehicle will be processing data and following coded instructions simultaneously.

According to ISO/IEC TS 24748-1, a typical software development life cycle includes a variety of stages. It begins with concept, and continues through development, production, utilization, support, and retirement. Understanding each progressive stage gives rise to making individual decisions and achieving milestones set out for the specific program. This reduces risks and uncertainties in cost, scheduling, and utilization of a new software.

This standard helps reduce uncertainties when dealing with the overall software application in our rescue vehicle. It is important to understand how to analyze and assess the needs of each software application related to a project. It is also important to know how to improve the process of working on development. The IEEE standard calls out 3 important factors when analyzing and assessing the process which will aid in our own development for our design project.

The first factor is to monitor performance of the group and the software being created. The second factor is to conduct periodic reviews to process any achievements and progressions. Third factor is to identify any improvement opportunities from the assessed results. It could be difficult to find ways to improve software development because it is already difficult enough to organize and develop an original project. However, the standard outlines specific tasks that will be beneficial to our design project. Prioritizing and planning will eventually lead to new lessons learned. Once these lessons are learned, improvements to any design are captured and easily achieved.

IEEE1609.0 Wireless Access in Vehicular Environments

This IEEE standard outlines specific regulations for wireless access in vehicular environments. It specifies that wireless access or transmitting data via wifi from a vehicle is a radio communication system that intends to provide short range communication between devices (DSRC). This standard is vital to our design project as pur rescue vehicle is a vehicle transmitting data short or long range distances wirelessly. IEEE calls these standards the WAVE standards and were developed to provide support for transportation safety, efficiency, and sustainability. Sustainability and environmental effects are crucial to our design project as it will be set out in water and eventually the ocean for rescue.

Within the standard 1609.0, IEEE calls out a related standard that applies to networking services for wireless transmission that includes many features. It outlines proper ways for WSA transmission and the use of Internet Protocol version 6 (IPv6) including streaming. It also outlines how to manage information and data that is communicating between the two devices.

Short range communication messages are specified in the SAE DSRC standards. They are important to understand for communicating short range data that is intended for vehicle-to-vehicle and vehicle-to-infrastructure. It includes specifications for safety exchanges between the two devices and the proper way to implement the messages. In order to classify a proper WAVE system, the IEEE standard specifies how the system application should offer safety and convenience to intended users. It should support and offer users greater situational awareness, potential threats, and hazards. Transactions between vehicle and hand-held devices should support a network with low latency. With a low latency requirement for this standard, the US. FCC allocated a spectrum band at 5.9GHz in order to support these types of applications.

There is no requirement for secure communication, however, depending on the application one should lean towards a secure environment for safety options to intended users. Lastly, the WAVE standard describes a protocol for short messages of data transferring. This allows for applications to directly control characteristics such as the transmitter power and channel number. It provides access to the PSID and MAC address of the destination that the data is being sent to. Short message data exchanges are outlined in the IEEE standard as follow:

- An application acting as a source creates WSM data for transmission purposes. It then addresses it to the MAC or PSID address.

- Based on any configuration that was assigned, the application or software should select an appropriate radio channel to control the transmission of data.
- A device dedicated foro receiving sata accepts the package and sends it to the communication stack.
- Based on the PSID, the WSMP then delivers it to the receiving entities.
- Finally, the receiving device whether infrastructure or hand held, knows the existence of the data package and the address of the originating vehicle and continues the exchange continuously. This can be done through unicast or broadcast.
- It is important to note that the same process can be said for internet protocols to support IP version 6 (IPv6)

Wireless Access Standard Design Impact

The wireless access in vehicular environments architecture standard impacts our entire design approach for wireless communication and data transfer. It allows us to properly communicate and exchange data between devices the correct way that follows regulations. Our rescue vehicle is a water based vehicle for any type of water, such as a lake or ocean. Hence, environmental and safety standards are crucial for our design and the wireless access standards help minimize any environmental issues we will encounter.

Our vehicle will constantly be sending data wirelessly through wifi and streaming video is a main feature for our design. In standard 1609.0, specific protocols for proper ways of WSA transmission and the use of Internet Protocol version 6 (IPv6) are established. Streaming is also included in these protocols and will help us understand proper ways to stream video based on these standards.

Our project design will include short range wifi data transmission. Long range transmission will be a goal for an updated model of the rescue vehicle, however, both long range and short range communication falls under the same WAVE standards and impacts our design. The standard calls out that the system should contain proper ways to establish greater situational awareness for its intended users, find potential threats, and contain any safety hazards. This only confirms that our rescue vehicle will have no problems following this standard because it will continuously stream video and live object detection which creates the intended situational awareness. Potential threats are continuously taken care of as the boat finds any person in need of rescue. Lastly, hazards are quickly monitored as the vehicle continuously sends data related to depth of the water to prevent any unwanted risk in a rescue attempt.

IPC - PCB Standard (Printed Circuit Board)

PCB standards are widely used for manufacturers to print reliable and regulated circuit boards. Common standards that provide reliability for the user and safe handling are acceptable methods for hardware installations, acceptable soldering and requirements for through-hole technology on circuit boards and surface mount parts. PCB standards are established through IPC or Association Connecting Electronics Industries. IPC regulates many standards tha manufacturers of PCBs need to follow for producing reliable products and circuit boards that will last for a long period of time.

The most widely used standard for manufacturers is IPC-A-610 - Acceptability of Electronic Assemblies. This standard outlines the proper handling of PCBs and acceptable methods for installing and soldering parts to the board. IPC-A-60 - Acceptability Standard for Manufacturing, Inspection, and Testing is a standard that outlines how to assemble circuit boards and the proper way to inspect them after the build. This ensures that manufactures hand circuit boards with care so that no failures arise and reliability can remain balanced. Inspection of proper coating, wiring, and layers are specified in this standard.

These IPC standards affect the project design by increasing reliability with manufacturers that are preparing the circuit boards. These standards allow for the possibility of catching the smallest manufacturing imperfections and fixing the problem before it exists. It reduces risk of overlooking proper PCB handling and helps avoid electrostatic discharge (ESD).

Design Constraints

Constraints are an important factor in any design project whether it is foro engineering or for a business model. Constraints are essential There are various realistic design constraints for the autonomous rescue vehicle.

Software Research

Tensorflow

Overview

Tensorflow is an end to end open source platform for machine learning. It is a Python based, free software library for dataflow and differentiable programming across a range of tasks. Tensorflow is capable of running on single CPU systems, GPUs, mobile devices, and large scale distributed systems. It will serve as the cornerstone of the programming required for the A.R.V. to recognize a disaster on the water and react to it.

Tensorflow began its life as DistBelief, a proprietary machine learning platform. It was later simplified and streamlined, as well as made more robust. These improvements produced the Tensorflow that is available now. It can run on multiple CPUs and GPUS. The platforms that support the software are 64-bit Linux, macOS, Windows, and mobile computing platforms including Android and iOS. This is a key feature for the requirements of this project. The Raspberry Pi has the power to run Tensorflow, and Tensorflow has the flexibility to run on a mobile device, which is the end goal user platform for the A.R.V. system.

Tensorflow and Raspberry Pi

The clock speeds of the Raspberry Pi 4 allow for it to effectively explore machine learning. The increase in RAM up to possibly 8GB also supports the processing-heavy nature of Tensorflow. We may also consider a CPU fan for cooling, as the high demand of Tensorflow may cause the Pi to run hot. Installing the library to the Pi will require existence in a Python SciPy virtual environment. A virtual environment is an isolated environment for a project to have its own dependencies.

Object Detection and Image Processing

Tensorflow supports a number of Deep Learning models. Specific to the A.R.V. application, we will implement object detection for it to detect shipwrecks or survivors. Tensorflow takes an image as input, which will be fed from a camera module mounted on the boat, with enough elevation to see out over the water surface.

Tensorflow expects a 300x300 pixel image, with three channels (red, green, blue) per pixel. This should be fed to the model as a flattened buffer of 270,000 byte values (300x300x3). Since the model is quantized, each value should be a single byte representing a value between 0 and 255. The model will output four arrays mapped to indices 0-4 with the following convention.

Figure #:

Index	Name	Description
0	Locations	Multidimensional array of [10][4] floating point values between 0 and 1, the inner arrays representing bounding boxes in the form [top, left, bottom, right]
1	Classes	Array of 10 integers (output as floating point values) each indicating the index of a class label from the labels file
2	Scores	Array of 10 floating point values between 0 and 1 representing probability that a class was detected
3	Number and detections	Array of length 1 containing a floating point value expressing the total number of detection results

The standard detection package contains 80 classes of objects. A technique called transfer learning may be implemented to add classes to this detection range. This will require sets of training images to teach the machine with. Transfer learning is focused on storing knowledge gained through solving one problem and applying to another related problem. For example, knowledge gained recognizing ships against glaciers or icebergs can be applied to recognize specific types of vessels.

Power Requirements

Component Selection

Overview

The primary source of power for the boat will be a rechargeable battery in the range of 7.2-11.1 volts. We will explore typical batteries seen in RC applications. It will consist of multiple cells that have a common individual voltage rating, wired in series to sum to a desired output voltage, The objective in assembling the power supply is a minimum system run time of 8 minutes, the system being the boat and all onboard components.

Voltage will need to be regulated to different levels based on the operating requirements of each component. We will implement voltage regulators and DC-DC converters for this task, and explore the working components of these essential tools. While these are options for the measurement and detection components of the A.R.V., the heart of the system, the Raspberry Pi 4, requires a 5.1V input voltage via USB-C. This will call for a dedicated department in the working office of the A.R.V. power system.

Boat Battery

Technologies

The primary options for RC vehicle batteries are Nickel-Metal Hydride (NiMH) and Lithium Ion Polymer (LiPo) batteries. NiMH is the older of the two and was extensively researched in the 1970s, while LiPo technology was heavily explored in the 1980s. Below is a comparison of the essential data points for the two technologies.

Table #:

	Nickel-Metal Hydride	Lithium Ion Polymer
Specific Energy	60-120 W*h/kg	100-265 W*h/kg
Energy Density	140-300 W*h/l	250-730 W*h/l
(Charge) Cycle Durability	180 - 2000 cycles	300-500 cycles
Cell Voltage Rating	1.2 V	3.0 V

The unit for energy density is a measurement of how much energy a battery contains compared to its volume, hence the unit Watt-hours per liter. The LiPo battery outperforms the NiMH in most analytical categories. LiPo batteries are lighter than their NiMH counterparts, and they deliver more power for longer periods. They can also be charged whether fully discharged or not. The performance advantages of LiPo are clear, but there are features where the NiMH has an edge that must be considered.

Overall, Nickel-Metal Hydride is a safer technology than Lithium Ion Polymer, as well as far more easily maintained. Trickle charging is typically used for the NiMH, which is a constant, low current in the range of C/20, where C is the current value obtained by dividing the mAh capacity of the battery by one hour. This low current allows the battery to continue charging after reaching capacity, although overcharging should still be avoided. Overcharging is a far greater concern for the LiPo battery, and is only one part of a much more complex charging and maintenance procedure.

LiPo requires specialized chargers that monitor the voltage level in each cell to ensure that that the charge in one cell does not exceed that of the others.

Without this monitoring, the battery's life and performance can be severely affected. Cell imbalance can even cause instability and risk to the user or system. Overcharging a LiPo battery may result in the battery expanding or "puffing", smoking, or even catching fire. Another consideration is that a fire caused by a LiPo is a chemical fire, so it cannot be put out by regular means. This calls for the use of a fire-proof LiPo bag for charging and storage, which brings another set of protocols to follow.

Lithium polymer batteries should not be stored fully charged for more than 2-3 days. This requires having a discharger in addition to a charger. They also should not be discharged below 3.0V per cell. Ideal storage voltage is 3.8V per cell. It is all these requirements that call for complex LiPo chargers, as well as careful ownership and use.

Negative effects from improper storage are not significant in hobby use, but they will have a larger effect when considering the capacity that the A.R.V. will be used in. It is intended as a standby measure to be called upon and relied on when every second counts, but may not be called upon for weeks or months at a time. This means storage is an important consideration, as it waits for a disaster to respond to. Batteries also experience negative effects on performance from extreme weather, whether too hot or too cold. Cold weather slows down the chemical activity in a battery, while hot weather will accelerate chemical activity, causing fluid to evaporate which will damage the battery. While either battery option will need to be properly waterproofed, LiPo batteries are far more volatile in water, as well as made unsafe from chips or nicks to their exteriors.

All of the above safety concerns shift the spotlight to the NiMH battery for implementation in the A.R.V., but the extensive power requirements of the system may call for a NiMH battery that is simply too heavy to support efficient operation. It is for this reason that we will compare the best batteries we can find from each of the two technologies.

Portable Power for the Raspberry Pi

Overview

The Raspberry Pi requires its power via a good quality, 5V USB-C connector with the following current parameters.

PSU Current Capacity	Max USB Peripheral Current Draw	Active Consumption
3.0A	1.2A	600mA

The Pi’s GPIO pins have a total requirement of 50mA, the HDMI port 250mA, and the Pi camera 250mA.

Portable chargers, which are popular bricks with USB ports and capacities in the 2,000-10,000 mAh range may be used to power the Pi, however they become heavy and bulky as capacity increases. We will explore two lightweight options that mount directly to the board: the PiJuice HAT, and the MakerFocus Raspberry Pi 4 Battery Pack.

PiJuice HAT

The PiJuice HAT has a baseline capacity of 1820mAh via a Lithium Ion Polymer Battery for 4-6 hours of constant use. The same LiPo principles and concerns from the typical RC examples apply to this battery as well. The HAT also has support for larger, 5,000 or 10,000 mAh batteries. It doubles as an Uninterruptible Power Supply (UPS) which can protect the board from sudden data loss. This is achieved with a configured, managed shutdown that kicks in when the main power is depleted. It has a low power deep-sleep state with smart wake up, as well as onboard timers such as a watchdog that keeps it on and running. This would be useful in downtimes for the A.R.V. as mission information develops.

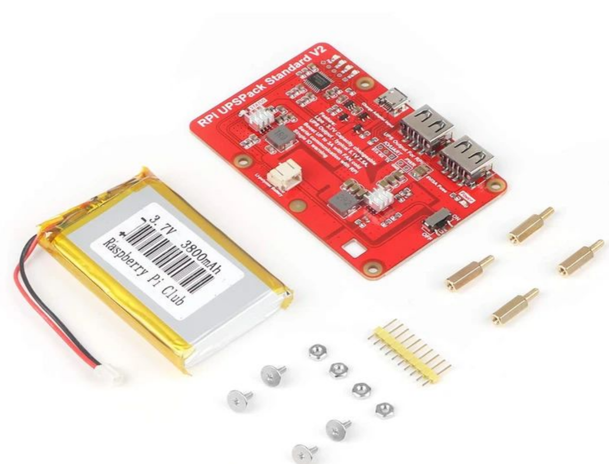
The on board Real Time Clock (RTC) keeps track of time whether it is powered or connected to the internet or not.,. There are RGB LEDs for battery level indication. There are even buttons that may be programmed and implemented to trigger actions via scripts. A key advantage is the header on the power supply. It allows for further expansion. Additionally, the HAT only uses 5 GPIO pins on the Raspberry Pi, leaving plenty of room for add ons before calling upon its own pins. The HAT is versatile in charging and replacement options. It will accept charge via the on board USB-C, the board’s USB-C, or from the onboard pin headers. It is compatible with any single cell LiPo or LiIon battery. It is the most popular solution for portable Pi power.

Figure #:

MakerFocus Raspberry Pi 4 Battery Pack

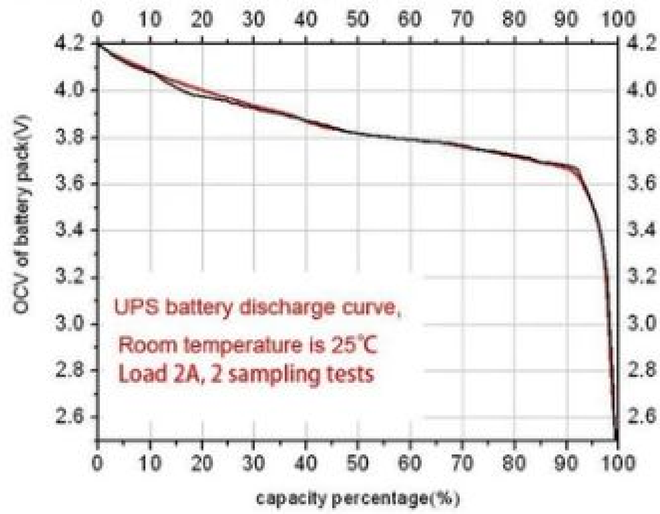
The MakerFocus Raspberry Pi 4 Battery Pack is a popular alternative to the PiJuice HAT. It is similar in concept but differs in execution. It does not offer some of the HAT's key features like headers and advanced timers, but it is significantly cheaper and accomplishes the core function of a power supply effectively. It may be charged in the on or off state and has 4 battery indications LED's - slightly more accurate than the HAT's 3 LEDs. It has dual USB output and has overcharge protection for the lithium battery. It has a capacity of 3800 mAh and can power a Pi board for up to 9 hours.

Figure #:



The discharge curve for the pack is below. It offers a steady voltage over 3.6V, then a steep dropoff for the last 10% of its capacity.

Figure #:



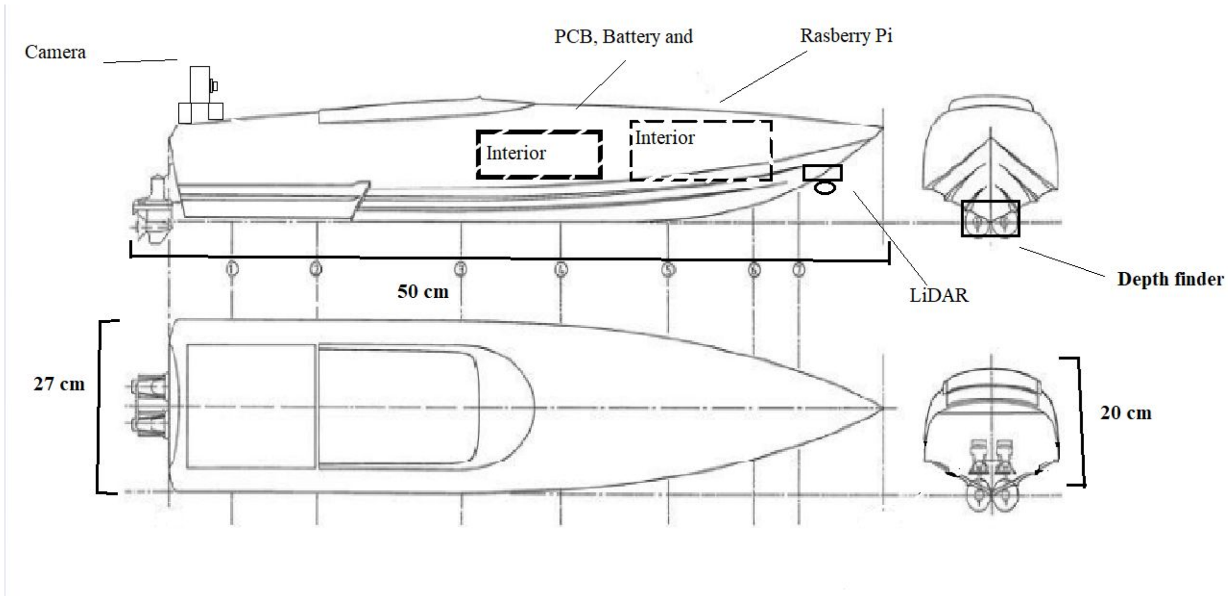
The table below outlines a comparison between the Pijuice HAT and the MakerFocus RPi Battery Pack.

Table #:

	PiJuice HAT	**MakerFocus RPi Batt Pack**
Capacity	1820 mAh	3800 mAh
Cost	$88.95	$20.99
Runtime	4-6 hours	9 hours

Project Prototype Illustration

Figure 1. Initial Design Illustration



Above is the prototype illustration of our completed project. As seen in the image we will be inserting all extra circuitry inside the interior of the hull, including our PCB, raspberry Pi and Battery.the location of these items in the interior is a rough estimate as we will most likely move them around to optimize our pace and balance.

On the exterior of the boat we have both the measurement of the boat as is given in its data sheet, but also the placement of our exterior sensors. Most of the placement is fairly intuitive, the depth finder will be mounted on the bottom of the boat sealed in a watertight epoxy. This is so that we can aim the transducers towards the bottom of the water to receive our best ping possible. (see section for more on the transducer)

Our raspberry Pi and PCB boards will both be located inside the sealed hull of our boat. The final placement for these will change as time goes on. This positioning will be finalized once we see where the pre positioned motors and circuit boards inside the boat are placed. The inside of the hull is water tight with a rubber sealant so there is no concern of the boards being damaged. (see section for more on PCB and Raspberry Pi)

For our model of the boat there are small compartments for carrying cargo located on the rear of the boat. These will be removed making space for our camera, this is why they are not included in the diagram of our prototype. After these are removed there will be a small stand erect for the camera to go on top so that it has a clear field of sight for its image processing. (for more information on the camera see section)

The last exterior sensor we are adding is the liDAR. This will be attached to the front of the boat pointing in the same direction as the camera. We do this so that we are sure they are looking at the same objects so that the liDAR can determine the shape and distance from the boat to the object it is. All wires and connections to these sensors will be fed into the hull so that they can connect to the microcontrollers. These holes will be sealed so as to guarantee the interior stays dry.

Project operation manual