Automated Rescue Vehicle (A.R.V.)

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***Abstract* — This paper presents the design methodology, research components, and implementation results of the A.R.V. project. The system was developed with the goal of assisting in search and rescue efforts on large bodies of water. The key features of the system are autonomous movement and object detection. These features allow the user to themselves scan the water or otherwise assist in rescue efforts. This project was chosen for its healthy mix of electrical and computer engineering requirements, and for its ability to increase safety in an enormous industry.**

***Index terms* — Autonomous vehicles, object detection, microcontrollers, image analysis, image classification, DC-DC power converters**

I. Introduction

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 this intuitive level of assistance.

It is the directive of this project to provide a lightweight, portable solution to the search and rescue 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 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.

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 under which we intend to implement the A.R.V., 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 in 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 is not designed in a manner to risk another disaster if a malfunction occurs. As an independently funded project, cost was in heavy consideration with the selection of each component.

The initial prototype sketch of the A.R.V. is provided in the next figure. This was constructed as a map of component locations, with protection and weight distribution as dividing factors.

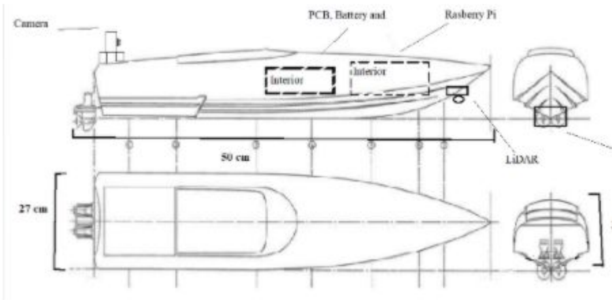

Fig 1. Initial Prototype Illustration

II. Design Requirements Specifications and Constraints

Quantitative and qualitative design requirements were outlined for the A.R.V. to guide the design and construction of the project. Three of these requirements were chosen to be focused on in the project demonstration, being the degree of certainty to which a person is being detected, the refresh rate of the GPS location, and the communication range between the user and the system.

Requirement	Value
Object Detection for a Person	70% assurance
GPS Location Update	<5 seconds
Communication Range	>10 meters
System Runtime	>30 minutes
Speed	<6 miles per hour
Battery Lifetime	>30 minutes
Low Battery Alert	<= 6V

Fig 2. Design Requirements ___: Demonstrable

Due to the portable nature of the project, power specifications needed to be established and strictly adhered to from the beginning of the design process. These specifications would govern component selection, realistic design requirements, and most obviously the design of the power system.

Further requirement specifications of the overall system were classified under Level 1. Level 2 set forth specifications for the vessel itself, and Level 3 pertained to the controller interface itself.

Level 1

- Weight limit: 15lbs
- Dimensions: 18in L x 8in W x 8in H
- Rechargeable
- Reasonable durability to shocks or small impacts
- Wireless data transmission

Level 2

- Sufficient buoyancy and hydrodynamics after the addition of new components
- Maximum motor power of 8000rpm
- Power system and circuitry waterproofing
- Indication for low battery

Level 3

- A laptop compatible with WiFi or Bluetooth
- Capable of displaying live video while maintaining portability
- Display of both video feed and data transmission
- Display of low battery

Upon the establishment of design requirements, relevant constraints were researched and introduced in order to set limits on the scope of the project., and ensure safe design practices.

Economic and Time Constraints were quantified by a construction time frame and project budget. The A.R.V. is entirely self funded, as aforementioned, so an initial budget of 600 USD was set. The construction time is roughly the time frame of the Senior Design 2 Course, or August 2020 to December 2020.

Environmental, Social, and Political Constraints have a somewhat unique priority in a project that involves large bodies of water. There are many considerations to be made in the interest of not contributing to pollution and not endangering marine life. One of the components at the forefront of this concern is the LiPo battery, which will be detailed technically later in this paper. It is rechargeable, and thus does not contribute to potential ocean waste in design. However, if not properly secured and protected, it can contribute to waste in practice.

Ethical, Health, and Safety Constraints are indirectly paired with Environmental Constraints for this particular project. The protection of the LiPo battery continues to be the priority, as exposure to water creates an extremely dangerous chemical reaction. This reaction is a chemical fire that creates hazardous flames, temperatures, and fumes.

Manufacturability Constraints played a significant role in the pandemic era. Inventory shortages and extended shipping times called for backup components to be selected and several distributors of the same component to be found.

Sustainability Constraints governed the power consumption considerations in the project design. We did not intend to ever create a scenario where the A.R.V. is stranded with a dead LiPo battery and electrical components that would inevitably end up in the ocean.

III. System Components Overview

The A.R.V. system can be viewed on a large scale by its major operating components. Additional parts serve to support these essential devices, being the boat, microcontroller, camera, GPS module and battery.

The boat selected is a Flytec 2011-5 RC boat. It has several standout features that make it an ideal candidate for modification and implementation to suit the requirements of the A.R.V. system. It is large in size, relative to other RC boats: 50x27x20 cm (height accounting for antenna). This large size allows for confidence in operating the A.R.V. in adverse conditions.Despite this size, the boat remains lightweight and durable thanks to its ABS plastic construction. The 2011-5 has exceptional run time from a single charging session. The factory power supply is able to run the standalone boat for up to 24 hours. This power supply will be later detailed in the power system overview. The impressive run time is achieved from a charge time of 10-12 hours. The boat is capable of 3.4mph or 2.95 knots. The final standout feature of the boat is the ample internal space. This is a crucial feature for the needs of the project. The other RC boats in consideration had enough internal space for factory components with little extra. The Flytec splits into two halves, the upper portion and the hull. When the boat is opened, a large area is revealed that has enough room for the additional components to be installed twice. The halves are easily reassembled and sealed with an o ring that follows the edge of the points of separation.

Two microcontrollers were selected for the A.R.V. An MSP430 will be implemented in the PCB design, later detailed. This implementation will handle the GPS signal transmission, as well as the voltage monitoring of the system. The MSP430 boasts extremely low power consumption, ADC and UART communication, and vast support resources. The Raspberry Pi 4 Model B was selected to handle the object detection and image processing requirements. The Pi is an extremely powerful microcontroller. It boasts a minimum 2GB of RAM and a clock frequency of 1.5Ghz. It is built on 64 bit architecture and uses a Cortex A72 ARMv8 chip. The Pi also has factory WiFi capability, which provides system communication. It also has a wide range of support resources, and a proprietary OS that is optimized for its capabilities. This microntoller has been previously implemented in advanced roles like object detection and machine learning, which gave confidence in resting the key feature of the project on its shoulders. The configuration of the MSP430 is detailed in the overview of the PCB design. The Raspberry Pi transmits camera data to the PC display via WiFi. An important note regarding the Pi is its power supply. While this will be detailed in the power design section, a quick glance at this supply shows a portable, 3.7V LiPo battery pack with built in protections and connection through a circuit board. The overall scheme of the Raspberry Pi 4 implementation is shown below.

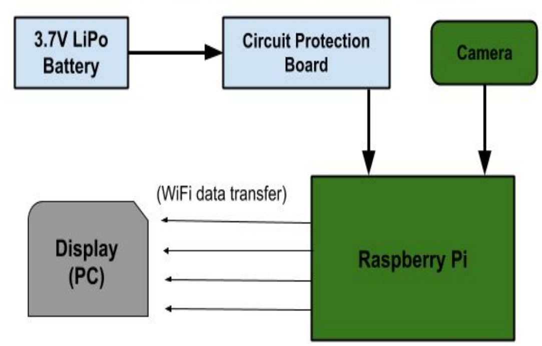

Fig 3. Raspberry Pi 4 Configuration

The next key feature of the Raspberry Pi 4 leads directly to the third essential component of the A.R.V. This component is the Raspberry Pi Camera Module v2. It is a proprietary component and is the camera that works best with the Raspberry Pi. It is capable of 1080p and is compatible with the A.R.V.'s object detection software. The Raspberry Pi has a dedicated port for connection with the module and makes installation seamless. There is a single driver installation required for basic camera operation. The camera's connection cable is long enough to support mounting the lens on a platform that will allow the camera to see over the water surface.

The device chosen to transmit GPS location data is the Neo 6M GPS module. It is a compact, cost effective device that is easily integrated with a microcontroller such as the MSP430. It also has a backup battery and on board memory chip. GPS data transmission will be carried out via UART, and is detailed in the GPS section. It has a transfer rate of 1 Hz and a 27 second start up to initial transmission time.

The battery for the A.R.V. is in fact two separate batteries. One handles the responsibility of powering the boat and PCB design, while the second handles the responsibility of powering the Raspberry Pi and the Camera Module v2. The first step in selecting batteries was making the decision between Lithium Ion Polymer (LiPo) or Nickel Metal Hydride (NiMh) technologies. LiPo technology proved to be more efficient in supply powering, as well as more lightweight and compact. These advantages are balanced by disadvantages in higher maintenance and safety concerns when compared to NiMh batteries. It is of utmost importance to keep water away from LiPo batteries, an obvious obstacle for the A.R.V. system. These safety concerns briefly pointed toward NiMh technology for choosing a battery, however a battery of this type that would satisfy the power requirements of the A.R.V. would be too heavy and bulky, running the risk of compromising the buoyancy and maneuverability of the boat. As a result, both batteries were selected to be LiPo type.

IV. Power Requirements and System Design

The power system for the A.R.V. is integrated into the hull of the boat, along with the control and transmit/receive components. This is where the cornerstone of the PCB design is laid. All components that require a power supply for functionalities are listed in the table below. This table outlines all voltages needed to operate the full system. It is also with this information that the DC-DC converters were designed.

Qty.	Part	Operating Voltage	Max Current	Power
2	Motor	5V-9V	500mA	2.5W - 4.5W
1	MSP30F5529	3.3V	5.3mA	17mW
1	Raspberry Pi 4	5.1V	1.2A	6.12W
1	Pi Camera	3.3V	480mA	1.58mW
1	GPS Module	3.3V	67mA	22mW
1	Wifi Module	3.3V	250mA	825mW
1	Motor Driver	7.4V	2A	14.8W

Fig 4. Powered Components in the A.R.V. System

As mentioned in previous selection, two batteries were chosen to satisfy these system requirements. The first is the factory Flytec battery, a 7.4V 5200mAh, 4 cell LiPo. This battery is sufficient for the 7.4V requirement of the motor driver, and will also be stepped down to meet the needs of components in the 3.3V range. The motor driver (See VII. Automation) has an on board 5V converter that allows for an input range of 5V-12V. The Raspberry Pi has unique power requirements, being 5.1V delivered via USB-C connection. It is this specific role that the MakerFocus Raspberry Pi Battery Pack fills. It is the combination of a slim 3.7V, 3800mAh LiPo battery pack, and a circuit board that serves as the bridge between the Pi and the battery. It is capable of running the Pi for up to 9 hours, however the lofty processing needs of object detection and image processing will reduce this figure. The circuit board offers protections against undervoltage, overvoltage, and overcharge, as well as on board charge level indication via LEDs.

The first important specification needed in the DC-DC converter design was the current draw from each load. These provided a rough estimate on the maximum current output that needed to be set for the regulator. The DC-DC converter was designed using TI's Webench

Power Designer Tool, with an efficiency requirement of 88%. The foremost design parameters of any DC-DC converter are the input and output voltages. We chose an input range of 5V-12V to not only satisfy the 7.4V battery in use, but also allow for implementation of a larger 11.1V LiPo battery in the future for higher motor speeds. The output requirement is 3.3V with as little ripple as possible. The converter is a buck converter design. The design schematic and block diagram are shown below.

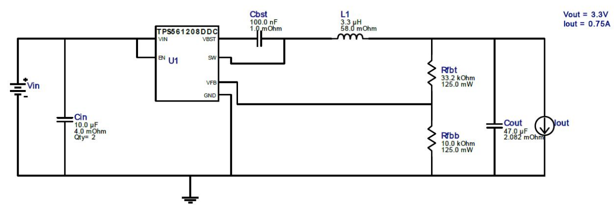

Fig 5. DC-DC Converter Design Schematic

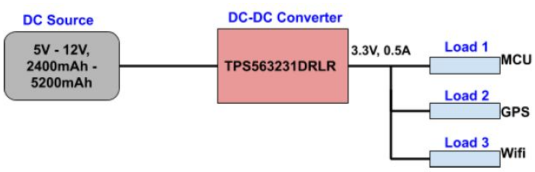

Fig 6. DC-DC Converter Block Diagram

V. Voltage Monitoring

A worst case scenario for the A.R.V. is a loss of power leaving it just as stranded as the survivors it is looking for. This hypothetical was the birth of the voltage monitoring function. The voltage of the portable Raspberry Pi power pack is what is monitored, because its life is much shorter than that of the battery that powers the movement of the boat. The core of this function is the ADC offered by the MSP430, which is implemented on the PCB design. The ADC pins of the MSP have a 3.5V input limit, so the voltage from the LiPo battery pack is stepped down by a factor of 3. The reading is then multiplied by 3 before being sent to the display. The resolution of the ADC is 10 bits. The digital output is converted to the proper voltage reading to be easily identified by the user. This design scheme is shown in the next figure.

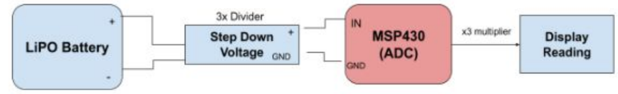

Fig 7. Battery Voltage Monitoring Design Scheme

VI. PCB Design

The core of the PCB design is the MSP430 footprint. This footprint contains all 80 pin outs of the microcontroller. There are connections to the pin header footprint for communication with the test, rst, rxd, and txd lines. These lines are used for USB interface with a computer. Connections are also made for the GPS and Motor driver interfacing and connect to the pin headers pinouts 7-14. A crystal resonator is used for clocking purposes on the main board. The next core design feature is the DC-DC converter. The necessity of the converter was covered in the power section, however it is important to note here one of the most important components in the converter's implementation on the PCB. This key component is the inductor that limits the output current of the regulated voltage. This is an important measure in protecting the additional system components in the 3.3V input range. The design scheme and final component layout of the board are shown in the next two figures.

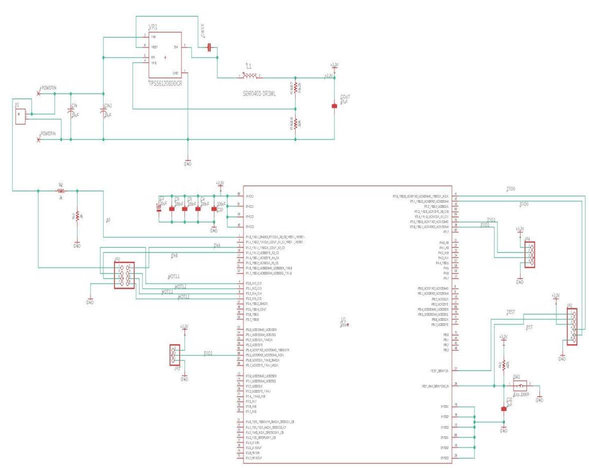

Fig 8. PCB Design

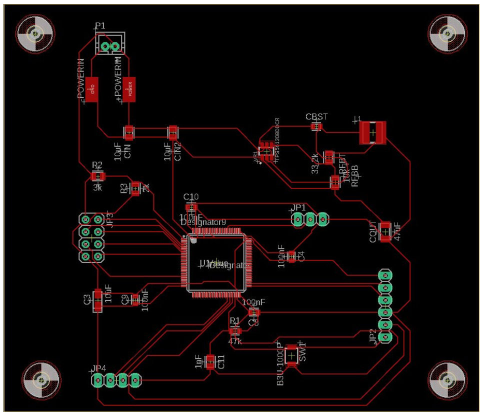

Fig 9. PCB Board Layout

VII. Automation

The 'A' in A.R.V. is for its Automated movement. This feature is governed by the H-Bridge Motor Driver, which drives each of the boat's two motor's either forward or backwards. It has logic communication pins that allow for autonomous control. The motor requires approximately 6V, however, the driver used to control the motor using an H-bridge contains two MOSFET's that have a voltage drop of 0.7 volts. Hence, the voltage required is 7.4V for full motor potential. The driver contains two motor connector inputs that can be used as a Motor A and Motor B connection. These pins are where the motors and propellers are connected to. In order to interface with the motor speeds, the driver has 5 logic pins that are used to communicate with a microcontroller. In this application, that microcontroller is the MSP430 implementation on the PCB design. A PWM signal is needed for the enable pin to turn on and off at the user's discretion. When the pulse goes high, the enable pin gets set to 5V through the onboard regulator. This turns on the motor. The input pins 1 through 4 are used to set a speed or set a direction that the motor is spinning. This is repeated for the second enable pin for Motor B. The Motor Driver's guide is an automation function that will have the A.R.V. traverse whatever body of water it has been placed in. The block diagram for this entire motor design outlines how to interface with the module using an MSP430 and how to set up all connections for power and communications. It is shown in the next figure.

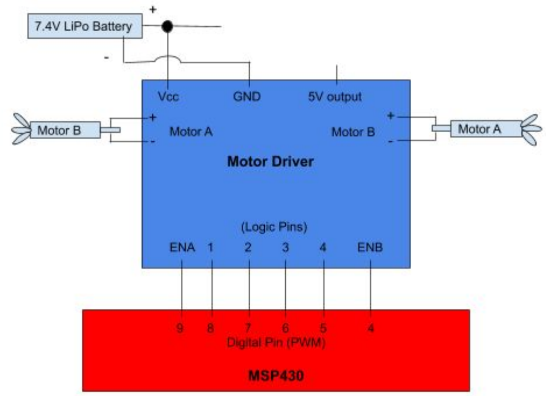

Fig 10. Motor Driver Control Scheme

VIII. GPS Transmission

The transmission of the A.R.V.'s coordinates is a collaboration between the 6M GPS module and the MSP40 implementation on the PCB. The MSP430 will attempt to connect to a Wi-Fi network, and if successful, the GPS will begin relaying data to Ubidots every five seconds. The need for the coordinates of the boat to be compared to desired coordinates creates an interrupt where the MSP430 will need to continuously compare the desired coordinates with that of the GPS module's readings. This comparison will allow the user to track the vehicle's movements without needing to manually control it to the requested destination. The GPS module communicates via UART with a baud rate of 9600. The language of the chip is NMEA (National Marine Electronics Association) Sentences. These sentences are decoded, sorted, organized, and finally display as latitude, longitude, and altitude. The block diagram of the GPS configuration is shown below, as well as an example of the GPS data transmission.

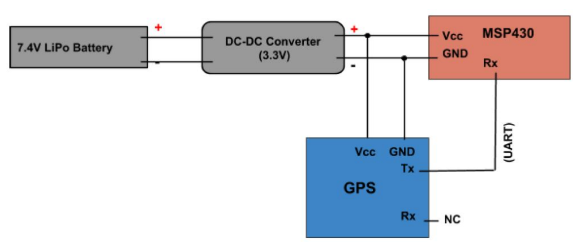

Fig 11. GPS Module and MSP430 Design Scheme

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$GNRMC,181722.00,A,4000.1256100,N,08301.5461206,W,0.000,,270718,,,A,V*0F
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Fig 12. Raw GPS Module Data

IX. Object Detection

The object detection feature of the A.R.V. is what sets it apart from any other autonomously controlled vessel. It allows the system to not only report back to the user that a particular object is seen, but also the degree of certainty to which it is seeing what it believes an object to be. The Raspberry Pi Camera v2 has standard features like high resolution and wide angle view that support this application. It also has the unique physical feature of an extended flex cable connection. This allows for the connection to the Pi to be made safely in the hull of the boat, while the cable runs up an elevated platform that the lens will sit atop. This allows for the software to process a more complete view of an object from above, rather than a 2D glimpse from a level view.

The workload of the object detection feature is carried by the end to end, open source platform, Tensorflow. 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 function in this application inside of a Python SciPy virtual environment, allowing for its own dependencies. The standard detection package contains 80 classes of images with the ability to expand via machine learning. The standard package is able to distinguish everyday objects and with interest to the A.R.V., it is able to easily detect people. Person detecting test results are shown below, with an average degree of certainty of 87% achieved throughout the test.

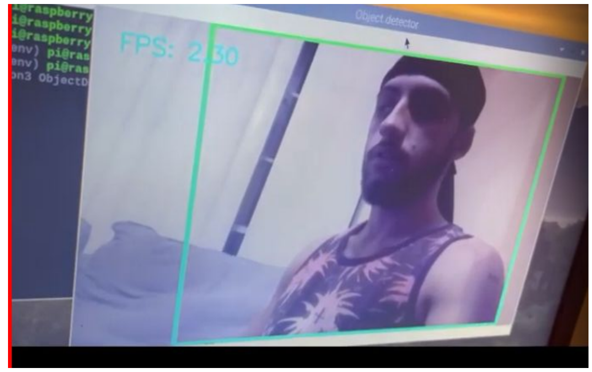

Fig 13. Object Detection Testing

X. User Interface

The interface is a web platform under Ubidots. Ubidots is an IoT website that provides an efficient method of collecting and displaying the data that the ESP8266 Wifi Module is sending from the MSP430 on the PCB. It also provides a variety of widgets to make use of in order to have an aesthetically pleasing and easy-to-use user interface to display and interpret data. The user view of voltage monitoring and GPS location data is shown below.

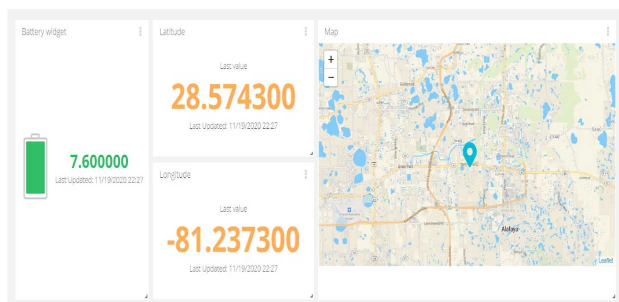

Fig 14. User Interface - Voltage Monitoring and GPS Location

XI. System Application

The GPS features of the A.R.V. are the key to its real world capabilities. Its ability to constantly compare its precise location to a desired destination, be it static or dynamic, are what allow for its two main possible applications, both active and reactive.

The reactive application of the A.R.V. is the input of a last known GPS location of a vessel, or other coordinates of interest. The A.R.V. would then be deployed to autonomously travel to those coordinates, while transmitting object detection findings through image processing. This operation would be carried out as search teams scanned areas that the ocean may have taken wreckage or survivors to.

The active application of the A.R.V. is the constant comparison of its own location to a dynamic set of coordinates. This translates to a duty such as constantly following a cruise ship as its coordinates change. If a passenger overboard incident occurs, the A.R.V. would immediately detect the lost passenger in the water, and send an alert to the user interface that could be displayed in the bridge of the ship. As defined in the project requirements, a degree of certainty would need to be met that what is being seen is indeed a person, and not marine life or ocean debris.

These real world applications give way to the possibility of the A.R.V. on a large scale. With additional funding, a larger boat would be procured that could withstand open ocean conditions. Similar hardware would be implemented, however more powerful designs would be used, increasing control and communication ranges, runtime, and image processing frame rate. For the purpose of small scale demonstration, a swimming pool will be used as the body of water, allowing for the A.R.V.'s creators to safely demonstrate its ability to detect a person in water.

XIII. Conclusion

The A.R.V. proved to be a challenge worth pursuing. It has a strong purpose and realistic function. The dangers of ocean travel are ever present, from commercial and military, to tourism and private vessels. As a team, we identified and tackled a problem for the benefit of people all over the world. The hope is for the A.R.V to never be needed in an emergency situation, but accidents cannot be avoided. Estimated survival in warm waters with a life jacket is three to five days, disregarding sharks and dehydration. Every second counts, and every pair of eyes adds to the chances of recovering survivors. It was our mission with this project to make an advanced technological contribution to this effort.

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