Lifeguard Robotics

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The Autonomous Lifeguard Project

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Abstract

The Autonomous Lifeguard Group has developed a system that provides rapid support to distressed swimmers. It is composed of two sub-systems: a command center, which will locate the swimmer, and an autonomous water vessel, which will navigate to the swimmer. The command center is an encoded tripod with a mounted scope that will be located on a Lifeguard's post. A Lifeguard will center the scope on a distressed swimmer and at the push of a button, the GPS location of the swimmer will be wirelessly sent to the vessel. The vessel, docked in open water, will navigate to the swimmer upon recieving this information. Once the location is reached, the swimmer will grab hold of the vessel and await the arrival of a Lifeguard. Figure 1 illustrates a mock scenario.

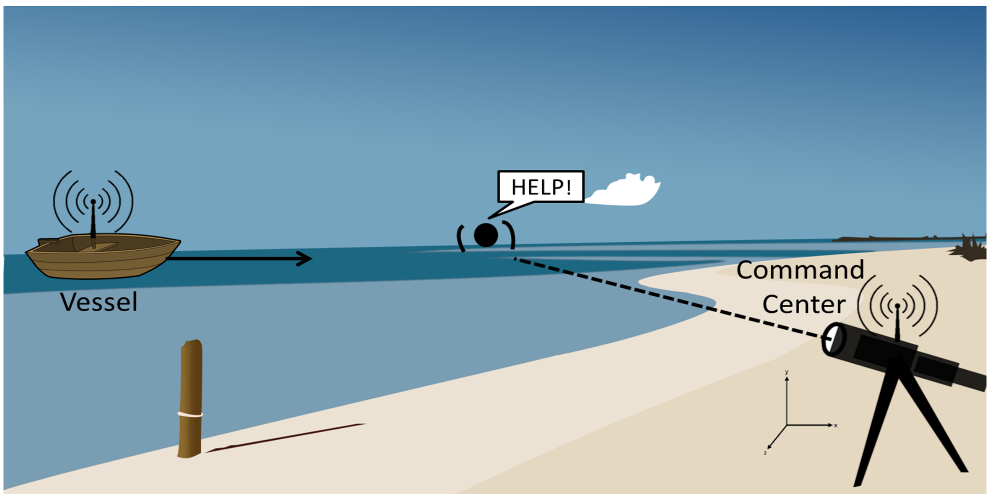

Figure 1: **Mock Scenario**: The command center locates the swimer and sends location information to the vessel who navigates to the swimmer.

Background

The current technologies developed for emergency marine response vehicles consists of radio-controlled boats outfitted with buoyant materials, such as EMILY (Emergency Integrated Life-saving Lanyard) from Hydronalix. EMILY, depicted in Figure 2 on the next page, is a 4-ft long remote controlled buoy that can travel up to 22 mph. This device offers floatation support to distressed swimmers and possess the ability to tow swimmers to safety. EMILY has the potential to save drowning individuals although has prominent drawbacks. The first is that it must be deployed from the shore where it travels through the wave-breaks. This region of the water has been reported to destabilize EMILY, making it very difficult to control. The second issue is that EMILY must be controlled remotely by a human operator. This means that EMILY's ability to rescue a drowning victim is dependent on how well the operator can navigate and his field of view. The final drawback is that the total cost to deploy EMILY on a beach is $9,950, which can be fairly expensive.

The Autonomous Lifeguard system has been developed to address the drawbacks that EMILY experiences. First, our product will be deployed within the body of water and docked at a set

Figure 2: **E.M.I.L.Y (Emergency Integrated Lifesaving Lanyard)**. A remote controlled buoy designed by Hydronalix.

waypoint. This will allow our life craft to be closer to the distressed swimmer while bypassing the wave-breaks in order to efficiently navigate. Secondly, our device will function autonomously and won't require a human operator. The lifeguard on duty will be able to swim toward the drowning individual while our device navigates to them. Granted our device doesn't possess the ability to tow the swimmer to shore, it will be able to navigate at speeds rivaling that of EMILY. Additionally, it will provide support to both the swimmer and Lifeguard, ultimately reducing fatigue, which is known to negatively affect the quality of a rescue. Finally, our system will be available for a total of $3,500 when factoring in manufacturing and labor costs, an affordable price for a viable emergency response system.

Our Vision

The Autonomous Lifeguard Project is centered around two sub-systems that work in unison to achieve the goal of rescuing a drowning individual with minimal human intervention. The first sub-system is the command center which will be referred to as ComPAS (Command Post Acquisition System). The second sub-system is the autonomous water surface vessel, also known as AtLAs (Autonomous Lifeguard Assistant).

ComPAS is an encoded tripod with a mounted scope, where a lifeguard would use the scope to locate a distressed swimmer. Once the lifeguard is able to locate the swimmer within the cross-hairs of the scope, the push of a button will allow triangulation techniques to be employed to obtain geographical coordinates of the swimmers relative position. Once this button is pressed, these coordinates will be sent via wireless communication to AtLAs, at which point the lifeguard may deploy towards the drowning individual.

Once AtLAs recieves the coordinates of interest, it will autonomously navigate to the drowning victim. An on-board GPS and compass will allow it to utilize a PD (proportional and derivative) controller, based on heading, to traverse the open water. Upon reaching the vicinity of the distressed swimmer, AtLAs will utilize smart path-finding and human sensing techniques to precisely locate the swimmer. The swimmer will then be able to grasp hold of AtLAs and await the lifeguard's arrival.

Research Method

Interviewing Lifeguards

The initial phase of the Autonomous Lifeguard Project was to investigate the needs of lifeguards when rescuing a drowning individual. Our intention was to develop a system that would assist lifeguards instead of replacing them. After speaking with various lifeguards, we found they were interested in the idea of a water craft saving a distressed swimmer at a speed faster than that of a human. The lifeguards advised us to focus on a low-cost and low-maintenance system that would be easy to use. This helped shape the scope of the project to fit within a budget of $4,000, incorporate an intuitive and simple user interface, and provide quick set-up and calibration protocols.

Top-Level System Overview

The two-part system is composed of various sensors, actuators, interfaces, and communication modules, as depicted in the system block diagram shown in Figure 3 on the following page. Each sub-system has a dedicated microcontroller that acts as the interface between peripheral hardware and the software state machine embedded within. The systems communicate between one another via wireless protocol over XBee radio modules. The flow of information is centered around the microcontroller which deciphers inputs and generate the appropriate outputs. All source code has been made available to the public on our GitHub repository[1].

ComPAS

The ComPAS uses various sensors to determine the drowning individual's location. A barometric pressure sensor provides a measurement of height, while magnetic rotary encoders are used to measure the pitch and yaw angles of the scope. A global position sensor (GPS) provides a local the position of the scope as a reference point that is used as the origin. By mathematically projecting a ray from the scope down to the observed point on the water, the coordinate of the drowning person is calculated at this intersection in a north, east, and down (NED) coordinate frame[2]. System logic is handled by a hierarchical finite-state machine (FSM) that provides an event driven framework to guide the flow of information and respond to real time situations. State transition diagrams detail the system's behavior, and can be seen in Appendix A on page 20. The lifeguard interacts with this system via a user interface composed of an LCD screen and push buttons. An image of a completed prototype of the ComPAS is shown in Figure 12 on page 18.

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[1] Source code availabe at: http://github.com/dagoodma/sdp

[2] The NED coordinate frame is a geographical coordinate system on a local tangent plane where the origin in this implementation is the center of the scope.

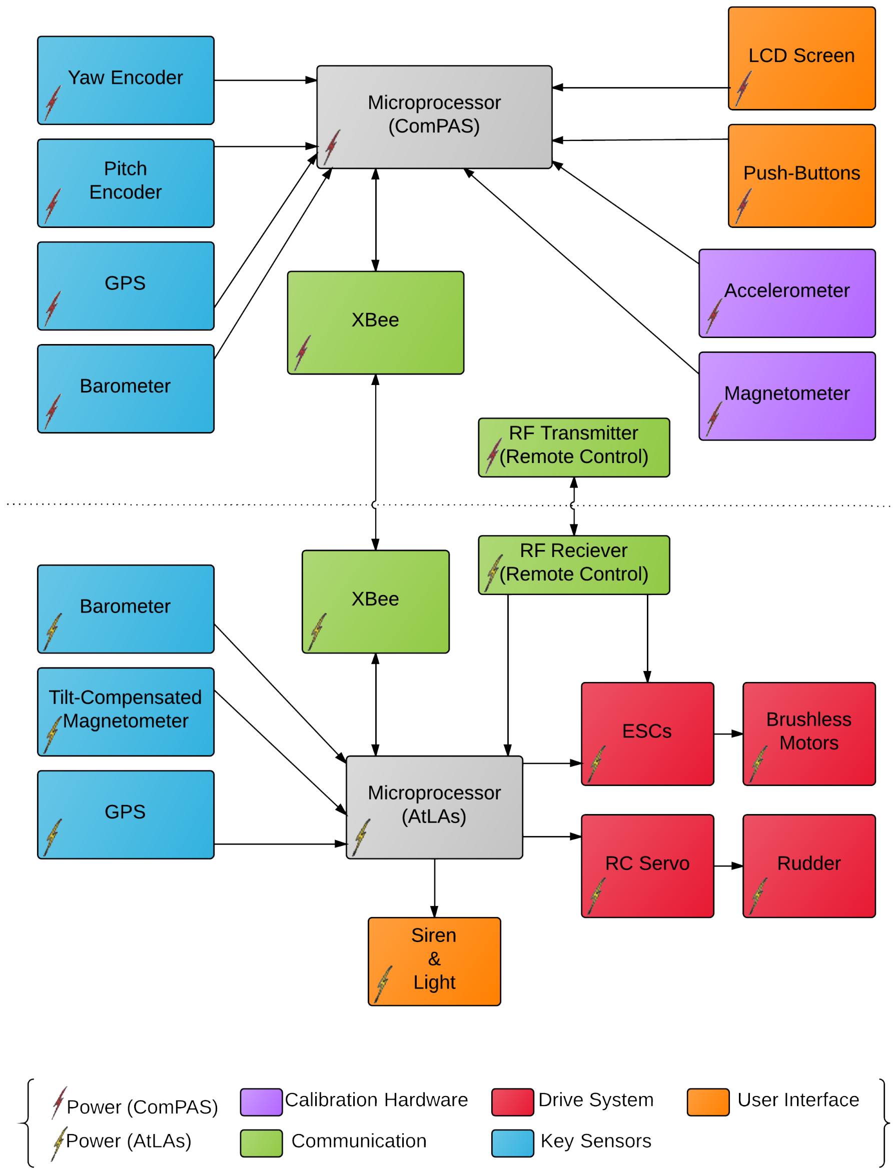


Figure 3: **Top Level Block Diagram**. Both sub-systems have their own respective sensor ensemble, user interface, and actuators. The common node is the communications which tie both systems together.

Hardware Overview

At the heart of the ComPAS is a PIC32 microcontroller that is interfaced with a variety of sensors for data acquisition and user interface components for field use. The ComPAS is operated by the user through a push-button interface with an LCD display. The ***Rescue*** button is used to send the AtLAs to rescue the person sited in the crosshairs of the scope. The ***Stop*** button is used to immediately stop the AtLAs in its place, causing it to wait for further instructions. The ***Ok*** button is used to clear error messages that may occur, as well as for confirming the cancellation of an action. The ***Cancel*** button is used to cancel the current action after confirmation is given with the ***Ok*** button, such as a rescue mission or a state keeping instruction, causing the boat to stop and wait for further instructions. If the boat is stopped and ***Cancel*** is pressed the boat will return to its station waypoint after the cancellation is confirmed by the user. A ***Reset*** button was implemented for restarting both the ComPAS and the AtLAs. All communication between the ComPAS and the AtLAs was accomplished using XBee Pro radios, which provided a medium for the exchange of MAVlink[3] messages at a range of up to one mile. Schematics of both printed circuit boards (PCBs) inside the ComPAS can be seen in Appendix C on page 26.

We evaluated many types of scopes to be used for the sighting and targeting of a drowning victim at a distances greater than 300 feet from the shore. We considered spotter scopes, rifle scopes, telescopes, binoculars, and range finders. The spotter scope offered a wide field of view, however the zoom was too large for our purposes and it was outside of the price range of a low cost solution. The binoculars were too difficult to modify and mount given their form-factor. The rifle scope offered decently narrow field of view, cross-hairs for targeting, manual zoom, and was easily mountable. After testing the Bushnell Banner, Dusk & Dawn, 3-9 x 40 mm rifle scope at a local sports store, we decided to purchase it and incorporate it into the design of the ComPAS. The scope, interface, and electronics for the ComPAS were mounted atop a Velbon DF 40 lightweight photo/video tripod, which was modified to allow for angular measurements of pitch and yaw.

Triangulation

Triangulation was accomplished using a custom built encoded tripod that allowed for angular position measurements along the pitch and yaw axes of the scope. Two 14-bit, I2C protocol, AS5048B magnetic rotary encoders from Austria Micro Systems were chosen. In order to accurately calibrate the encoders for ensuring optimal measurement of angles, additional sensors are used during a calibration routine. The encoders were first implemented using an interrupt driven PWM framework; this relied on measuring the pulse width of an analog signal sent by the encoders. The precision and reliability of this framework did not meet our needs due to high sensitivity to processor performance and thus an implementation relying on the I2C protocol was adopted to obtain angles in a more reliable and precise way. A schematic showing all I2C devices is available in Appendix C on page 26. After successfully integrating the encoders in software, they were then physically mounted onto the tripod using a 3D SolidWorks model of the tripod before being finally installed onto the system.

In order to determine the distance of the drowning person from the ComPAS, pitch measurements are scaled by the height of the scope from mean sea level. The BMP085 barometric pressure sensor is used on both the ComPAS and the AtLAs in order to measure the difference in altitude between

[3]MAVlink is an open source lightweight, header-only message packing library, that provides a protocol for communication with micro air vehicles. Documentation and source code can be found here: http://qgroundcontrol.org/mavlink.

the two devices. This provided an absolute height that could then be used to triangulate the position of the drowning person while accounting for the error caused by the fluctuation of water level caused by daily tides and ocean waves. To implement the barometer, we first integrated it into software. Upon its completion, we performed testing on the two barometers with a known altitude difference between them. Figure 4 shows a time plot of the measured height difference between the two devices after low-pass filtering. This data shows a convergence of the error to less than half of a foot in a few minutes. By subtracting this offset, we were able to get a height difference between two barometers making the ComPAS' use more modular and easier to implement in new locations without the need for manual altitude measurement each time.

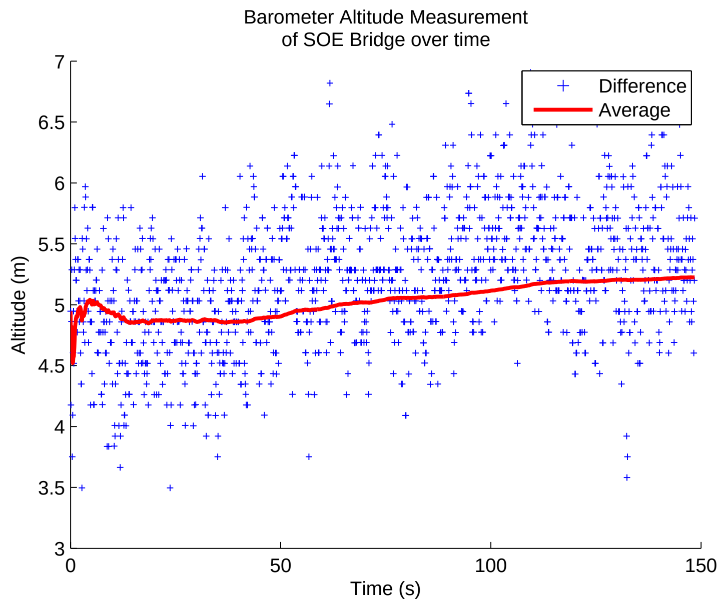


Figure 4: **Barometer Height Difference Test**. Time plot of the measured height difference between two barometers after low-pass filtering (red).

By combining the angular measurements from the encoders with the height obtained by the barometers, we were able to calculate the NED coordinate position of the drowning person and wirelessly radio it to the AtLAs in the water. The ComPAS receives Earth-centered, Earth-fixed (ECEF) coordinates, which are Cartesian X, Y, and Z coordinates with the center of the Earth as the origin, from its GPS device. The GPS chosen for this task was the u-blox LEA-6, which can provide position measurements with an accuracy of 8.2 feet[4]. The ComPAS periodically sends the ECEF coordinate of its position to the AtLAs. This is used by the AtLAs in order to determine its position relative to the ComPAS in a NED frame by performing a coordinate transformation using the ECEF coordinates of both the ComPAS and the AtLAs. When the lifeguard sites the victim and presses the lock button on the ComPAS, the drowning individual's location is determined by mathematically projecting a ray from the scope down to the water, and calculating a NED vector to the point where the ray intersects the water. This vector is then sent to the boat, allowing it to navigate to the location of the individual with help from its internal feedback control system.

[4]The accuracy provided by the GPS was able to be improved through an error prediction algorithim which is discussed in the Challenges in Coordinate Acquisition section.

Calibration

To successfully measure angles from the yaw encoder with respect to a local NED frame, where north is the origin, a magnetometer was required for obtaining a reference to true north. The HMC6352 was the magnetometer chosen for this task. It outputs heading in tenths of a degree, and is accurate to one degree. Similarly to the encoders, the magnetometer uses I2C to communicate with the Command Center. Because the magnetometer measures heading with reference to magnetic north, corrections were implemented in software to compensate for this offset, which differs regionally with the Earths magnetic field. The magnetic declination from geodetic true north, obtained from the National Geophysical Data Center, is specific to the location in which this system is used. The user is able to calibrate the yaw encoder to true north by swiveling the scope to face north, and holding the position for three seconds while the green ready light is on. Once the yaw encoder has been calibrated, the pitch encoder can then be calibrated.

A 3-axis accelerometer is used in concert with the magnetometer during the calibration of the Command Center. While the magnetometer gives heading in reference to north to calibrate the yaw encoder, the accelerometer is used to calibrate the pitch encoder by providing a reference position for when the scope is flat or level with the horizon. This is crucial to obtain accurate measurements of the distance to the drowning victim from the ComPAS. The accelerometer was implemented using the same I2C module used to implement many of the other sensors. During calibration, the user swivels the scope to level it with the horizon, and holds this position for three seconds while the green ready light stays on.

Challenges in Coordinate Acquisition

The accuracy of our navigation system is subject to an amount of uncertainty due to various sources of error in our systems. The major sources of uncertainty are the precision of the GPS, the resolution of our encoders, and the accuracy in calibration of the pitch and yaw encoders to be level with the horizon and truth north respectively. We have made good effort to predict and improve our accuracy with several approaches.

We have designed and tested a method of filtering uncertainty from the GPS position of our ASV. This method involves a pseudo-differential GPS implementation, in which the Command Center measures and records its instantaneous GPS position error. Due to the close proximity of our Command Center to the ASV, we have shown that their errors are correlated, and that if the position of one receiver is well known its error can be measured and used to correct the position of the other receiver. To show this, we performed error correlation testing between two GPS receivers in close proximity. Figure 5 on the following page shows a time plot of the latitudinal and longitudinal errors from the first fix, to nearly four-hundred seconds later. The plot demonstrates that the error in one receiver closely tracks the other, which means that two to four feet of error can be removed from the remote receiver by subtracting the measured error of the stationary receiver from the others position in a NED coordinate frame.

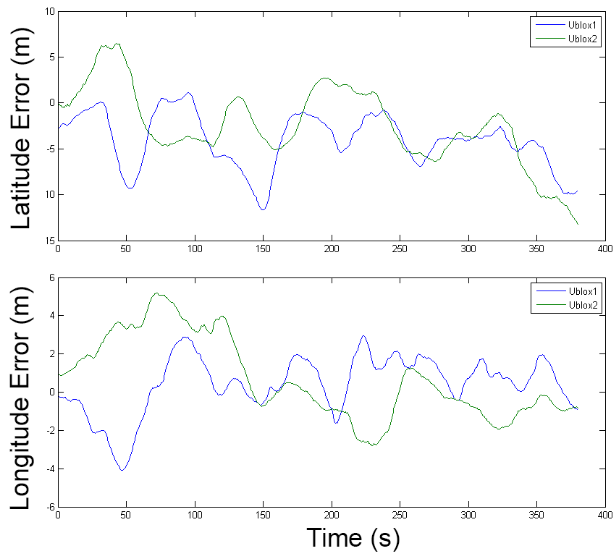


Figure 5: **GPS Error Correlation Test**. Correlation between the measured error of two GPS receivers in close proximity.

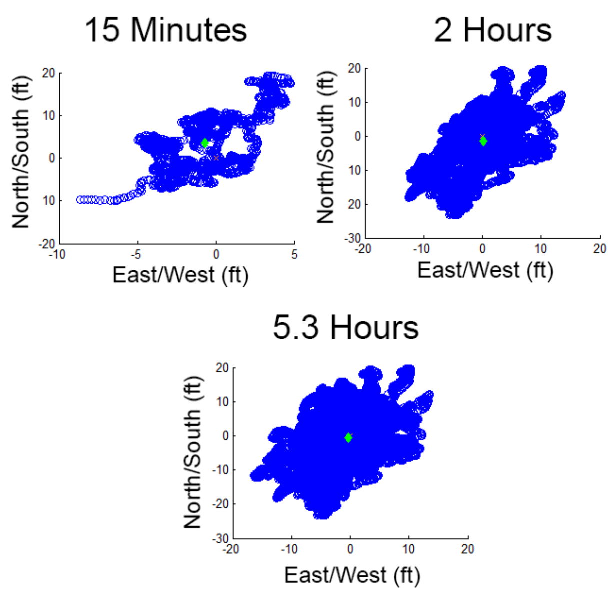


Figure 6: **GPS Error Convergence Test**. Measured error convergence in position of two GPS receivers over time.

The ability to filter the error experienced by one receiver using the measured error from a nearby receiver requires the position of the receiver measuring the error to be well known. Another test we conducted shows that the position of a stationary receiver will converge over time if position measurements are averaged over a period of time of at least five hours. Figure 6 shows a linearized plot of latitudinal and longitudinal position measurements on two GPS receivers in close proximity at time steps of 15 minutes, 2 hours, and 5.3 hours. The red 'X' shows the average position measurement, and the green diamond shows the true position of the receiver as estimated from a map. The plots show convergence to the true position as measurements are accumulated and averaged over time. After calibrating our Command Center's position, we periodically send error measurements to the ASV in the water and improve the precision with which it can reach a drowning individual.

The resolution of the encoders was considered as a major source of error in the measured position of the drowning person. We have significantly reduced this source of uncertainty by using 14-bit encoders, which allow for 0.0219° of resolution and 0.05° of accuracy. Figure 7 shows the uncertainty in position that arises from encoder resolution as distance from the shore increases. The resulting uncertainty becomes an ellipsoidal shape around our targeted point. By choosing encoders with a 14-bit resolution and precisely mounting the magnets on top of them (within 0.5 to 1.0 mm), we are able to minimize the amount of uncertainty contributed by our encoders to be almost negligible in comparison to the uncertainty from human error, when used at distances of under 300 feet. However, greater distances from the shore can be realized by increasing the height of the command center above the water, using higher resolution encoders, obtaining a sturdier tripod made of a material with less flexibility, which reduces human error and error induced by vibration and undesired movement, or implementing human sensing capabilities onto the AtLAs to allow it to search for the drowning person once reaching near the desired point.

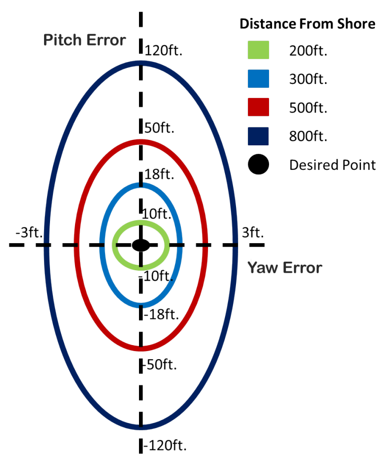


Figure 7: **Encoder Error from Resolution**. Uncertainty in measured position due to encoder resolution at various distances from the shore.

AtLAs

In the water, the AtLAs relies on an array of sensors and actuators to navigate to the drowning person. The navigation system is guided by on-board GPS and a tilt-compensated magnetometer. Due to variable weather and pressure fronts, a barometric pressure sensor located within the hull of the AtLAs is used to provide a mean sea level reference signal to the ComPAS. Using the ComPAS's geocentric position as an origin, the AtLAs's position is transformed into a local NED coordinate system and a desired course and velocity is calculated by an on-board microprocessor. A digital proportional-derivative (PD) control system tracks the desired course and actuates the brushless DC motors and servo-controlled rudder to steer the boat to the drowning individiual;

a block diagram for the control system can be seen in Figure 8. Similar to the ComPAS, all logic and autonomous control is handled by a hierarchical FSM whose state diagrams can be seen in Appendix B on page 23. A schematic of the PCB hardware within the AtLAs is shown in Appendix C on page 26.

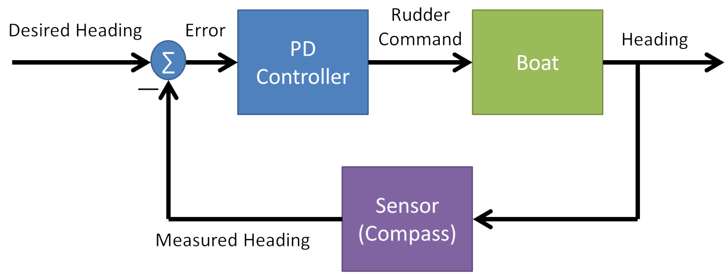


Figure 8: **AtLAs Feedback Control System**. The proportional-derivative control system for the AtLAs was implemented digitally using a microcontroller, and tracks a desired course heading towards the drowning person.

The AtLAs' main task is autonomous navigation to a desired point of interest. This includes the implementation of a drive controller, a method for deciphering location information, and a means to communicate with the ComPAS. The general navigation implementation consists of an origin location that the reference frame is centered about; this origin is the ComPAS, since it is a static entity, meaning that navigation efforts will be in context to the location of the ComPAS.

Communication

Communication is achieved via radio-frequency. A XBee module, as explained earlier, is used to communicate with the ComPAS. The message passing of location information is handled by MAVLink. The AtLAs' internal state-machine will wait for messages sent from the ComPAS. Once a message is received, it is unpackaged via MAVLink and the location information is extracted.

Navigation and Control System

The GPS unit on-board the AtLAs is used to obtain its current location. A vector can be drawn from the ComPAS (origin) to the vessel, where the phase represents the current heading and the magnitude represents the distance to the vessel. Similarly, a vector can be drawn between the desired waypoint and the ComPAS, representing the desired heading and distance. The parameter of interest is the heading, which serves as the input to the controller. A depiction of this reference frame can be seen in Figure 9 on the following page.

The control system for the drive function is a PD controller which takes the current heading of the vessel as input and actuates the rudder to correct for heading, as seen in Figure 8. Due to the highly dynamic environment of water, the PD controller allows the boat to correct for drift and slip. When designing the control system, we had to address the fact that rudder actuation and velocity have an inverse relationship in water. At high speeds, small rudder actuation is enough to maneuver appropriately, whereas the opposite is true when traversing at low speeds.

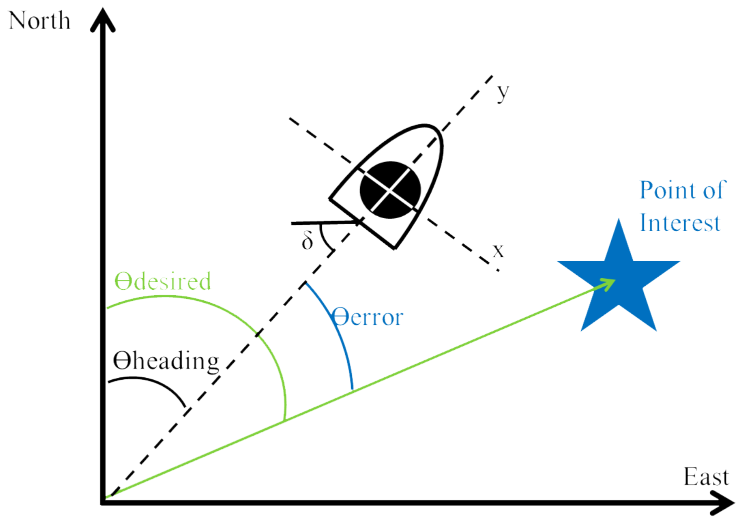


Figure 9: **Reference Frame**. The correction in heading is computed from the difference between the current heading of the vessel and the desired heading of the point of interest. The reference frame is with respect to the ComPAS as the origin.

The current heading of the AtLAs is measured via a tilt-compensated magnetometer[5] corrected for true north. A desired heading is calculated using the method detailed earlier where the difference between the two headings results in an error that is input into the controller. The controller, scales the PWM signal that drives the rudder servo-motor based upon the magnitude of the error with a weighted parameter that can be tuned for various environments. The velocities of the propellers are dependent on the distance between the vessel and point of interest, speeding when far and slowing down when close as to not harm the individual. Additionally, a bang-bang control is implemented when the vessel is near the point of interest by a configurable radius. This allows the rudder to actuate complete left or right when traversing at low speeds. A dead-band is implemented so that the rudder does not thrash when the vessel is near the point of interest in order to reduce rocking. A threshold value is chosen for this dead-band in order to tune for varying environmental conditions. Figure 10 on the following page illustrates the actuator effort output of our controller depending on a variation in heading.

The challenges dealt mainly with the controller output of the navigation system. On particularly windy days, the vessel would slip and drift more than usual. This was fixed by tuning the proportional and derivative gains of the PD controller. The prototype system requires proper calibration and tuning of the controller in the environment that it is to be deployed. Future implementations will focus on an adaptive controller that will tune the gains according to the dynamics of the environment. Wireless tuning may also be investigated, allowing users to access the controls via smartphones or computers.

Override Control

Override hardware was developed for manual control in the event of an emergency or malfunction. An interrupt-driven software routine handled the transition from autonomous to manual control

[5]The magnetometer measures three components (X, Y and Z) of the Earth's magnetic field. The measurement can be off by as much as 15° as the boat piches and rolls. A three-axis accelerometer determines tilt for compensation.

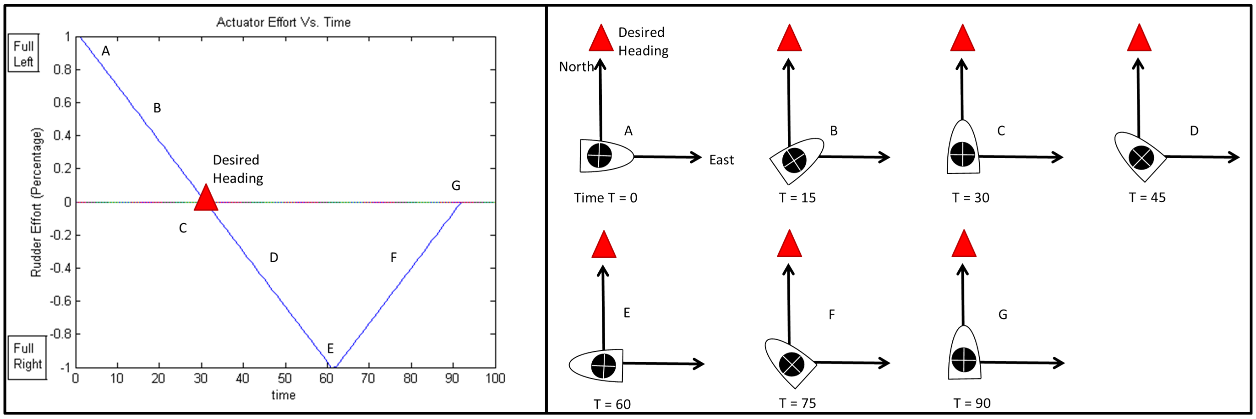


Figure 10: **Actuator Effort**. As the heading of the vessel deviates by a maximum degree (90 degrees), the actuator effort saturates in the respective direction. The effort starts to decrease as the vessel's heading tends towards the desired. If it surpasses the desired heading to the other hemisphere, the rudder actuates in the opposite direction to correct for error.

depending on the power state of the remote control. The 2.4 GHz receiver can relay the state of the remote control (on or off) on a unique channel (channel 3). This channel is held at a logic low if the remote control is in the off state and logic high when the remote is on. This transition from low to high on channel 3 triggers a software interrupt that toggles a MANUAL_ENABLE output pin that drives the override hardware.

The override hardware is composed of digital logic, in the form of a multiplexer, parsing signals from the microcontroller (autonomous control) and receiver(manual control). The select line is the MANUAL_ENABLE pin that is toggled in the interrupt service routine. The schematic for the override hardware is illustrated in Appendix C on page 26.

Water Proofing

The AtLAs, being located in the water, needed to be both rugged and waterproof. Both the hull and an interior electronics compartment was designed to be sealed from water intrusion. The waterproofing was done in multiple stages. First, the circuit board themselves were waterproofed by spraying the board-milled PCBs with a layer of water resistant spray to reduce moisture uptake. The final PCBs from Advanced Circuits were waterproofed by the addition of a soldermask layer; this did not completely waterproof them but it did make them more resistant to moisture levels. Beyond the level of waterproofing the circuit boards, actions were taken to enclose the entire systems circuitry into waterproof compartments. This was accomplished by housing the components in a watertight acrylic housing mounted to the interior of the hull. Inputs and outputs were routed through watertight seals and water absorbing bead were incorporated into the box to allow for removal of any excess humidity. Finally, Attempts were made at waterproofing the entire interior of the vessel. This was done by adding an acrylic cap to the top opening of the vessel. Caulking would then be added to any cavities between the acrylic cap and the vessel's hull. The opening for the battery compartment was designed with a removable cover gasket as to seal the opening in the acrylic cap.

Printed Circuit Boards

To make waterproofing easier for the circuitry inside the AtLAs, special attention was taken to the physical design of the components as well as the PCBs. The AtLAs IO shield was designed to incorporate all the system components onto one board as seen in Figure 11. When designing the PCB, considerations were taken for the placement of the power supply, the magnetometer, and the XBee. The Magnetometer, being sensitive to magnetic field fluxes, was laid on the board with no power or ground wires running beneath it. Furthermore, all components closest to the magnetometer were chosen to be low power with minimal transient peaks to minimize EMF spikes. The power supply for the different components was split into two lines, a fused 5V line and a fused 3.3V line. The 5V line powered the micro controller and the GPS. The 3.3V power supply was connected to the XBee, barometer, magnetometer, and accessory sensors (sonar and thermal). Finally, LEDs were added to each sensor to visualize data transfer and error codes.

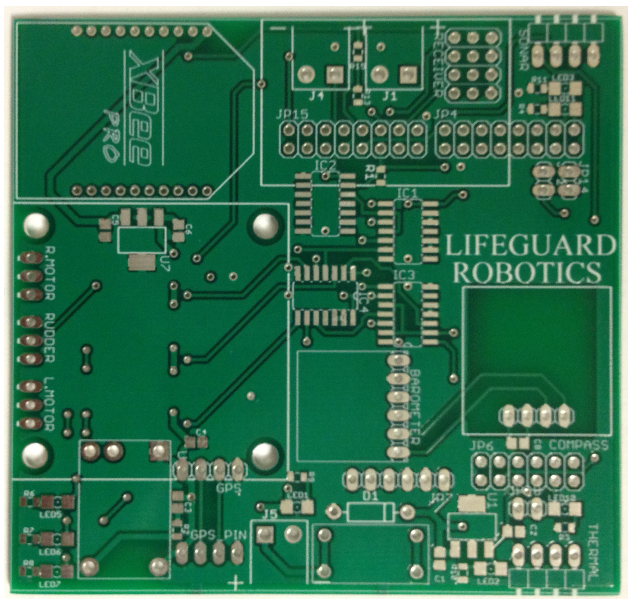


Figure 11: **AtLAs IO shield**. A custom printed circuit board for the AtLAs that serves as a shield for the microcontroller.

Physical Design and Motors

A rugged and powerful physical design was constructed to withstand the forces of nature and the wear over time while providing top performance during rescues. Additionally, safety features were implemented for the well-being of distressed swimmers. A buoyant bumper lined the face of the vessel to stabilize it in rough waves and to protect swimmers from collision. Brushless DC motors were installed to ensure that the top speed of the vessel surpasses that of a human swimmer. Ultimately, the system was able to travel at an average of 15 mph which is more than five times faster than a human can swim.

The IO shield was placed inside the waterproof component box located inside the vessel. Originally, the two brushless motor electronic speed controllers (ESC's) were originally located inside the box, however, because the sealed acrylic box did not allow for air flow, the ESCs overheated the enclosure and caused inaccuracies in the sensors as well as over-temperature protection mode on the motor controllers. To avoid overheat shutdowns, the ESC's were relocated into an aluminum box with higher heat sinking capabilities.

Software State Machine

The state machine that governs the functionality of the AtLAs is constructed similarly to that of the ComPAS. It uses a hierarchical structure of calls between layers of sub-state-machines to accomplish the goals of event checking and appropriate transitions. The three states that are native to the AtLAs' unique state-machine are station keeping, rescue, and override. An illustration of the state machines can be viewed in Appendix B on page 23.

The station keeping state allows the AtLAs to store a desired waypoint in memory so that it may navigate back to this point in the event that waves cause it to drift away. A radius may be set by a user so that station keeping is initiated only if the AtLAs drifts beyond a threshold.

The rescue state is initiated when the AtLAs receives the rescue message from the ComPAS containing the coordinates of the waypoint. The controller is activated during this state and the AtLAs navigates to the waypoint using the method described earlier.

The override state is initiated when the remote control is powered on. This toggles the MANUAL_ENABLE pin and drives the override hardware to accept signals from the receiver. When the remote is powered off, control is handed back to the autonomous state-machine.

Future Works

In order to further the capabilities of the Autonomous Lifeguard System, human sensing and an upgraded physical design will be implemented. The goal is to develop a system that can be deployed for the purpose of search and rescue in disastrous scenarios such as a flood, the capsizing of a ship, and general drownings on open bodies of water.

Human Sensing

Audio detection in the form of microphones will be implemented in the event that a victim is calling out for help in a disastrous scenario. Audio recognition software would allow the system to react differently based upon commands or keywords that are uttered, adding an additional level of intelligence to the system.

Visual detection will allow our system to intelligently navigate to an object of interest. Open source software such as OpenCV provides object detection and recognition libraries that can be used with cameras to precisely navigate to a point of interest, reducing the error that can occur with our current triangulation technique.

Heat signature detection is also a viable option when sensing for humans in an unknown environment. A thermal array (MLX90620) was investigated and our research showed that an RGB matrix output from our thermal sensor can indeed be used for detection. However, the resolution of our particular thermal sensor was too low (16X4) to achieve the distance that we were hoping to search (10ft).

Upgraded Physical Design

With further funding and resources, the physical design of the boat can be made more rugged and powerful. Towing capabilities are possible with gas powered engines and high-grade impellers. Additionally, a more buoyant and rigid craft can be constructed to withstand the weight of multiple humans and be deployed from helicopters or ships. With the addition of higher quality electrical components, the battery life and operating range can expand resulting in a low-maintenance and highly-efficient system.

Project Budget

The total budget for the Autonomous Lifeguard Project was $2,225. This cost was determined by the actual prices of the purchased components. This total budget is in regards to the physical components that make up both sub-systems. Labor and software were not included. A budget is included in Appendix D on page 31.

Results

The end result of the Autonomous Lifeguard Project was a working prototype system that is able to triangulate a position via the ComPAS and navigate to the desired position via the AtLAs. The ComPAS was able to triangulate a desired waypoint at a distance of 300 feet and successfully send location information to the AtLAs through wireless communication. The AtLAs was able to navigate to the position starting from an unknown location at least 100 feet away from the desired waypoint. Upon reaching the waypoint, the AtLAs transitioned into idle mode allowing the drowning volunteer to grab hold of the vessel. The internal state-machines of the sub-systems executed appropriately and were verified by log data extracted from debug harnesses. A completed prototype of the AtLAs is illustrated in Figure 13 on the next page.

Figure 12: **ComPAS**. Completed prototype of the ComPAS.

Figure 13: **AtLAs**. Completed prototype of the AtLAs.

Acknowledgements

The Autonomous Lifeguard Group would like to extend their sincerest gratitude towards all who have shown their support during the creation and development of our project. Thank you to all of the family and friends who have contributed to our cause, your generosity has been the lifeblood of our project.

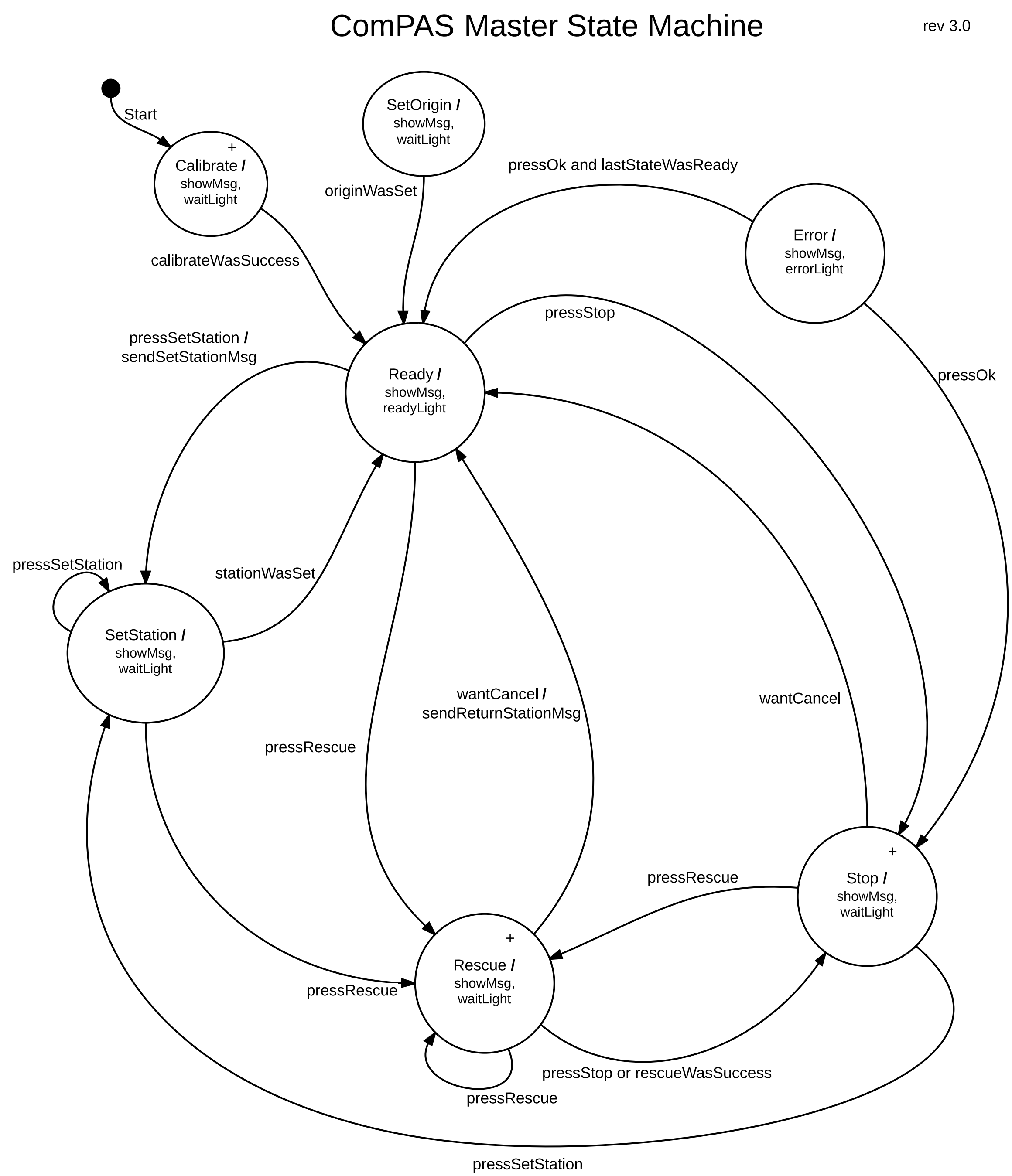
We would like to acknowledge the Kolsky Senior Design Fund for financial support. And a special thanks to BELs for the lab space and equipment.

Donors:
Poornima Deo
Katie Caploe
James Deo
Priyanka Deo
Nitin Nath
Doug Galinat
Cathrene Deo
Anjali Ram
Nick Nath

LifeguardRobotics.com

Appendices

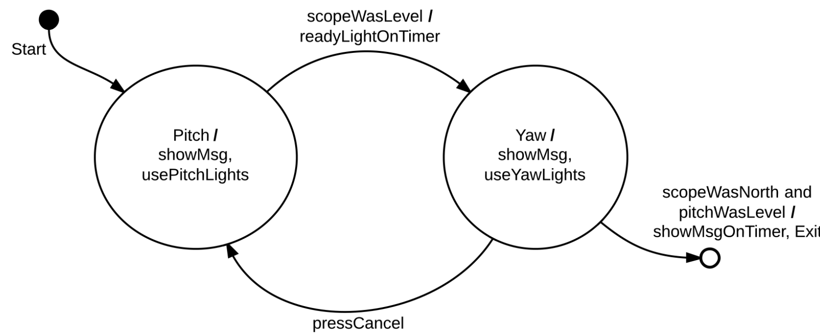
A ComPAS State Transition Diagrams



- All states (except Calibrate) can transition into the **Error** state, and the **Error** state will transition back to either **Ready** or **Stop** depending on which was the last state if *Ok* is pressed. However, **Error** can transition to any state from a button press.
- All states can transition into the **SetOrigin** state if the boat starts up and sends a request.
- The '+' symbol denotes hierarchical states with sub-states.

ComPAS Calibrate State Machine

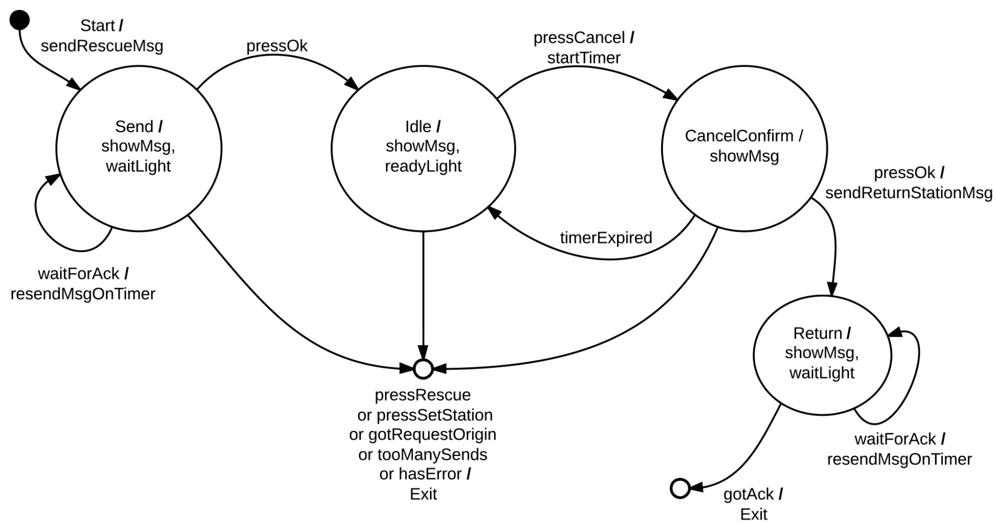
rev 2.0



* The user must hold the pitch level for 3 seconds while the two top lights are on to progress through each state.

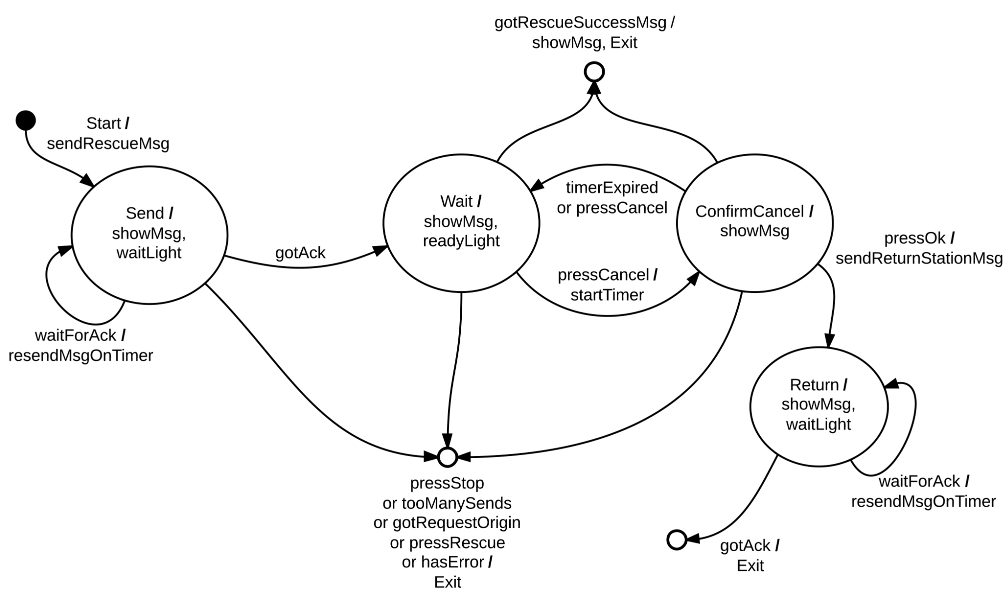
ComPAS Stop State Machine

rev 3.0



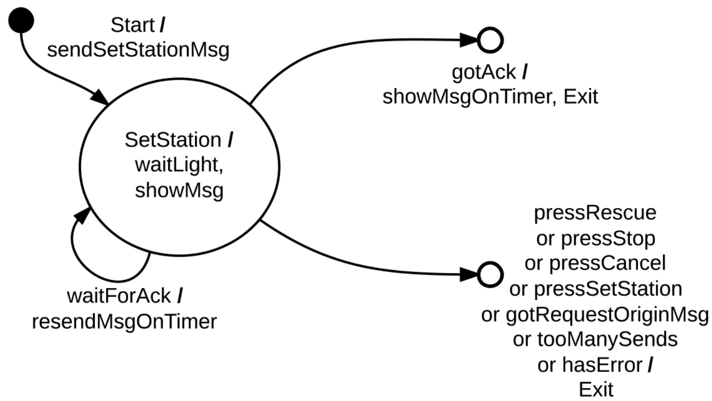
ComPAS Rescue State Machine

rev 3.0



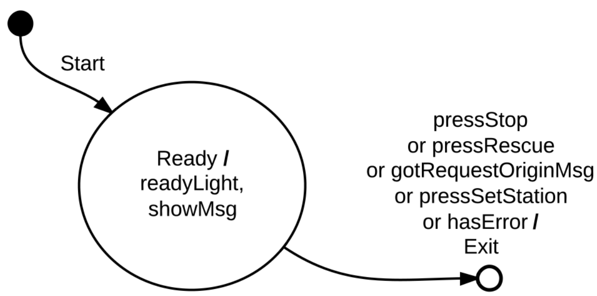
ComPAS SetStation State

rev 3.0



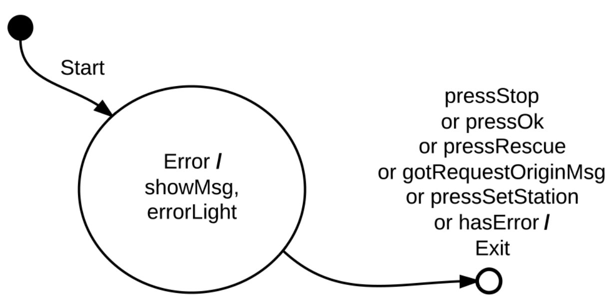
ComPAS Ready State

rev 3.0



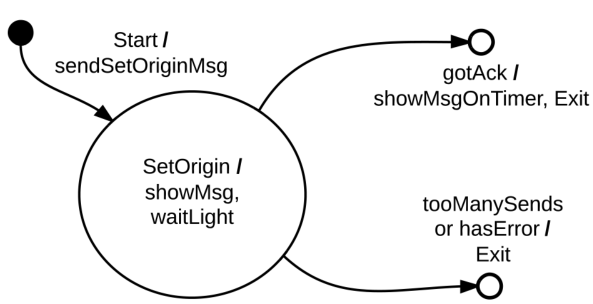
ComPAS Error State

rev 3.0

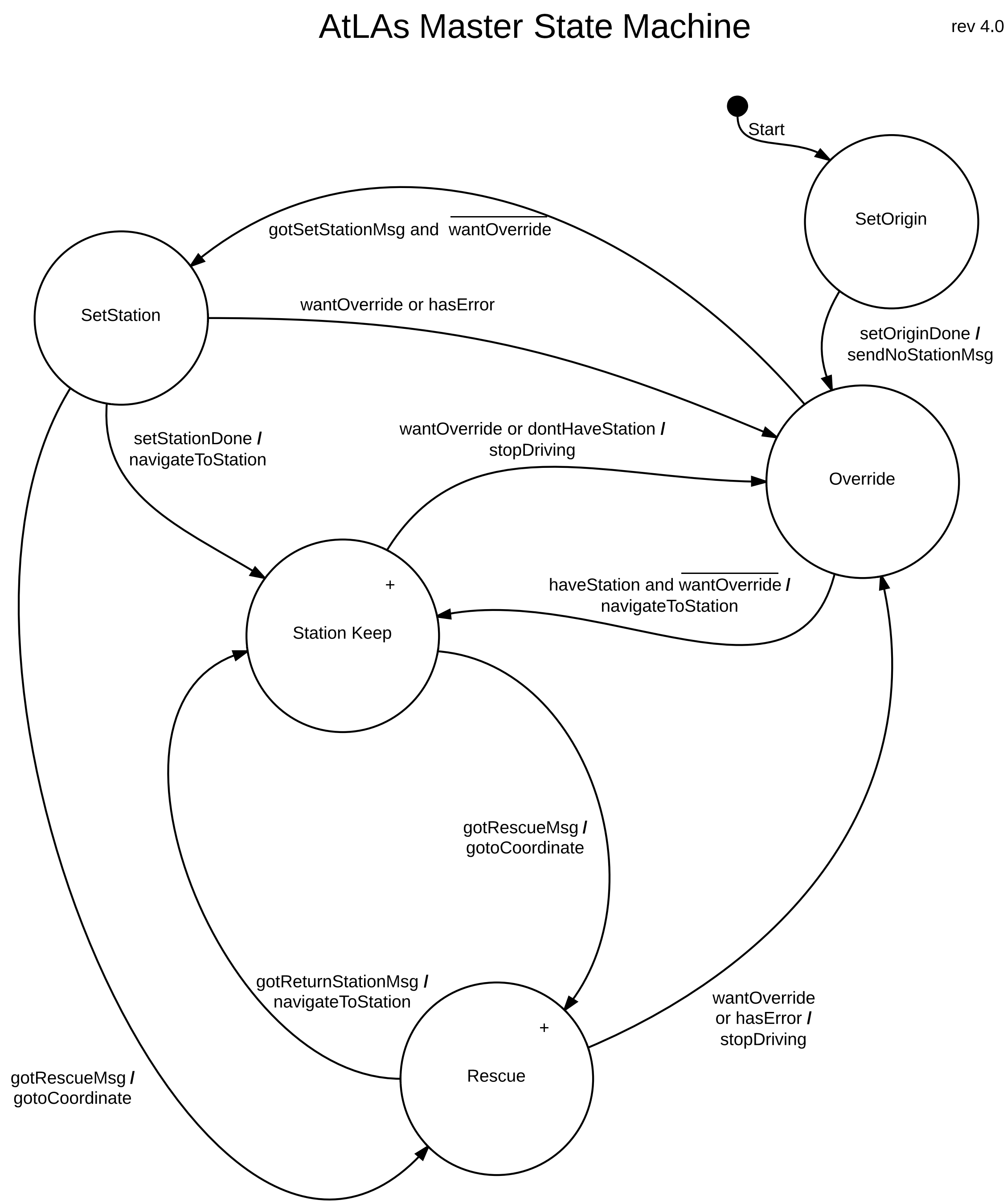


ComPAS SetOrigin State

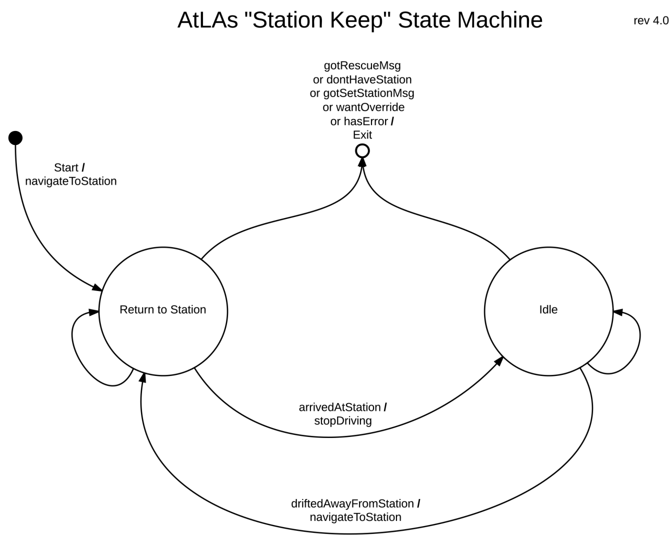
rev 1.0

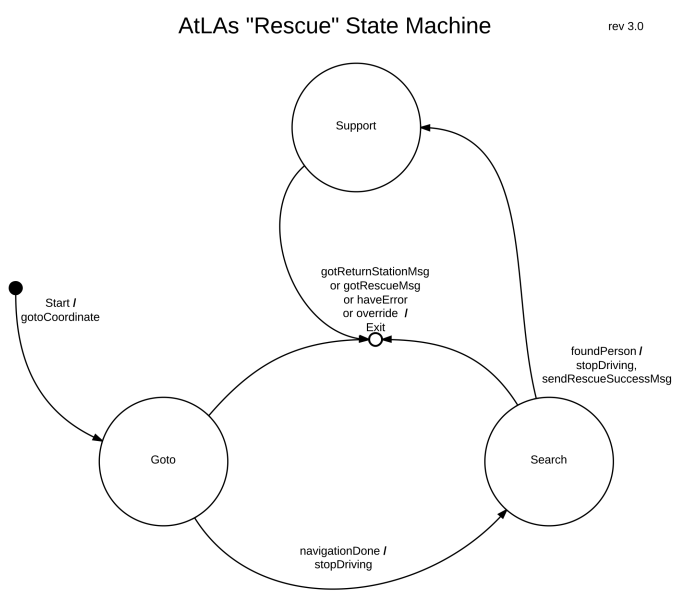


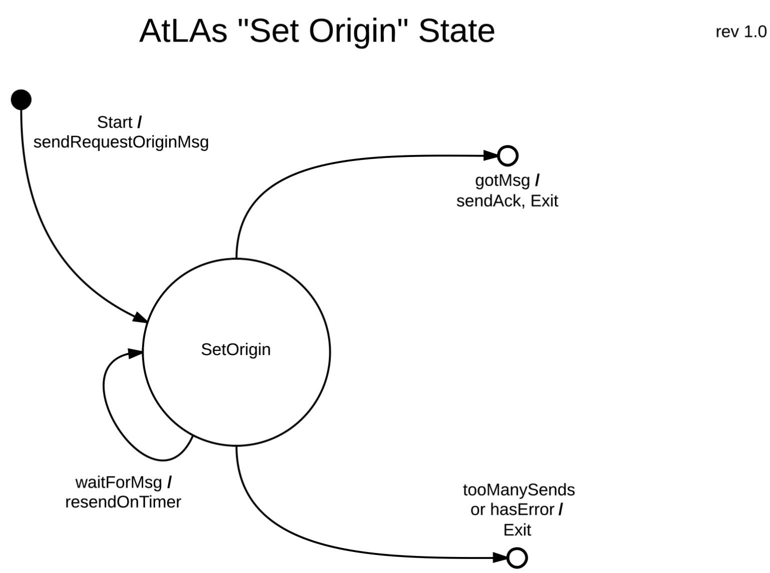
B AtLAs State Transition Diagrams

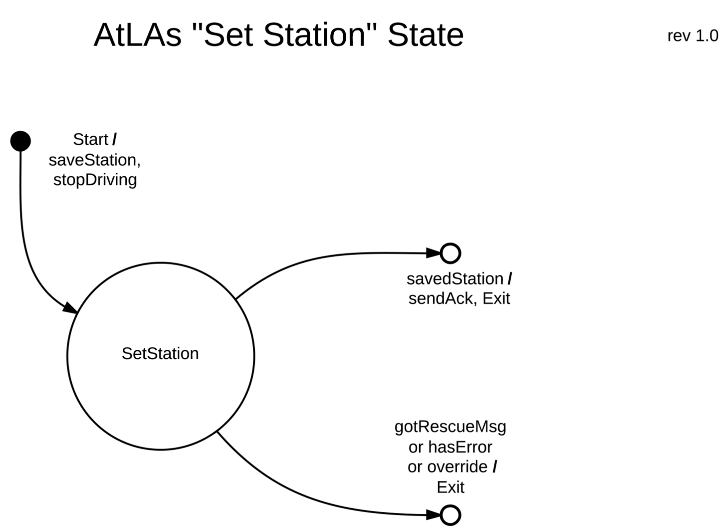


- All states can also transition to the **SetStation** state when gotSetStationMsg occurs.
- The '+' symbol denotes hierarchical states with sub-states.


AtLAs "Station Keep" State Machine
rev 4.0
gotRescueMsg
or dontHaveStation
or gotSetStationMsg
or wantOverride
or hasError /
Exit
Start /
navigateToStation
Return to Station
Idle
arrivedAtStation /
stopDriving
driftedAwayFromStation /
navigateToStation


AtLAs "Rescue" State Machine
rev 3.0
Support
gotReturnStationMsg
or gotRescueMsg
or haveError
or override /
Exit
Start /
gotoCoordinate
foundPerson /
stopDriving,
sendRescueSuccessMsg
Goto
Search
navigationDone /
stopDriving


AtLAs "Set Origin" State
rev 1.0
Start /
sendRequestOriginMsg
gotMsg /
sendAck, Exit
SetOrigin
waitForMsg /
resendOnTimer
tooManySends
or hasError /
Exit


AtLAs "Set Station" State
rev 1.0
Start /
saveStation,
stopDriving
savedStation /
sendAck, Exit
SetStation
gotRescueMsg
or hasError
or override /
Exit

C Schematics

Figure 14: ComPAS Interface

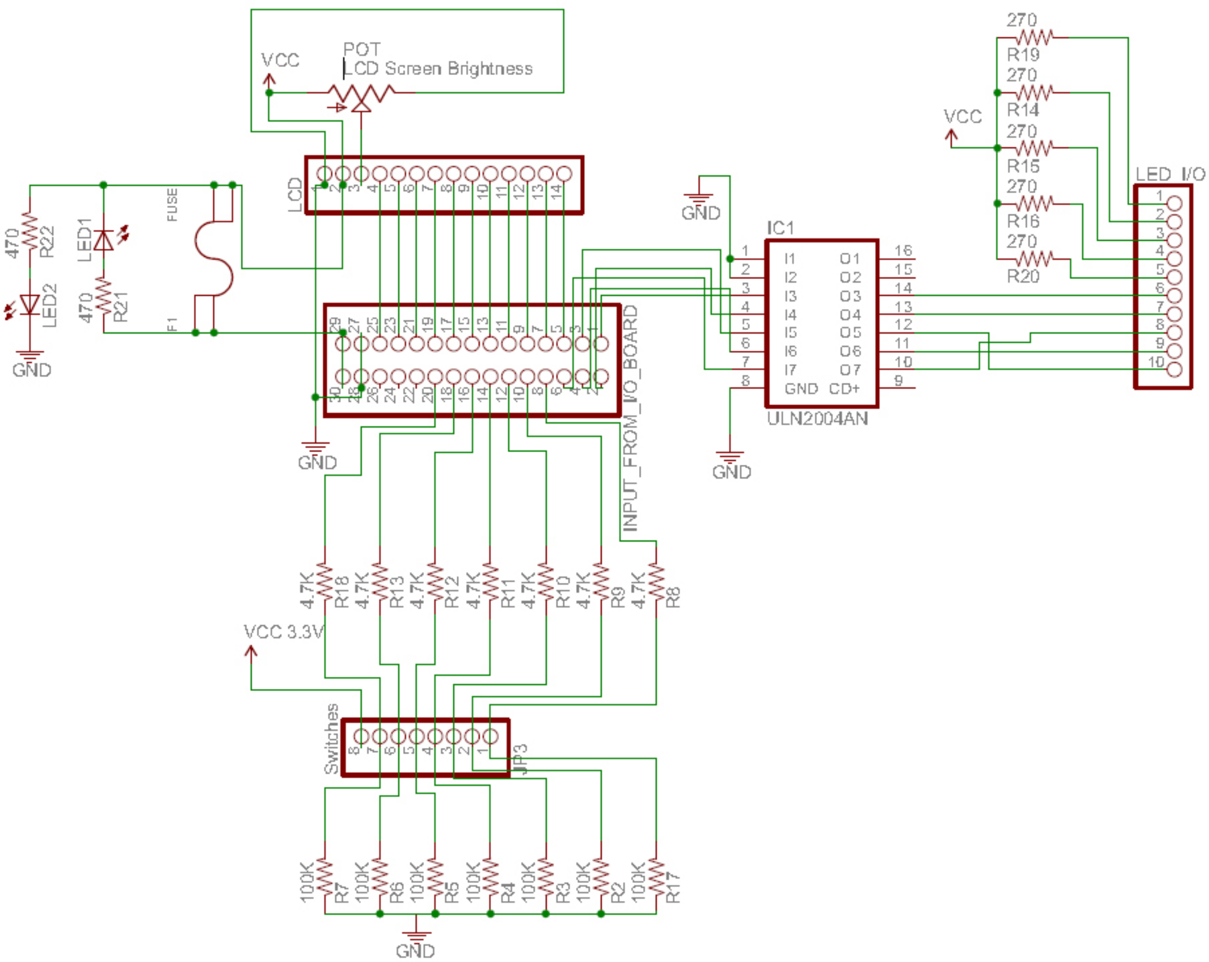


Figure 15: ComPAS I2C Devices

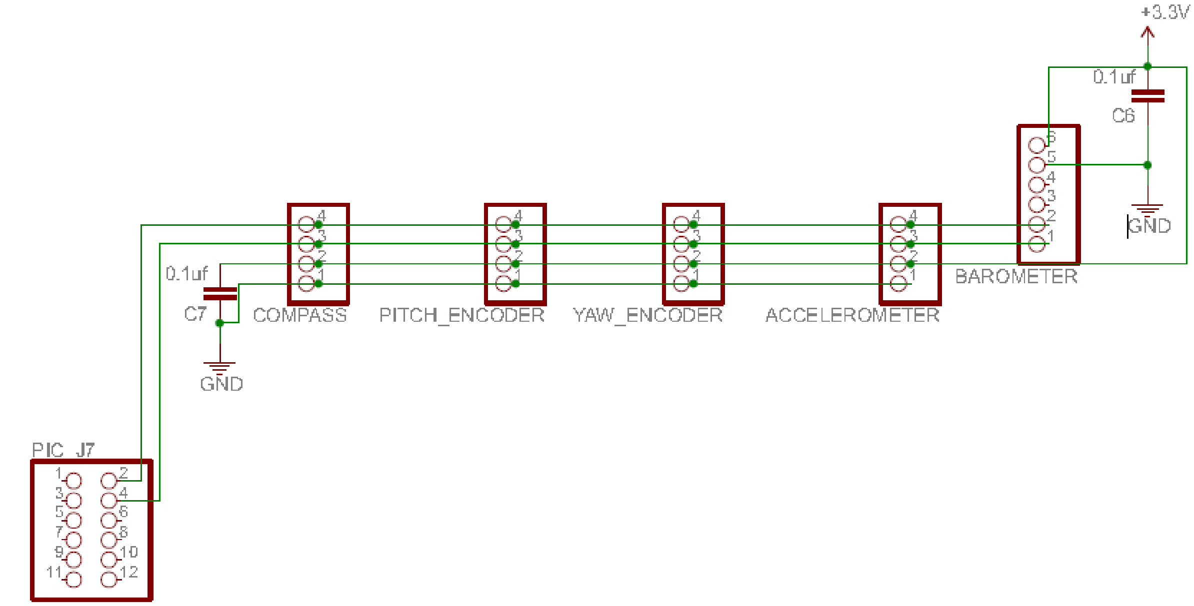


Figure 16: ComPAS Pitch and Yaw Encoders

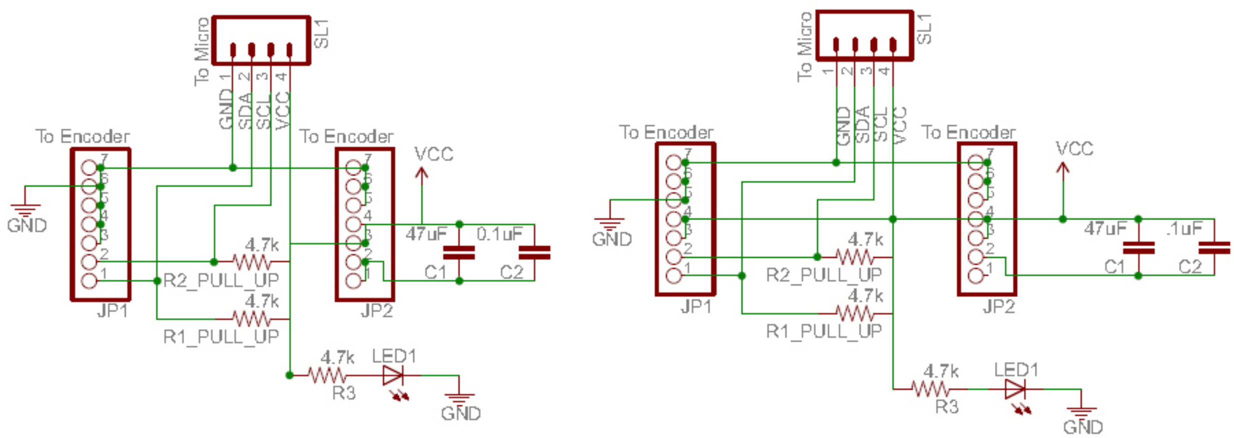


Figure 17: ComPAS and AtLAs Power System

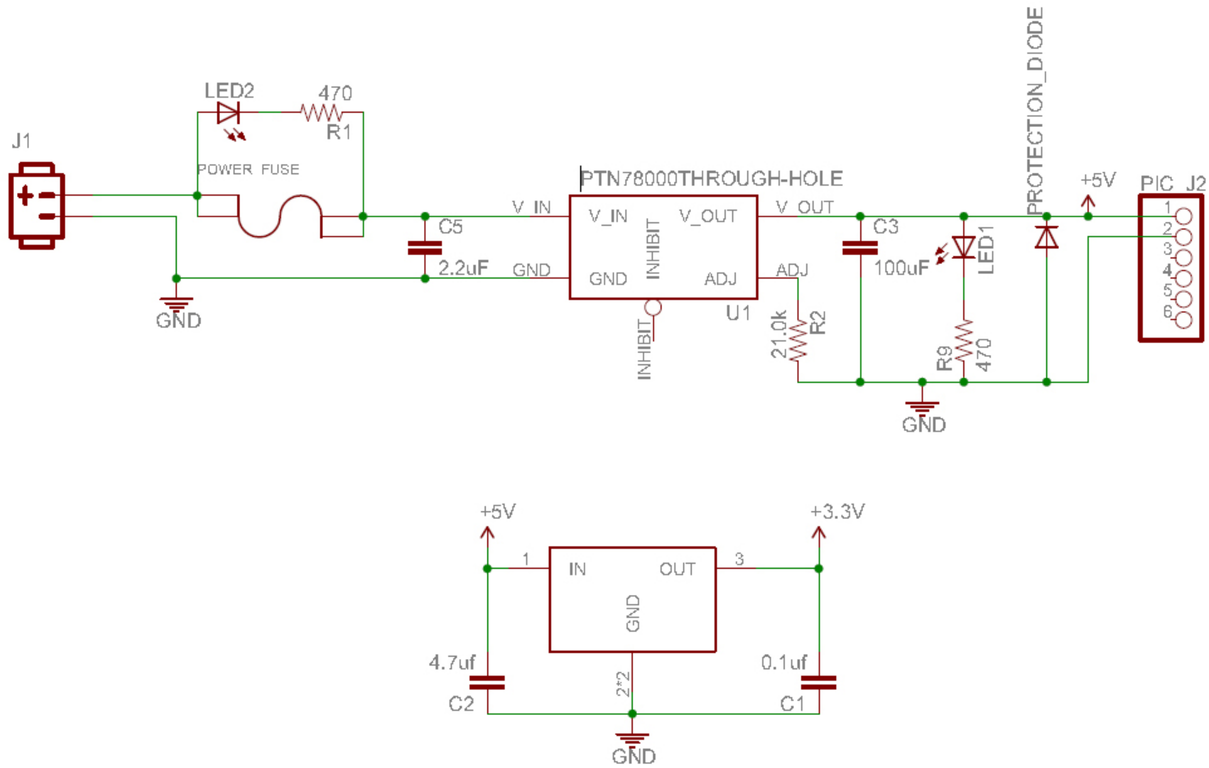


Figure 18: ComPAS and AtLAs UART Devices

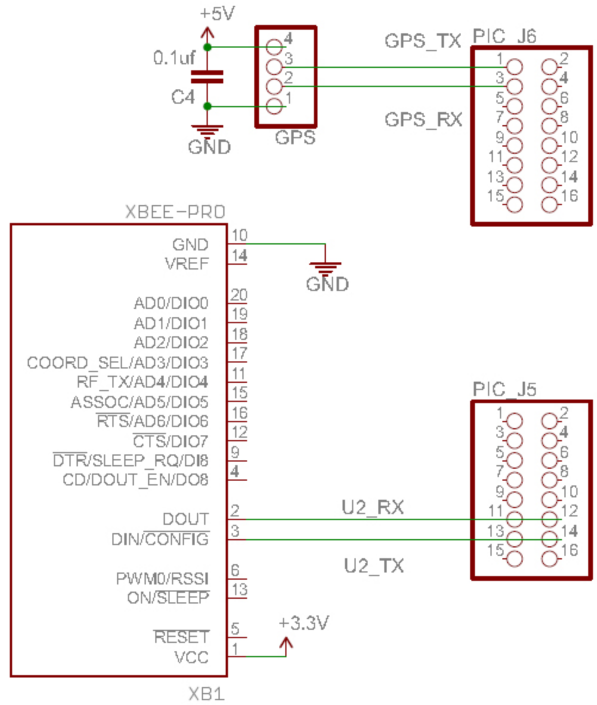


Figure 19: AtLAs I2C Devices

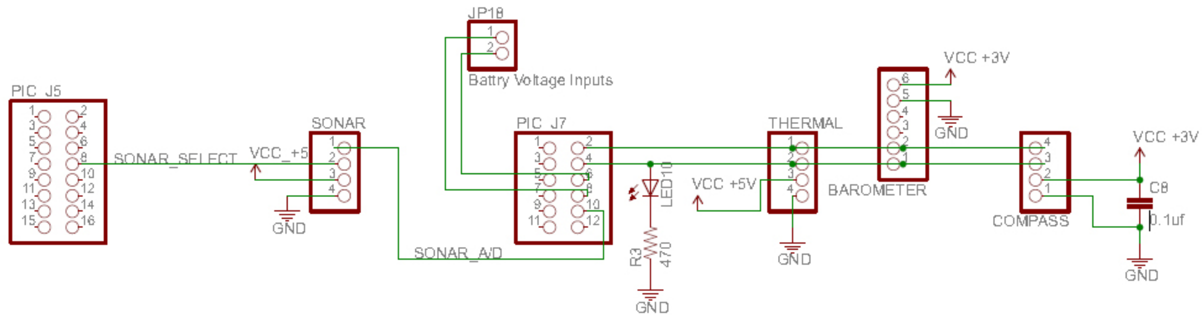
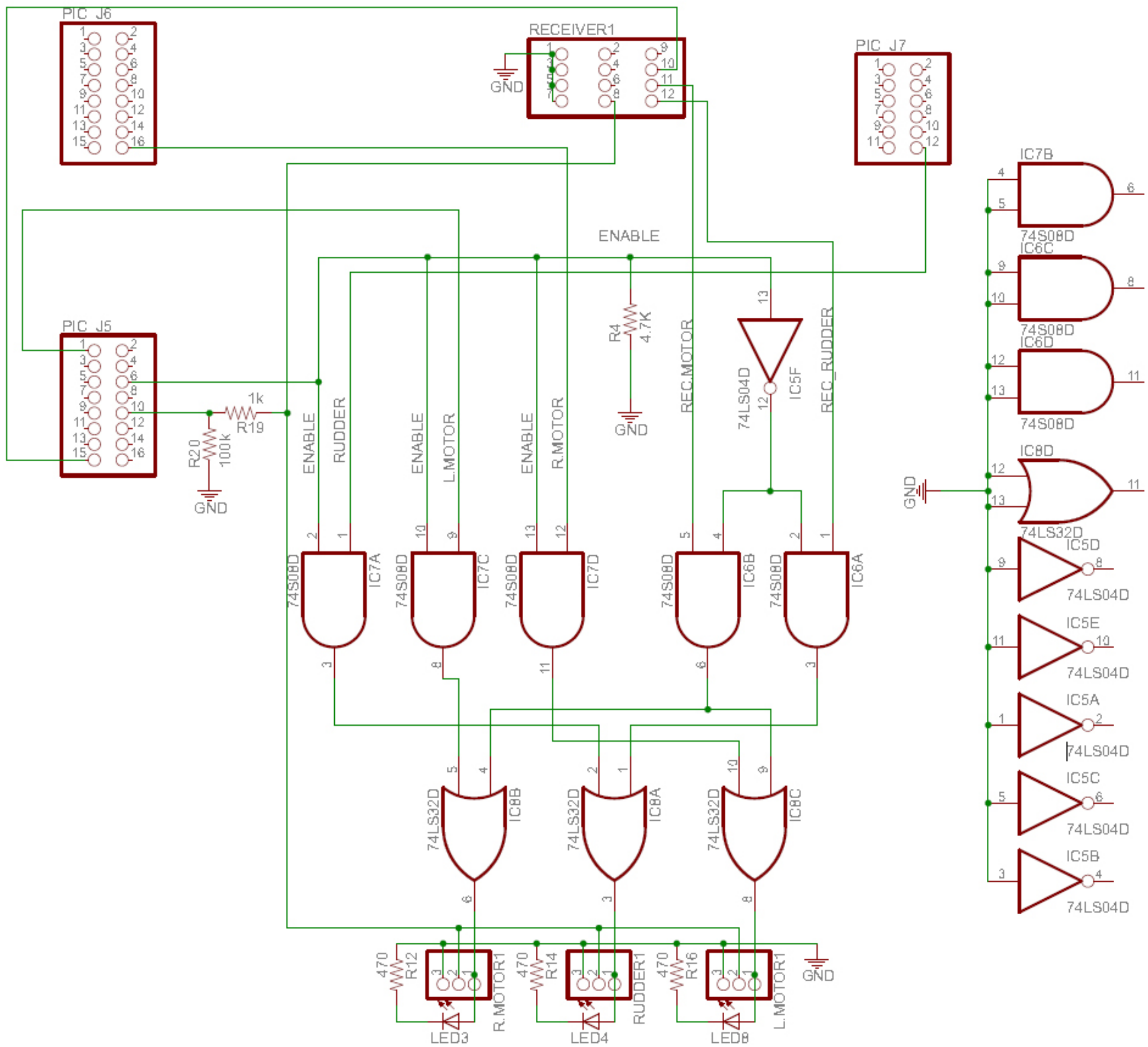


Figure 20: AtLAs Override System



D Budget

Itemized Budget

COMMAND POST ACQUISITION SYSTEM

Item #	Qty	Cost (each)	Total	Description
6	1	$170.42	$170.42	DigiKey Discrete components 5/9/2013
7	1	$91.88	$91.88	3DR GPS uBlox LEA-6 Breakout
8	1	$24.99	$24.99	Barometric Pressure Sensor - BMP085 Breakout
10	1	$33.54	$33.54	Triple Axis Accelerometer Breakout
11	1	$135.99	$135.99	Tilt-Compensated Magnetometer
12	1	$137.99	$137.99	Barska Blackhawk ED Spotting Scope 20-60x 60mm Angled Body
13	1	$20.00	$20.00	Vortex High Country Backpack Tripod
15	2	$52.20	$104.40	Black Acrylic
1	1	$49.95	$49.95	XBee Pro 60mW U.FL Connection - Series 1 (802.15.4)
22	2	$7.85	$15.70	14-bit magnetic encoder
1	2	31.9	$63.80	chipKIT Uno32
Total			**$848.66**	

Itemized Budget

AUTONOMOUS LIFEGUARD ASSISTANT

Item #	Qty	Cost (each)	Total	Description
1	1	$142.68	$142.68	45" RC Boat Hull
2	2	$12.50	$25.00	RC Boat Fender Skirt (Polyform G-4 Twin Eye Fender 6.5 x 23 - Black w/Air Adapter)
3	2	$68.24	$136.48	Motors and ESCs
4	2	$107.24	$214.48	Turnigy nano-tech 5000mah 4S 45~90C Lipo Battery Pack
5	1	$14.90	$14.90	Waterproof NEMA 4X enclosure/heatsink
6	1	$428.42	$428.42	Discrete components
7	1	$91.88	$91.88	3DR GPS uBlox LEA-6 Breakout
8	1	$24.99	$24.99	Barometric Pressure Sensor - BMP085 Breakout
11	1	$135.99	$135.99	Tilt-Compensated Magnetometer
17	1	$49.95	$49.95	XBee Pro 60mW U.FL Connection - Series 1 (802.15.4)
29	1	$28.97	$28.97	Ace Water proofing 3/28/2013
33	1	31.9	$31.90	chipKIT Uno32
40	1	$50.00	$50.00	PCB ordering
Total			**$1,375.64**	