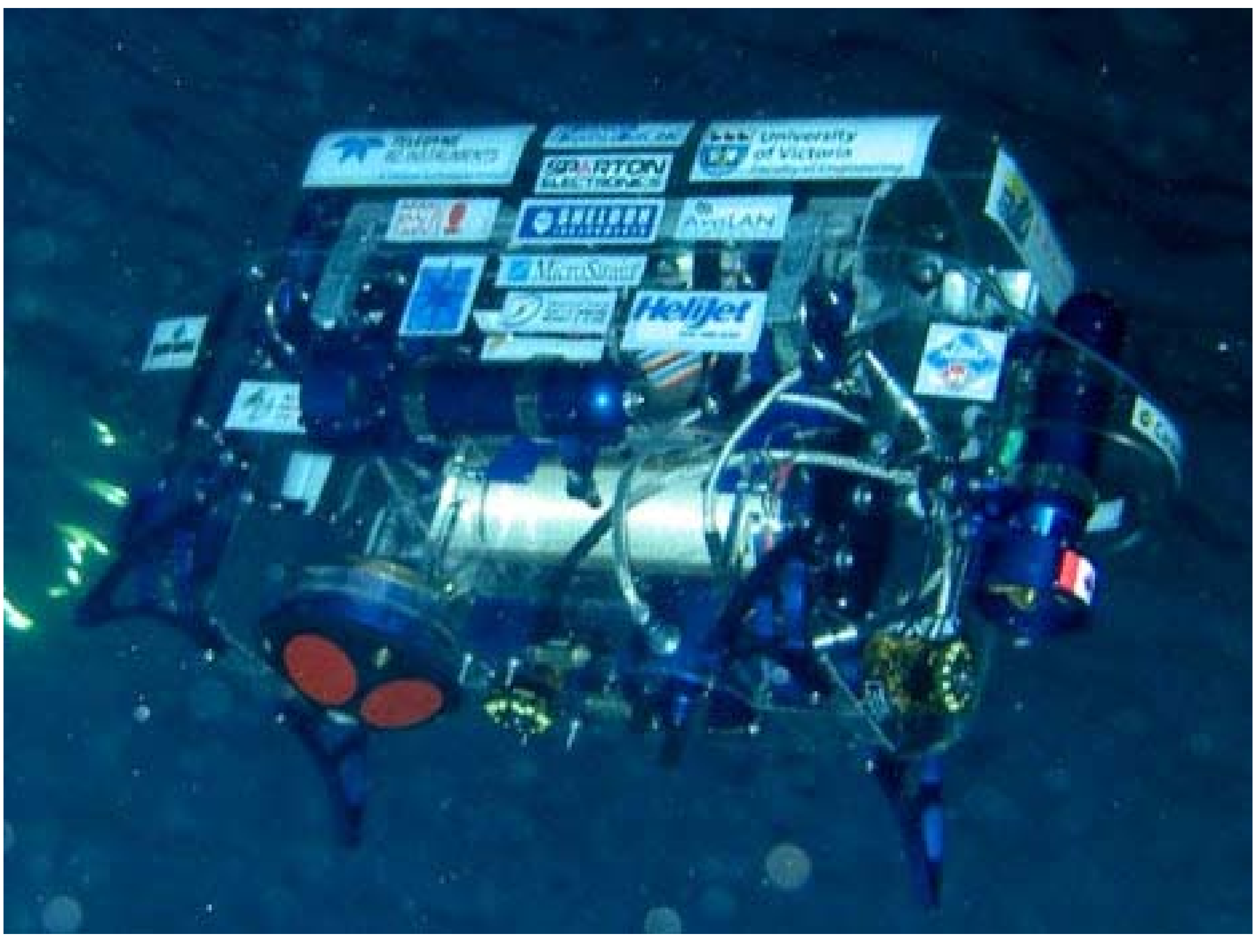
University of Victoria
MATE Technical Report

Aerius
University of Victoria Autonomous Underwater Vehicle Team (AUVic)
Victoria, British Columbia, Canada
http://www.auvic.uvic.ca/



ABSTRACT

This technical report describes the University of Victoria's remotely operated underwater vehicle (ROV) for entry into MATE's ROV Competition. AUVic, the University of Victoria's underwater vehicle design team, is entering this competition this year for the first time.

This report details the mechanical, electrical and software systems that make up the Aerius' overall design and functionality. It also details design challenges that were encountered and overcome during system integration, troubleshooting techniques and lessons learned during the design and testing of the vehicle, and future vehicle improvements. The report includes the team's reflections on the entire project, and a summary of the effect unmanned submersibles are having on exploration at the earth's poles.

The submersible consists of a flooded outer hull, and three dry inner hulls containing the batteries, electronics, and Doppler Velocity Log (DVL). Four Seabotix thrusters are employed to control the vertical and horizontal movement of the ROV. Also mounted in the submersible are the cameras, Inertial Measurement Unit, pressure sensor, compass, active and passive sonar, grabber arm, and weight droppers.

The PC-104+ stack is the backbone of the ROV's electrical system. It contains the Hub, DSP, ADC capture module, video capture card, serial expansion card Ethernet adapter, two PCs, and two power supplies. The Hub supplies power to all parts of the ROV, controls the weight droppers, and communicates with the motors and the grabber arm. The serial module communicates with the sensors.

In ROV mode, the software accepts velocity, heading and depth requests from the human operator and produces the desired results.

1. INTRODUCTION

A Remotely Operated Vehicle (ROV) is a submersible, tethered robot that is capable of performing complex tasks as directed by human operators. Unmanned submersibles are a very active area of research. Today's ROVs are extremely versatile, with applications including underwater structure inspection and maintenance, submarine rescues, underwater manipulation, and aquatic sample collections.

This is AUVic's first entry into MATE's ROV Competition. AUVic is primarily an Autonomous Underwater Vehicle (AUV) Design Team, but has this year adapted its AUV for ROV operation as well.

AUVic has made a substantial effort to develop a competitive product that can perform at an international level. In pursuit of the team's aspirations to build this vehicle, AUVic has made all efforts to acquire some of the most advanced technologies, integrated into an innovative new design. Through hard work and dedication, AUVic has significantly increased sponsorship, formed many corporate partnerships, and gained some of the most capable engineers of tomorrow.

2. MECHANICAL DESIGN

Aerius, shown in Figure 1, is designed to be ultra-compact and lightweight, while maintaining maximum versatility. Its overall size is approximately 93cm x 48cm x 40cm. Its streamlined design allows for simplification and increased accuracy in the navigation algorithms.

The vehicle was designed to have a stable orientation in the water. The thrusters allow for pitch and yaw control while roll is controlled by the layout of the components. With heavy components such as the Doppler Velocity Log (DVL) transducer and sonar units at the bottom, and the buoyant battery and electronics hulls at the top, the ROV will self-correct for any changes in roll.

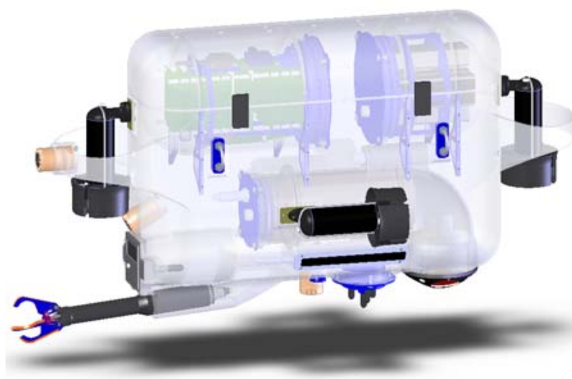


Figure 1 – 2007 Aerius design

The entire ROV weighs approximately 20 kg, and has been designed to be slightly positively buoyant. This has been achieved through engineering optimization and careful selection of materials. The outer and inner hulls have been precision molded using durable urethane. The aluminum components have all been CNC machined and anodized to create high quality sturdy components that are as aesthetically pleasing as they are functional. The high precision of CNC machining allows for an extremely compact design with tight tolerances. The vehicle layout is such that all components can be accessed quickly and easily. Troubleshooting and maintenance may be conducted with ease.

Overall, the design is similar to last year's model; however, this year Aerius has been given a 300 meter depth rating.

A. Outer Hull

The outer hull is a significant improvement over last year's model, and a large portion of the mechanical design effort was allotted for this component. Designed as a wet hull, it floods with water keeping the vehicle stable. The outer hull is similar in shape to the previous model, but that is where the similarity ends. The new outer hull is molded from durable urethane, and wherever possible, incorporates mounting brackets and support structures directly into the outer hull component. As a result, fasteners and small machined components are minimized, and unnecessary stress concentrations due to mounting holes are almost completely eliminated.

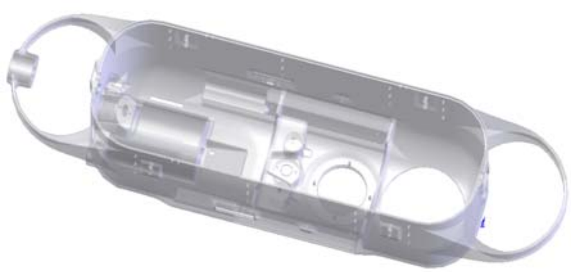


Figure 2 – Outer Hull (Bottom)

The top of the outer hull is a separate unit, and is held in place by four low-profile latches. This enables easy access to all components of the vehicle. The vehicle itself is very easy to assemble and maintain, due in large part to the careful design of the outer hull.

B. Electronics Hull and Battery Hull

The Electronics Hull and Battery Hull are both located at the top of the flooded outer hull. Much of the space inside these sealed hulls is filled with air, providing buoyancy to the vehicle. These components are precision molded from durable urethane, and are each sealed using a 6061 aluminum end-cap with two radial o-rings for a redundant seal. The cylindrical hull design allows them to withstand high water pressure without significant deformation.

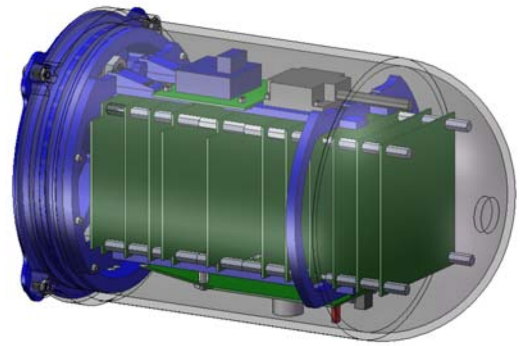


Figure 3 – Electronics Hull

The electronics hull contains the PCs and most of the electrical boards. Contents of this sealed hull include the compass, IMU (inertial measurement unit), sidescan sonar electronics, two dual-core PCs, power supplies, and PC104+ stack electronics. The electronics stack is mounted directly to the end-cap to simplify removal from the cylinder; when the end-cap is removed, all of the components come with it. This minimizes excess wires and cables. The stack can also be removed from the end-cap for maintenance. Four aluminum arms allow additional space for components to be mounted above and below the stack. The wires will run along both sides of the stack to the end-cap.

Figure 4 – Battery Hull

The battery hull contains six Thunder Power lithium-polymer batteries. This isolates Aerius' electrical systems and protects them from potential battery leaks and explosions. This also eliminates the need to unseal the electronics hull to change the batteries. Once the electronics hull is sealed, it should not have to be reopened.

The batteries slide into slots in circular aluminum brackets, which are mounted to the end cap using four aluminum arms. This facilitates easy removal of the batteries from the hull for recharging. Two complete battery hulls were built, to allow for on-the-fly battery replacement while in the field. The replacement hull containing charged batteries can be installed quickly, and the original battery hull taken back to the workbench for disassembly and battery recharging in a properly equipped environment.

The electronics and battery hull end-caps are equipped with Subconn connectors and a pressure relief valve for pressure equalization during assembly. The Subconn connectors allow power and control signals to be relayed between the inner hulls and to the rest of the ROV, and sensor data to be fed into the computer.

C. DVL Hull

The DVL Hull is a watertight enclosure containing the DVL transducer and its electronics. Both the transducer and electronics are supplied by Teledyne RD Instruments. While this hull is sealed and contains buoyant air, this component is actually fairly heavy and is located on the bottom of the outer hull.

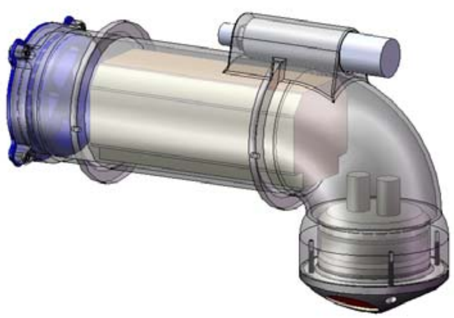


Figure 5 – DVL Hull

As with the other inner hulls, this component is precision molded from durable urethane, and the cylindrical hull design allows it to withstand high water pressure with minimal deformation. This component is designed to allow the electronics to be horizontal and the transducer to face downwards. As with the battery and electronics hulls, the horizontal end of the DVL hull is sealed using an aluminum end-cap with two radial o-rings for a redundant seal. The DVL transducer mounts directly to the bottom end, and seals using the transducer's three o-ring redundant seal.

The molded hull was designed to incorporate the mounting surface for the Applied Microsystems pressure sensor, and also includes flanges to mount securely to the outer hull.

D. Thrusters

There are four Seabotix 200 Watt brushless thrusters mounted directly to Aerius' outer hull. Two thrusters are mounted horizontally, one on each side, to provide forward and reverse motion. The remaining two thrusters are mounted vertically on the bow and stern of the submersible. They allow for depth control, and hold the positively buoyant vehicle below the water's surface.

Figure 6 – Seabotix Thruster

E. Grabber Arm

The grabber arm is a new addition to Aerius. It is mounted on the bottom front of the vehicle. The grabber arm cannot move relative to the vehicle, so it is mounted at a downward angle. Positioning of the grabber claws is performed by adjusting the vehicle's orientation in the water.

F. Cameras

Three Inuktun Crystal Cams are mounted in specific locations on the vehicle. One camera is mounted on the front of the vehicle pointing forward. Another is located on the center of the ROV's bottom surface, and is used for seafloor observation. The third camera is mounted on the front of the ROV, but at a specific angle so as to view the grabber claws.

Figure 7 – Inuktun Crystal Cam

G. Weight Droppers

There are two weight droppers located on the bottom of Aerius. They each use a permanent magnet to hold ball bearings in place. An electromagnet is used to negate this magnetic field, which releases the weights from the ROV. One weight dropper is positioned on each side of the downward camera; this is to provide the best weight release location relative to the camera view.

H. *Active Sonar*

Multibeam and sidescan sonar units are recent additions to the ROV. The active sonar system also includes the DVL. Since cameras have limited visibility underwater, the active sonar system was added to allow Aerius to see accurately and many times further than any previous vehicle. AUVic is working to merge sensor data from all three devices to create a virtual 3D image of the underwater environment. When this is complete, it will be possible to perform object detection and recognition.

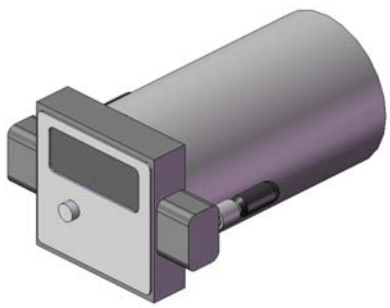


Figure 8 – Multibeam Sonar

Figure 9 – Sidescan Sonar

I. *Passive Sonar*

The passive sonar housing is machined from 6061 aluminum. It contains four Reson TC4013 hydrophones in a specific geometric configuration that allows for accurate three-dimensional locating of a sonar signal. The hydrophones are connected to the rest of the ROV using a single Subconn connector mounted on the top of the sonar housing.

Figure 10 – Passive Sonar

3. Electrical Design

The PC-104+ stack is the backbone of the ROV's electrical system. It contains the Hub, DSP (Digital Signal Processor) and ADC (Analog to Digital Converter) modules, Frame Grabber, and Serial (RS232) modules. The Hub controls power going to all parts of the ROV, while acting as a control for the weight droppers, and a RS232-to-I²C interface for communicating with the thrusters, grabber arm and temperature sensors.

Figure 11 shows a schematic of the ROV's electrical systems.

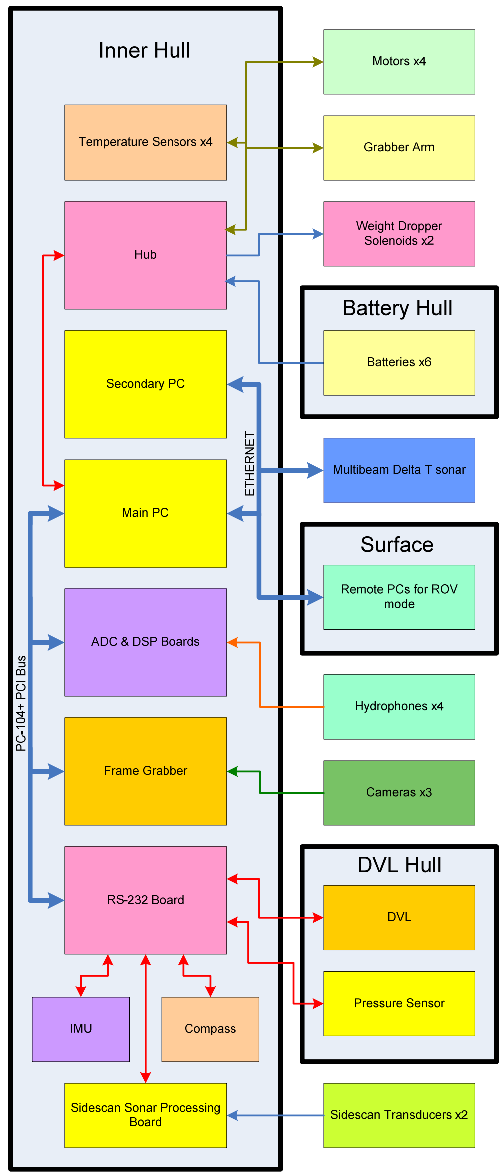


Figure 11 – Electrical Systems Schematic

A. *Hub*

The Hub provides the base-level control of the sub. It monitors the batteries and provides power to the rest of the system through a series of relays. The "Go" and "Kill" switches are attached directly to the Hub. These switches allow the sub to be activated once in the water, and provide an "emergency halt" should it have to be shut down quickly.

The brain of the Hub is an ATmega128 AVR microcontroller. The chip was chosen for its robust nature, large number of inputs and outputs, extensive user base, and excellent adaptability.

The Hub also controls current going to the weight dropper solenoids. The Hub communicates with the PC-104+ stack via RS-232 and relays messages to and from the PC to the motor controllers using the I²C bus.

B. Thrusters

Each of the motors is programmed to use the same I²C address so that it is possible to easily swap out one in case of failure. However, this presents a problem in that it is not possible to attach multiple I²C devices to the same bus that have the same address. In order to get around this, an I²C multiplexer chip is used select which one of the thrusters receives a command. Since the thrusters run on a separate power source from the rest of the electronics on the Hub and in order to make the Hub more electrically resilient, an isolator chip is placed between the ATmega128 and the I²C multiplexer.

C. Tether

The vehicle's tether is an 8-conductor 24-AWG (0.5mm diameter) water resistant cable. Of the eight conductors, four are used by Ethernet, three by video, and one for ground. All of the power for the sub is provided by the onboard batteries.

D. Batteries

The AUV is powered by five Thunder Power lithium polymer batteries. The batteries provide between 6.0V and 8.65V each, depending on level of charge.

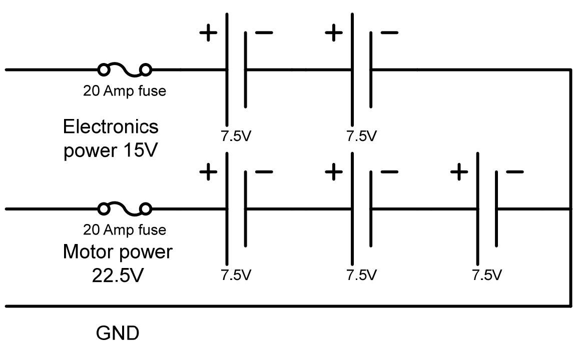


Figure 12 – Battery Configuration

The batteries are wired to provide two separate sources – two batteries providing a ~15V source for the electronics and three batteries providing a ~22 V source for the motors, weight droppers and grabber arm. This separation was done due to the different voltage requirements of the devices and to allow isolation of noise from the motors and increased battery life. Each source is protected by a 20A fuse. The sixth battery is not currently used, but is available for future electrical expansion.

E. PCs

There are two PCs inside the electronics hull. Each PC is a PC-104+ industry form factor Intel Core2 Duo based system. The PC-104+ form factor allows many commercially available expansion cards to be stacked on top of one another and be connected by PCI bus. The frame grabber, RS232 board, DSP board, and ADC board are connected to the first PC, while the active sonar is connected to the second one. The first PC provides the processing power for the Vision and Navigation software. The operating system for each PC is installed on a 4GB compact flash card that is connected to the IDE port.

F. Frame Grabber

The frame grabber captures images from the cameras, and digitizes them to allow for processing by the onboard vision system.

G. Serial Board

The serial board is another PC-104+ stack module, which contains eight RS-232 ports. These ports are used to communicate with the various sensors and peripherals: the IMU, compass, pressure sensor, DVL, sidescan sonar, and Hub.

4. SOFTWARE DESIGN

Aerius' software system is written primarily in Java and also features C and C++. As shown in Figure 13, the system is divided into several modules, which communicate over a TCP/IP based network server onboard Aerius.

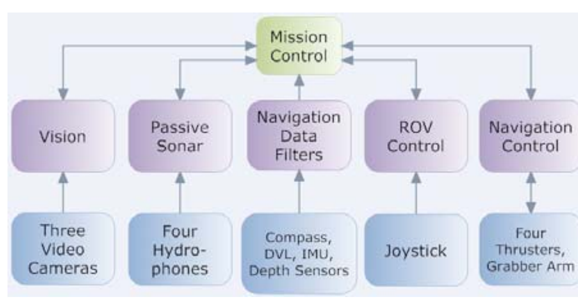


Figure 13 – Software Overview

The Mission Control module coordinates the actions of Aerius based on inputs from her sensors. The Vision module provides relative azimuth and elevation suggestions as well as size approximations for each object detected to Mission Control. The Passive Sonar module provides the azimuth and elevations to the sonar beacon to Mission Control.

The Navigational Data Filter receives data from Aerius' Compass, DVL, IMU and Pressure Sensor, and through a Kalman filter provides consistent and accurate data to Mission Control. Navigation Control receives navigational commands from Mission Control and issues the proper commands to the vehicles thrusters. ROV Control is used for testing and Intelligent ROV operation of Aerius. Intelligent ROV operation allows the operator to combine the power of the navigational control system with the logic of a human operator.

A. ROV Control

Aerius' ROV control allows a human operator to direct the vehicle with the use of a USB joystick. All communication requests are made possible through TCP/IP communication via a tether which connects Aerius' onboard computer to an onshore laptop.

Figure 14 – ROV Control Interface

The pilot can operate in either "Direct Control" mode or "Smart Control" mode. In "Direct Control" mode the ROV control software allows the operator to specify percentages of maximum thruster power. This allows the pilot the greatest control over the vehicle and is often beneficial in testing, and movement of the vehicle in very complicated underwater terrain. In Smart Control mode the operator is able to request specific velocities, depths, turn and pitch rates. With the large amount of automation this provides, the pilot is free to perform other tasks during the mission and can reduce fatigue on long distance missions. Both these options send commands directly to navigation control which implements them accordingly.

B. Navigational Data Filtering

For Aerius to navigate autonomously, the onboard navigation system must be able to determine the trajectory traveled from onboard sensor instrumentation only. GPS signals are not an option, as the carrier wavelength of a GPS signal is too short to penetrate far into the water.

The navigation hardware components on Aerius include the IMU, DVL, digital compass and digital pressure sensor. The ROV integrates the smallest hardware components currently available on the market in order to build a small, energy efficient vehicle.

The precision navigation system utilizes the IMU and is aided with ground velocity measurements provided by the DVL. Such a system is referred to as a Doppler-Aided Inertial Navigation System. A complementary software filter improves the gyroscope and accelerometer data, yielding more precise attitude estimation. Finally, a Kalman filter merges all sensor data together. The application of the Kalman filter creates smoother and more stable data estimation, which facilitates accurate knowledge of the ROV's position and attitude.

Kalman filters are employed when data from different sensors have to be merged in order to maintain high precision navigation. Sensors like the DVL have a limited update rate, which is usually in the range of 8 to 20Hz. The higher the update rate of navigation instrumentation, the more precisely navigation can be achieved. The Kalman filter estimates the gaps between the DVL readings, and produces a higher, "artificial", update rate. In conjunction with CSSF (Canadian Scientific Submersible Facility), a Navigation system has been developed specifically for the ROV utilizing a complementary filter for orientation, and a Kalman filter for positioning and attitude.

C. Hub Firmware

Aerius' lowest level of software operates on the hub. This software is responsible for translating thruster levels and grabber commands into electrical signals. The board communicates with Aerius' onboard computer through RS-232. Once the commands arrive on the board they are interpreted and the appropriate command is issued to one of the four Seabotix thrusters or the Seabotix grabber arm through the I2C protocol. This protocol was used due to its simplicity and compatibility with Seabotix's devices. The bottom-side control software also monitors Aerius' thrusters, grabber arm and three onboard temperature sensors for errors. If it detects an error, a warning message is issued to the onboard computer and the appropriate actions are taken to ensure the safety of the vehicle and its operators.

D. Vision

The vision system can be broken into three parts: data collection, transmission/decoding, and analysis.

The data is collected by three Inuktun Crystal Cams. Each of these cameras outputs a NTSC signal, with 480 TV lines of resolution. One of the cameras points forward, the second camera points directly downwards, and the third camera will be used to coordinate any grabber arm activity.

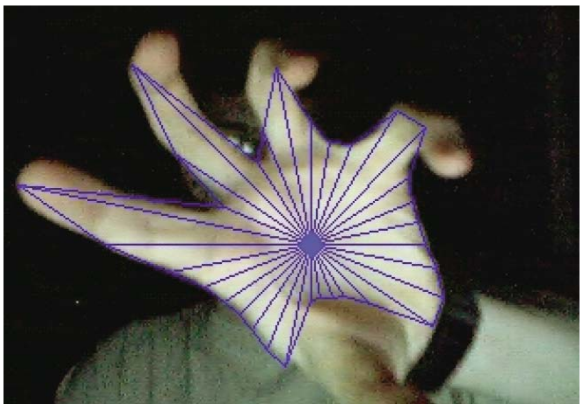


Figure 15 – Vision

The video from these cameras goes to a CM7326/CM7327 Frame Grabber module, from RTD Embedded Technologies, Inc. This board is located on the PC-104+ stack, and converts the NTSC analog signal to a digital signal that can be processed by the Vision software. Additionally, both the analog and digital video signals from the cameras can be sent to the surface over the tether.

The analysis of the data is one of the most crucial areas of this process. A Vision server thread is always running on the ROV, and can provide appropriate directions or headings to Navigation when called upon. When activated, the Vision server accesses the current video frame from the Frame Grabber. Next, the Vision server performs an analysis on the image, and returns the results to Navigation. Navigation adjusts to this new heading, and the process repeats, with the Vision server returning more headings for Navigation to follow.

The digital image processing is done in three steps.

1. HSL or RGB, high and low boundaries are chosen from a list of presets. At this time, the appropriate secondary analysis is also chosen. Both of these cases are dependent on the parameters passed in from the Control software. This allows the Vision module to run specific algorithms for each portion of the course.

2. The program scans through the image once, creating polygon approximations around the areas that meet the HSL criteria.

3. Two processes (A & B) can now occur in parallel.

   A) The polygons are analyzed according to the secondary criteria, and return data to navigation. Sometimes data will only be returned once several frames have been processed. (Flash rates, double checking, averaging, etc.)

   B) At this point new image data can be loaded in from the camera(s), and will be ready for the next analysis. The current frame of pixel data can be overwritten, because the polygons encompass all the data that is needed for the secondary analysis.

E. Passive Sonar

Sonar is an important localization tool for any underwater vessel. Sonar is classified as either active or passive: active sonar transmits a signal and receives a reflected version of that signal; passive sonar receives signals transmitted from an outside source.

The ROV's passive sonar system receives underwater transmission signals between 20 and 40 kHz from a predefined source. It will determine the angle from the submarine to the transmitter on both the horizontal and vertical planes.

The signals will be received by the array of four hydrophones, converted to digital data and processed by an embedded digital signal processor. The phase differences between the signals received by each hydrophone create peaks when processed with a generalized cross-correlation method. The peaks are an estimate of the time differences between the hydrophones, and angles are determined from the calculated time delays. This method is well established and has proven to be a robust solution that can operate effectively in high noise environments.

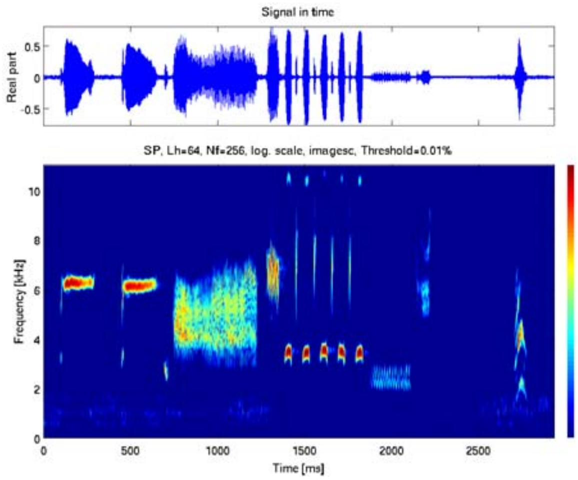


Figure 16 – Passive Sonar Spectrum

The passive sonar system is designed as a DSP solution. This means that the input signals from the hydrophones are immediately digitized, then stored in buffers and manipulated in software. This method has been chosen because it is simple in terms of hardware and because parameters and algorithms can be easily adjusted in software.

Components were purchased "off the shelf" and no extra circuitry was developed.

The Sheldon Electrical DSP module fits on the PC-104+ stack. It uses a powerful 32 bit Texas Instruments 225-300Mhz TMS320C6711DSP processor, and has a 32 bit PCI bus which will be used to connect it to the host PC. This module, in conjunction with the ADC module, takes input from the four hydrophones and processes the signals separately with a high degree of accuracy. Once the signals are converted to their digital equivalents, they are analyzed and processed by the PC.

The ADC module is also made by Sheldon Instruments and plugs directly into the DSP module. It is the SI-MOD6800-HG-250 model which features 16 double-ended or 32 single-ended analog inputs, two SAR 16 bit ADCs sampling each channel at 100 kHz, high and low gains from 1 to 1000, and 36 digital I/O channels. This board was chosen because it is designed for use with the DSP module and the high gain eliminates the need for external pre-amplifier circuitry.

F. Navigational Control

The system was initially designed in Matlab, to determine stability characteristics. Afterwards, it was ported to the Java framework and refined on live hardware.

The Control module uses two independent PID loops to maintain a constant heading and depth. The system is manually tuned on hardware change, but is resistant to minor variations in weight and motor power. The system only implements heading, depth and axial speed control. Position control was omitted since the submarine does not operate in all six degrees of freedom. This task was left to a higher level control-system which is planned for future developments.

The motor controllers are designed to be able to control the angular velocity of the propeller, regardless of the speed of the vessel in water. The motor controllers use a PI algorithm, to allow for rapid response and zero steady-state error. They are also entirely independent, requiring only a tachometer feedback from the motors themselves to function.

G. Mission

The Mission Control server is at the highest level in the software hierarchy, coordinating the global state of the submarine and the state of each subsystem. It makes calls to Vision, Sonar, and Navigation to dictate how each portion of the course is carried out. The mission software comprises of a main mission class and individual tasks for each mission objective.

Mission tasks are constructed as a finite state machine. The state machine controls the mode of each module, which in turn controls what data is returned from these modules. It takes data from the ROV's subsystems and returns navigational requests, telling the sub where and how to move. Each task will return one of three possible outcomes for the objective: completed successfully, not completed, or timed out.

The main class executes smaller tasks, determining the order in which tasks are attempted based on previous outcomes. The clauses in mission will determine if a task should be retried, and which task should follow a successful or failed execution. This results in an intelligent solution in which the submarine is able to make decisions and recover from errors.

5. DESIGN CHALLENGES

Aerius' control and navigation system obtain its abilities from the diversity of software and electrical sub-systems on board. However, in order for Aerius to operate at her peak, each of these subsystems must be able to communicate and work together effectively and efficiently. With system integration often being the most technically demanding and error prone process in the design and construction of an underwater vehicle, the issue was addressed in three phases: technical specifications, implementation, and system evaluation and modification.

The technical specifications were defined by several of AUVic's most involved programmers and electronics specialists to ensure compatibility between all subsystems. The process was started by creating a list of requirements and their relative importance as shown below.

1. *System Reliability* – No single subsystem can crash another subsystem.
2. *Communication Speed* – Large amount of data can transfer quickly.
3. *Information Relevance* – Subsystems receive only up-to-date data.
4. *Standardization* – Communication Protocol available to all systems.
5. *Ease of Implementation* – Ability to be implemented in many programming languages.

These requirements and the power of Aerius' onboard computer led to the decision of using TCP/IP network communication as the backbone with RS-232 being used to communicate with the lowest level of hardware. TCP/IP provides proven high speed, standardized error-corrected communication, and while RS-232 is not as reliable or high speed, it performs well in embedded applications due to its low overhead and extensive history of use.

With the requirements determined, AUVic's software team reviewed the existing subsystems and designed a solution. The solution used TCP/IP and RS-232 as required while ensuring that the most current information was easily available to each subsystem and its programmer. Aerius' software team started by building a network server that could receive and transmit data to and from each subsystem. The server was created in Java to ensure rapid development and was designed to only pass data between sub-systems, thus not parsing data and increasing transmission speed. Once the server was created, a network client framework was developed for Java, C and C++ to allow all subsystems to communicate with the server.

The network client for Java was created with very few problems due to the high level approach Java takes. Unfortunately, the C and C++ network clients provided a larger challenge due to the complexity of network programming and file parsing in each respective language. However, through review of technical books and with the assistance of other programmers, the framework was created for all three languages.

Once all systems were created, the communications were tested. Several issues were detected relating to system stability and individual clients' ability to slow the whole system down. However each issue was solved in turn with small modifications to the code.

The complex and potentially error prone challenge of integrating the many subsystems of Aerius was overcome. This was achieved through a defined design process and an organized testing strategy. Moreover, through effective team collaboration, all requirements were fulfilled by the final solution.

6. LESSONS

Over the course of the past year, the team members have learned valuable lessons, and gained many new skills. AUVic learned one very important lesson regarding the value of using off-the-shelf components wherever possible. Last year's submersible was a complete re-design in all aspects. An ambitious project as a whole, and much more so with the choice to design and manufacture thrusters from scratch.

The thrusters consisted of Maxon brushless motors, sealed inside a lightweight CNC machined aluminum enclosure. Custom motor-controllers fit within the thruster housings, and attached directly to the motors. This was to save space within the sealed electrical hull, reduce the number of wires going to the electrical hull, and to isolate the vehicle's electronics as much as possible from noise generated by these motor controllers.

While this seemed like a good idea at the time, many problems were encountered with the custom motor controller electrical boards.

The motor controllers consisted of three 4-layer 30mm diameter electrical boards, stacked on top of each other. A considerable amount of electronics was to be fit in a very small space. Problems were first encountered during assembly. Two capacitors turned out to be much larger than specified, and did not fit well between the boards. Space was already very tight within the thruster housings, but with a bit of work, the components were adjusted to accommodate for the extra space required.

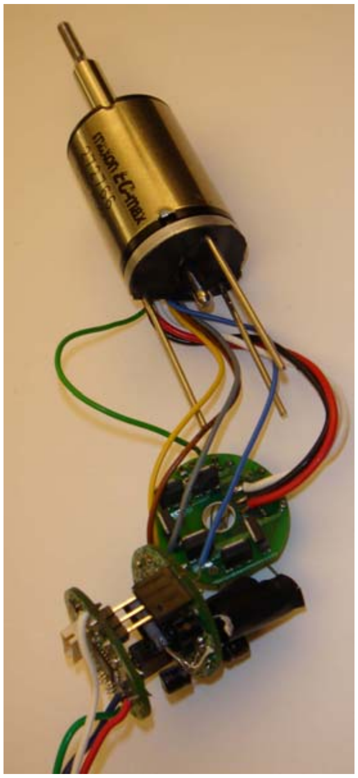


Figure 17 – Custom Motor Controllers

The considerable time required for assembly of the boards and for the subsequent troubleshooting was not accurately anticipated. The completion of the thrusters system took much longer than anticipated, and put the team's schedule behind.

While on site at a competition last year, the motor controllers started working intermittently, and then proceeded to fail completely. Over the course of the next three days, the team devoted themselves to repairing the boards so AUVic could compete successfully, but to no avail. Two boards were thought to be repaired, but these failed again on subsequent competition runs.

When designing such a complex system, problems are expected. Because the entire vehicle is essentially a first prototype, but is required to be fully functional, it must be designed very carefully so that no major problems are encountered that cannot be easily fixed.

The major problem with the motor controller electrical boards was that too many electrical components were located in too small a space. The tolerances on the electrical boards were so tight that it was difficult to properly solder the components. The design was faulty in that it was simply too difficult to populate, and this was something that could not be remedied except with completely new motor controller boards.

After the experience with the motor controllers last year, the custom thrusters were completely scrapped. These were replaced with Seabotix thrusters, which were integrated into the vehicle soon after they arrived. The Seabotix thrusters are an off-the-shelf solution; therefore, minimal testing was needed, and almost no troubleshooting was required for the thruster implementation.

These problems with the motor controllers severely hurt AUVic's standings during the completion, but a valuable lesson was learned. To avoid such problems in the future, as many off-the-shelf components will be used as possible. This saves design and implementation time, and most importantly, the individual system works before it arrives, and the only work required is implementation.

7. TROUBLESHOOTING TECHNIQUES

In encountering any problem, especially a technical problem, a systematic and thorough approach is beneficial. The problem solving approach used by the AUVic organization is based on a top down analysis. To perform a top down analysis one must break down the operation of a malfunctioning system into sub-systems. Each sub-system should be organized in a parent-child tree so inter-system dependences can be observed. Once each sub-system is identified, its expected behaviour and response to input must be specified.

Starting at the bottom-most child of the system, the behaviour of each node should be verified by applying a known input. If an error is detected, the sub-system should be broken down into more sub-systems if applicable and the process repeated. As each sub-system is verified you can move up the parent-child tree and verify the next sub-system until the problem is found. In the case when two or more branches intersect, each branch of the tree should be verified separately before the intersecting parent node can be verified.

In large scale systems this approach can become very confusing and time consuming if not documented properly. To solve these problems the AUVic organization creates system diagrams during development which can be referenced at the time of debugging, such as the diagram in Figure 18.

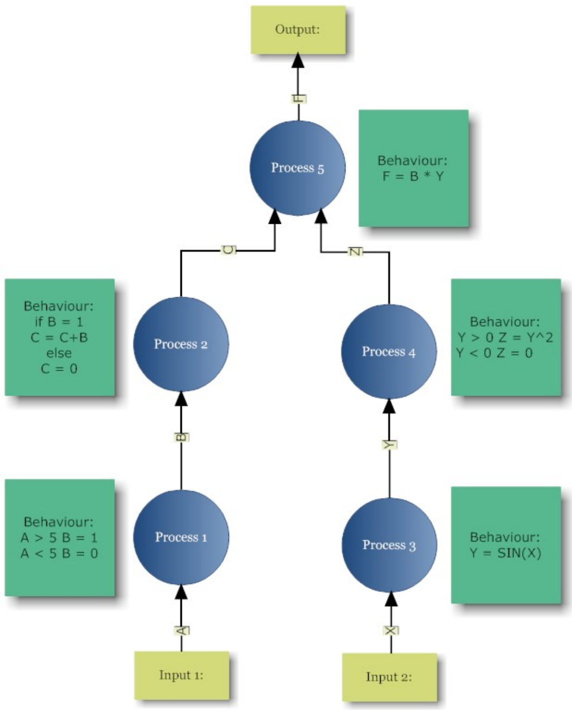


Figure 18 – Example System Diagram

A top-down analysis is often a time consuming processes however with proper documentation it produces efficient, consistent and accurate results.

8. Future Improvements

AUVic has ensured Aerius is well equipped for all situations it may face. Even with its large array of instrumentation and sleek body, there are a few changes planned next year for Aerius. These improvements include further development of its Active Sonar systems, tether composition and management system, increased navigation accuracy, and increased manipulation capabilities.

9. Reflections

This project has introduced AUVic team members to the marine industry and has allowed them to interact gaining vast amounts of knowledge within this complex area. These connections and support from the industry have led to coop/internship placement for many of the students at some of the leading marine companies from around the world. This experience has allowed AUVic members to work hands on with a quality product and industry instrumentation making members an excellent asset to any marine-based company.

It is through these experiences and efforts that AUVic competed in the Canadian Engineering Competition. The team’s efforts resulted in a first place win and a special award for Technical Excellence. With these achievements AUVic has been focused upon in newspapers, radio and television stations across the country, some of which include CBC, the Vancouver Sun, and the Times Colonist. In addition, in the coming months AUVic will be filming an episode of “Leading Edge: Innovation in BC” airing on the Knowledge Network in January.

Aerius is the product of the team’s collaboration and hard work. AUVic members stand proud as the creators of Aerius, but as always are excited for continuing progress and improvements on the vehicle.

10. Exploration at the Poles

The Arctic ice cap, and the ocean beneath it, is one of the last unexplored regions of the Earth. Roughly the size of the United States, the Arctic region contains hundreds of known varieties of animals and plant life, and possibly thousands more which are yet to be discovered. These unknown species, combined with an estimated 25% of the Earth's oil reserves, make the Arctic a hotbed for scientific research and exploration. Historically, however, the Arctic has seemed to give the cold shoulder to scientists and explorers alike.

Dozens of Arctic expeditions have taken place over the past two thousand years, most in hopes of reaching the North Pole, and later in hopes of locating a "north-west" passage for trade and transport. Prior to 1909, when Robert Peary made the first documented successful expedition to the North Pole, the majority of expeditions ended tragically, frequently in the death of the explorers. Since then, numerous explorations have been attempted, but very little useful data has been gathered.

Previous "methods" for explorations and gathering of scientific data have been very inefficient. Often limited by the endurance of human beings, data has been recorded by hand, using instruments of questionable accuracy. Expensive expeditions only last for a few weeks at most, and only explore very small regions of the arctic. These expeditions exist almost exclusively on the surface of the Arctic ice cap, leaving the miles of ocean beneath a mystery.

With the recent advances in robotics, and technologies in underwater exploration, efficient Arctic exploration has become a realistic possibility. Through the use of Autonomous Underwater Vehicles (AUV's), and Remotely Operated Vehicles (ROV's), exploration can be done from the comfort of a ship, and enormous amounts of data can be gathered simultaneously. Combined with new sensor technologies, this allows for surveying and exploration of large areas in short amounts of time, quickly unravelling the mystery of the Arctic region. [1] [2]

11. Acknowledgements

AUVic would like to thank all those involved with the team, and all those who have contributed to its success. Each and every individual has made a difference in the output of the end product, and AUVic thanks you all. The following people have been invaluable resources for AUVic.

Thank you to:

- Dr. Michael Miller – Dean of UVic Engineering
- George Csanyi-Fritz – Faculty of Engineering (UVic)
- Dr. Brad Buckham – Department of Mechanical Engineering (UVic)
- Maria Lironi – UVic Communications
- Ray Brougham – Prototype Equipment Design
- Kory Pollner – Prototype Equipment Design
- Dean Steinke – Dynamic Systems Analysis
- Harry Maxfield – Teledyne RD Instruments
- Gina Lopez – Teledyne RD Instruments
- Omer Poroy – Teledyne RD Instruments
- Randy Marsden – Teledyne RD Instruments
- Paul Devine – Teledyne RD Instruments
- Jeff Lemker – Solid Concepts
- Scott Lubel– Solid Concepts
- Mark Reibel – Solid Concepts
- Scot Thompson – Solid Concepts
- Gary Karns – Advanced Digital Logic
- Dieter Beck – Advanced Digital Logic
- Martin Mayer – Advanced Digital Logic
- Chris Roper – Roper Resources
- Robin Kent – Hardigg Cases
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- James Buescher – SPAWAR Systems Center
- Ryan Stenson – SPAWAR Systems Center
- Darryl Davidson – AUVSI
- Dave Novick – AUVSI
- Angela Carr – AUVSI
- Gretchen Wherry – AUVSI
- AUVSI Competition Judges
- Jill Zande – MTS MATE
- MTS MATE Competition Judges
- Jason Bazylak – UVic Engineering Co-op
- Sean McConkey – UVic Engineering Co-op
- Andrea Giles – UVic Co-op
- Office of the Dean of Engineering

12. Sponsorship

AUVic would like to send out a special “thank you” to all its sponsors, as they have made this project possible and have enabled the students at the University of Victoria to take part in an amazing educational endeavor. Due in no small part to all the sponsors’ generous contributions, this organization has been able to build a world-class competitive vehicle.

Many thanks to:

- University of Victoria – Faculty of Engineering
- Teledyne RD Instruments
- Solid Concepts
- Subconn
- Prototype Equipment Design
- Imagenex
- Focal Technologies
- Alcatel
- Seabotix
- Canadian Scientific Submersible Facility (ROPOS)
- Engineering Students Society
- University of Victoria – Cooperative Education
- Dynamic System Analysis
- Inuktun
- Applied Microsystems
- Sheldon Instruments
- Altech Anodizing
- Thunder Power
- ORE Offshore
- Great Ocean Adventures
- Deepsea Power and Light
- Roper Resources
- Jasco Research Limited
- NSERC
- Queale Electronics
- Oceanworks International
- Advanced Circuits
- C&C Technologies
- Romor Atlantic Limited
- Teleflex Marine
- Hardigg Cases

13. CONCLUSION

Aerius, AUVic's 2007 unmanned underwater vehicle, is a considerable improvement over previous vehicles. This year's submersible is the second version in an iterative design process, and has added ROV capabilities to a previously "autonomous" vehicle. Complements of our sponsors, AUVic was able to integrate some of the world's most technologically advanced instrumentation onto an ultra-compact unmanned underwater vehicle. In conjunction with our partnering sponsors, the University of Victoria has been able to create its finest vehicle ever.

14. AUVIC TEAM MEMBERS

The AUVic design team includes students with expertise in Mechanical, Electrical, Computer and Software Engineering, as well as Business Administration. The core members of AUVic are:

Matt Burdyny – *Project Director, Business Affairs, Mechanical Design*
Jamie Marshall – *Mechanical Design*
Ian Clark – *Software Design, Electrical Design*
Mark Butowski – *Software Design, Electrical Design*
Tony Kroeker – *Software Design*
Tyler Price – *Software Design*
Will Fraser – *Software Design*
Gabby Odowichuk – *Software Design*
Caleb Shortt – *Software Design*

15. REFERENCES

[1] "National Geographic News" - Nov. 8, 2004. http://www.nationalgeographic.com

[2] "NASA - The Jeremy Project" http://quest.arc.nasa.gov/arctic/explore/index.html

APPENDIX I

BUDGET

Vehicle Components

Sensors

Doppler Velocity Log	$25,000
Inertial Measurement Unit	$12,500
Magnetic Compass/Gyro	$1,250
Pressure Sensor	$3,500
Hydrophones (4)	$4,800
Underwater Camera's (4)	$7,000
Side scan sonar	$5,500
Multibeam sonar	$35,000

Electronics

Primary Core Duo PC104+	$4,500
Secondary Core Duo PC104+	$4,500
Com port board - PC 104+	$350
Frame grabber - PC 104+	$650
Power supply - PC 104+ (2)	$1,400
DSP board - PC 104+	$3,000
ADC board - PC 104+	$1,250
Fiber Optic Conversion board - PC104+	$7,500
Fiber Optic/Electrical Slip ring	$4,000
Custom HUB board - PCB	$500
Test Range Blinker - PCB	$350
Wiring - Cables	$150
Electronic Components	$1,000

Mechanical

Underwater Connectors/Cable Assemblies	$30,000
Fiber Optic Tether/Connectors	$25,000
Brushless Thrusters (5)	$8,750
Grabber Arm	$2,500
Pressure Relief Valves	$1,250
Urethane Casts - hulls	$50,000
Materials	$2,000
Machining	$12,500
Anodizing	$1,500
Hardware and Fasteners	$300
Vehicle Stand	$250
Floatation	$500

Other

Vehicle Case	$2,500
Sponsorship Decals	$500
Total Vehicle Components	**$261,250**

Team Costs

Uniforms	$3,750
Co-op Registration Fees (6)	$3,600
Co-op Employment Funding (2)	$18,500
4th Year Design Project Funding (4)	$1,000
Team transportation costs	$1,000
Team Vehicle	$10,000
Team Trailer	$7,500
Team Hospitality	$500
Sponsor Hospitality	$750
Corporate Visits	$5,000
Sponsorship Costs	$500
Pool Tests	$1,500
Conference Displays	$2,500
Conference Costs	$10,000
Promotional Material	$2,500
Phone, Phone Setup, Long Distance Bills	$750
Competition Registration Fees	$750
WEC Competition Travel	$750
CEC Competition Travel	$2,000
AUVSI/ONR AUV Competition Travel	$10,000
MTS MATE ROV Competition Travel	$5,000
Telus IEEE Innovation Competition	$3,500
Total Team Costs	**$91,350**

Total Costs

Vehicle Costs	$261,250
Team Costs	$91,350
Shipping and Customs Costs	$10,000
Total Project Costs	**$362,600**

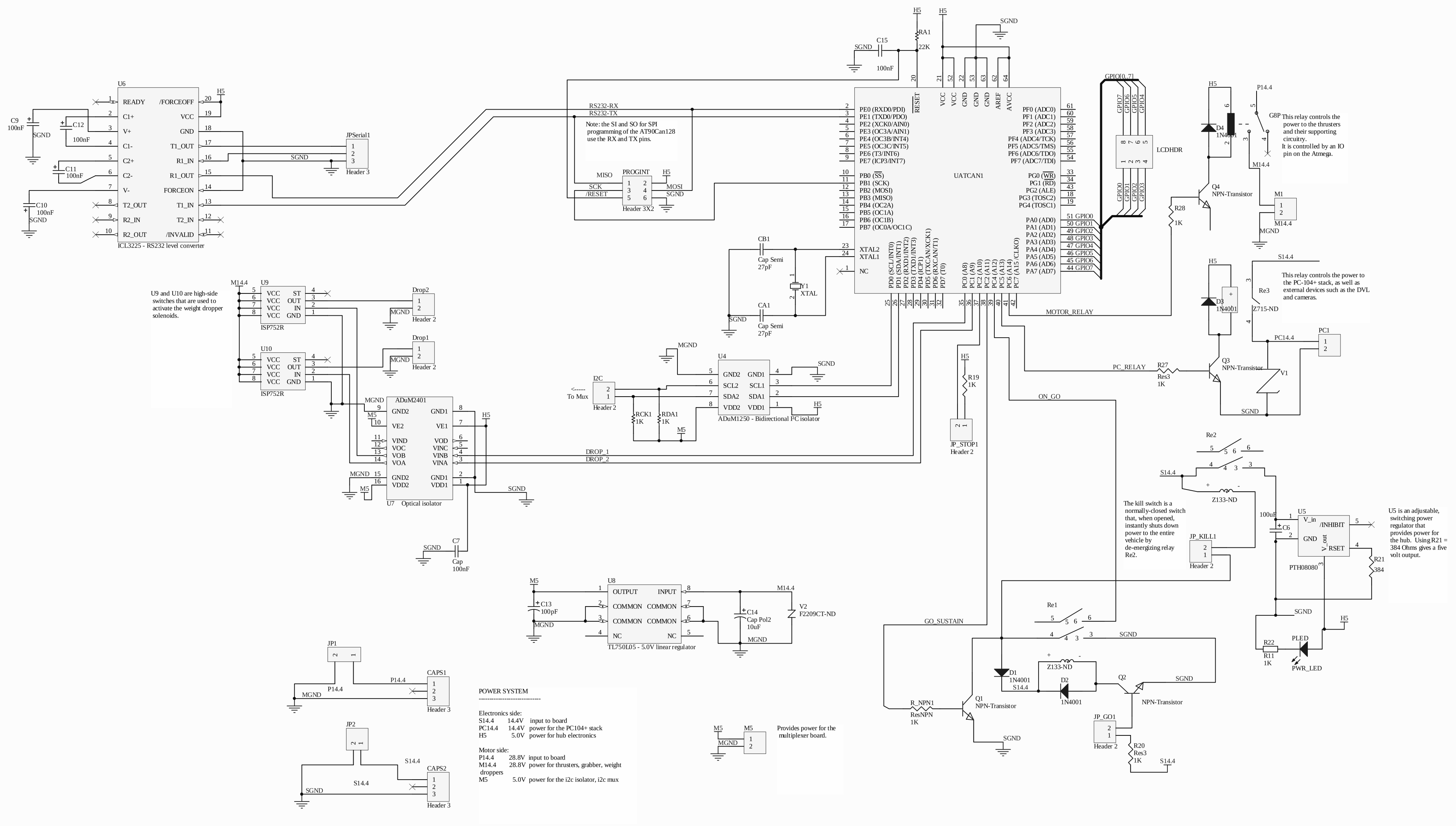
Revenue

Grant Allocations	$23,100
Component Sponsorships	$294,750
Financial Sponsorships	$40,750
Prize Money	$7,500
Total Project Revenue	**$366,100**

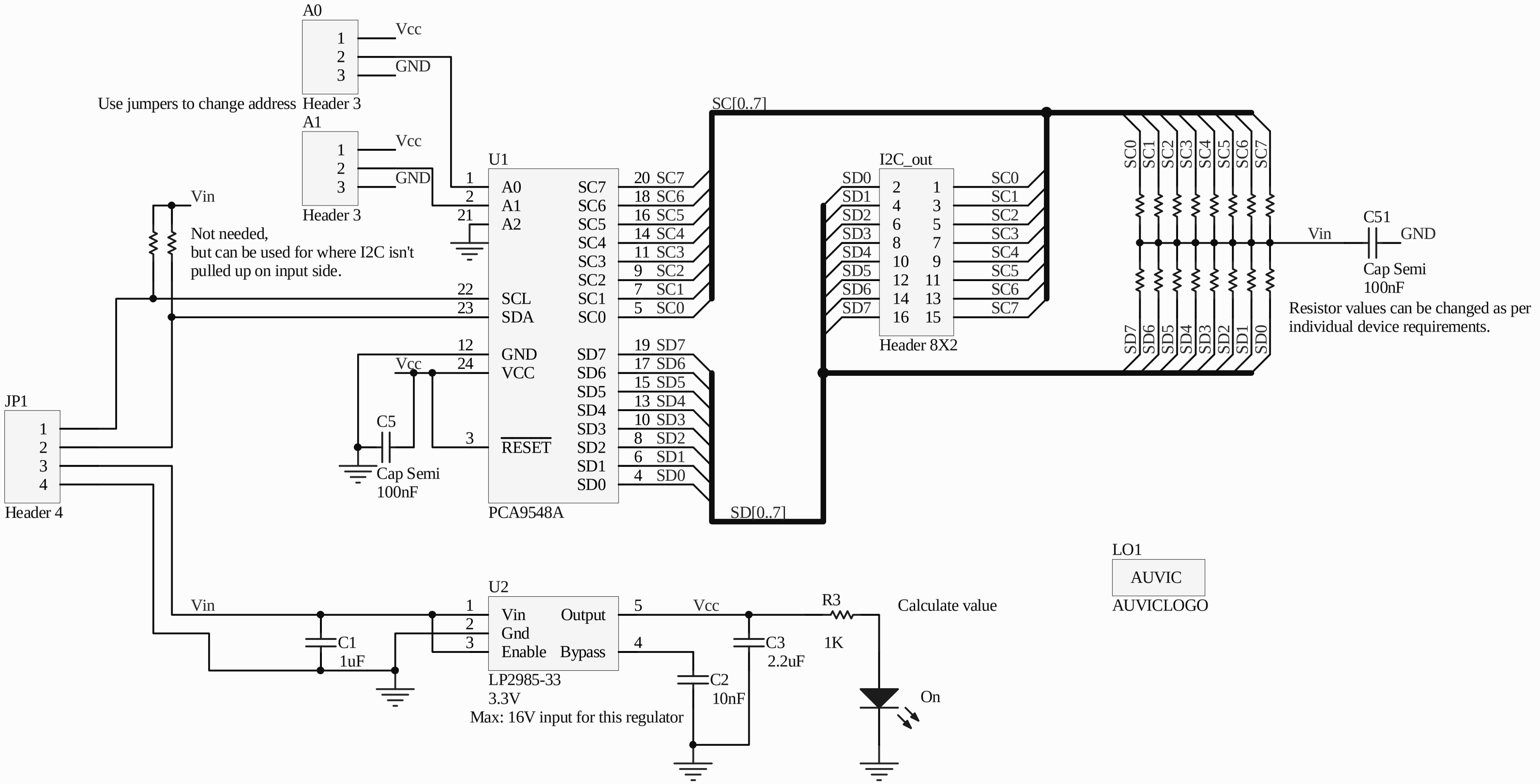
Please note due to confidentiality agreements with corporate partners, individual sponsorship amounts may not be disclosed.

APPENDIX II

ELECTRICAL SCHEMATICS



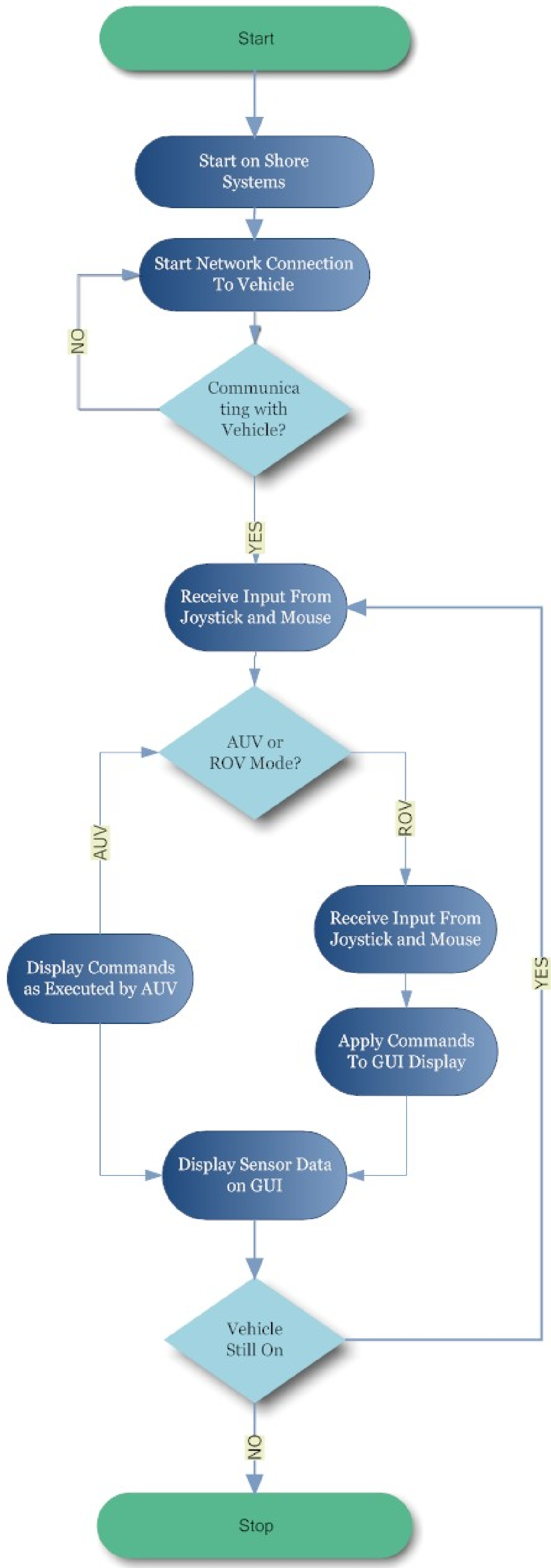
Title	AUVic HUB		
Size	Number		Revision
A2			3.0
Date:	21/05/2007	Sheet1 of1	
File:	D:\AUVIC\elec-2007\Hub\Hub.SchDoc	Drawn By:	Ian Clark



Title	I²C Multiplexer Breakout Board		
Size A4	Number		Revision 1.2
Date:	21/05/2007	Sheet 1 of	1
File:	D:\AUVIC\..\Multiplexer.SCHDOC	Drawn By:	Ian

APPENDIX III

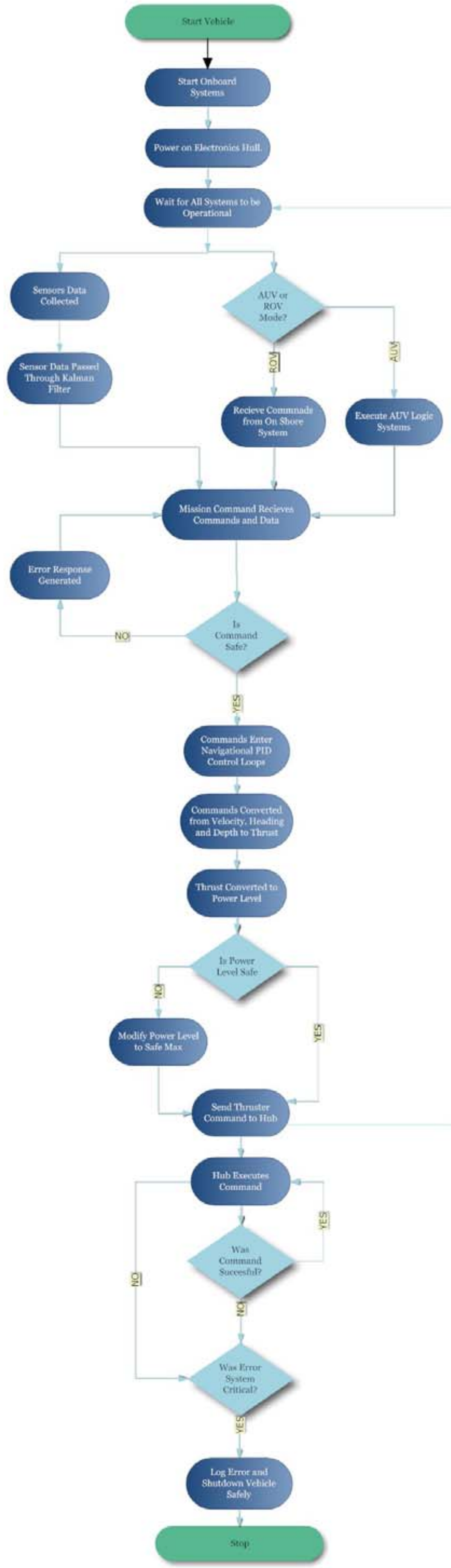
TOP-SIDE CONTROL FLOWCHART



Start
Start on Shore Systems
Start Network Connection To Vehicle
NO
Communica ting with Vehicle?
YES
Receive Input From Joystick and Mouse
AUV or ROV Mode?
AUV
ROV
Receive Input From Joystick and Mouse
YES
Display Commands as Executed by AUV
Apply Commands To GUI Display
Display Sensor Data on GUI
Vehicle Still On
NO
Stop

APPENDIX IV

BOTTOM-SIDE CONTROL FLOWCHART



Start Vehicle
Start Onboard Systems
Power on Electronics Hull.
Wait for All Systems to be Operational
Sensors Data Collected
AUV or ROV Mode?
Sensor Data Passed Through Kalman Filter
ROV
AUV
Recieve Commnads from On Shore System
Execute AUV Logic Systems
Mission Command Recieves Commands and Data
Error Response Generated
NO
Is Command Safe?
YES
Commands Enter Navigational PID Control Loops
Commands Converted from Velocity, Heading and Depth to Thrust
Thrust Converted to Power Level
Is Power Level Safe
NO
YES
Modify Power Level to Safe Max
Send Thruster Command to Hub
Hub Executes Command
YES
Was Command Succesful?
NO
NO
Was Error System Critical?
YES
Log Error and Shutdown Vehicle Safely
Stop