Team 6: SEA 2 See

Project Proposal and Feasibility Study

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Executive Summary

The present technology available for marine research is limited, and improvements to this technology are crucial to understanding dynamic underwater environments. This paper proposes a project focused on developing an unmanned, remotely operated submersible that will operate as a submerged environment analyst (SEA) in freshwater lakes. This device must have full, three-dimensional range of motion, including the ability to dive and resurface. It must also be able to operate at a depth of 30 feet below the surface while transmitting clear, live video to the host unit.

The preliminary design presented here satisfies all of these project requirements. The submersible will utilize an open-hull design for simplicity, and a ballast tank with a pump will be used to control the depth. The device will also use a three-motor configuration with one rear motor and two side motors to move in any direction underwater. A low lux, light sensitive camera will be mounted on the front of the SEA to allow for accurate control and to provide relevant information about the submerged environments it is exploring. It will be controlled via a tether that is connected to a host unit with a monitor and a control unit above the surface.

Upon completion, the SEA will be delivered to the Annis Water Resources Institute in Muskegon, MI. There it will serve in research, education, and outreach roles. Their primary focus is on Lake Muskegon, so some aspects of the design were tailored around the characteristics of that lake. They would also like the device to have some sort of mounting system, so that various water sensors can be attached to take data.

A schedule for completion of this project, along with a cost breakdown, is also included to prove the feasibility of the design. The stage is set to move forward, with final assembly and a field test in Lake Muskegon with the Annis Water Resources Institute expected in early May of 2009.
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1. Introduction

1.1 Motivation

There is a wealth of undiscovered information beneath the surfaces of the oceans and lakes that cover this planet. While technology has advanced in many other areas, this domain remains largely unexplored. Unmanned, remotely operated or autonomous submersibles hold a lot of potential, and the use of these devices has steadily increased. They are also very valuable in the education field by generating interest and putting research and exploration capabilities directly in the hands of students. The feasibility of the development of a remotely operated, miniature submersible is explored, and a proposal for that project is laid out below.

1.2 Problem Statement

As the human population continues to rise, our impact on the world around us increases as well. Recently concerns have surfaced regarding changes in the global climate, and while the primary cause of these events is debated by some, our responsibility to respond to these issues is clear. One of the biggest fears related to global climate change is the impact it will have on oceans, lakes, and other bodies of water. Along with this kind of macroscopic event, underwater environments are affected every day by human activity and various other factors. These environments are highly dynamic, and the technology available to study them is limited. In order for these environments to be properly managed, or at least maintained, new tools to study them need to be developed.

This project seeks to develop a submerged environment analyst (SEA) in the form of an unmanned, remotely operated vehicle (ROV) that can be used to effectively explore freshwater lakes. This device must operate in a complex medium while being able to control its motion and relay information regarding its relative location underwater. Along with that, it must provide relevant data about its surrounding environment. Since these environments are so dynamic and it is difficult to predict which functionality will be most important in future research, the SEA must be highly versatile, so that it can adapt to many different end users and applications. The design and construction of this device must also be done in an efficient and cost effective manner, while providing the high reliability required in a research field.

This specific device must also satisfy additional requirements since it will be delivered to the Annis Water Resources Institute (AWRI) in Muskegon, MI after completion. The device must serve AWRI’s three main objectives: research, outreach, and education. They must be able to easily use and understand the SEA so that they can maintain it with minimal contact with our team. Reliability is also more important, since the submersible needs to be of use to the research institute years down the road. This expands the problem to meeting both the basic requirements established above, and the further requirements resulting from the collaboration with the Annis Water Resources Institute.
2. Project Objectives

2.1 General Capabilities of the SEA

The submersible will need to be able to change its buoyancy in order to control the depth at which it operates. Using a variable buoyancy system, the submersible will need to achieve relatively neutral buoyancy to remain stationary or for the ability to be controlled at various depths.

To achieve effective control of the submersible, it must be fully capable of three dimensional range of motion (at various levels of buoyancy). Also necessary to achieve effective control of the submersible is ability of the operator to see clearly where it is moving relative to the environment. These are necessary for the SEA to be properly propelled in the intended direction.

For purposes of research, the submersible should be able to support and integrate data measuring equipment. The submersible will not always be used for data collection missions and since data measurement devices are expensive, the submersible should be capable of easy installation and removal of that equipment.

2.2 Specific Design Objectives

The submersible’s final design needs to be easy to transport. Because AWRI will be operating the submersible from many different locations, the prototype must be as small as possible for ease of transporting. However, functionality should not be sacrificed for compact size.

Operating underwater, the submersible should be able to function at a depth of 80 feet. Because AWRI will be using the submersible specifically in Lake Muskegon, it should be able to operate at the lake’s deepest point of 80 feet. This will require the SEA to withstand the pressure and temperature present at this depth.

Since the submersible will be unmanned, the design must incorporate visual feedback of some kind. Live video feedback from the submersible will be provided by a video camera. A clear and illuminated image will need to be provided to the operator for effective underwater navigation of the SEA from the surface. In addition to navigation purposes, the video camera will greatly benefit the education and outreach missions set by AWRI.

The propulsion system on the submersible should consist of high torque motors that provide enough speed and maneuverability to properly navigate the submersible in three dimensions. The motors should provide enough power to push the SEA through seaweed and overcome naturally occurring water currents in lakes.

The submersible should be designed for the easy addition of data collection sensors. To serve AWRI’s research needs, the SEA must be able to carry different water sensing equipment.
Conductivity, temperature, pH, oxygen levels, and carbon dioxide levels are some of the main water qualities that AWRI is interested in and would like to monitor with the SEA.

### 2.3 Criteria for Success

#### 2.3.1 Ballast Tank Control

The ballast pump must fill and empty the ballast tank enabling the SEA to become neutrally buoyant at various depths in Lake Muskegon. Further, utilizing a functional ballast system, the submersible must be able to dive and surface without manually weighing the submersible down or pulling it up by the tether. This will ensure the submersible will be adequate for use by the Annis Water Resources Institute.

#### 2.3.2 Three Dimensional Range of Motion

Once the submersible has achieved neutral buoyancy at a desired depth, it must be able to move in response to the operator’s desired direction. This includes moving up and down (depth) on a micro level, at various depths on a macro level.

#### 2.3.3 Live Video Feed

To be successful in navigating the SEA, the submersible must stream live video to the operator. The video feed should provide a quality image so that the environment is clearly distinguishable to the operator. The video feed should be relatively clear of noise and the environment should be illuminated. In addition to navigating, this will also enable AWRI to achieve their purpose of education.

#### 2.3.4 Complete Integrated Functionality at Depth

As the Annis Water Resources Institute will use the SEA for research and educational purposes in Lake Muskegon, it must be completely functional at a depth of 30 feet. At this, the average depth of Lake Muskegon, all components of the design must perform as previously required.

### 3. Discussion

#### 3.1 Christian Perspective

As Christians, we are bound by Christian moral law to care for God’s creation. As engineers, we are bound by the engineering code of ethics to “hold paramount the safety, health and welfare of the public” [1]. These responsibilities play a key role in designing the submersible for a specific purpose. First of all, the submersible will allow us to learn more about God’s intricate creation by exploring underwater environments. This could lead to a better understanding of marine science and the discovery of new scientific findings. The SEA could also lead to spurred interest in the field and could potentially be a tool from which further studies are initiated. Second of all, the submersible could potentially allow the human race to understand more about the impact of
human activity on marine ecosystems. By serving scientists as a research tool, the submersible could be a major factor in learning more about ocean acidification and coral reef destruction, the impact of invasive species in the Great Lakes, as well as the living and breeding trends of many fresh water fish. The earth is made up of 80% water. To explore and conduct research in such dominant avenues of our planet could potentially provide critical knowledge to knowing where the future welfare of humanity falls in the context of climate change.

Design norms such as stewardship, justice, integrity, and transparency will be taken into consideration as the SEA is developed. As far as is possible, the materials used to construct the submersible will be environmentally responsible so as to factor stewardship into design. If the submersible becomes an effective tool for gathering data, it could lead to the discovery of pertinent data revealing the level of severity of human impact on the environment. Depending on the severity of the situation, the data can also provide a means by which action is taken to issue justice, via the reconciliation of environmental issues. (i.e.: responsibility of solutions issued to countries proportionate to their contribution to problems). In order to factor integrity and transparency into the design, the design process will be well documented, design decisions will be supported honestly, and various design alternatives will be considered.

3.2 Patent Research

Research on existing patents shows that similar remotely controlled submarine designs do already exist and have been protected. The United States Patent and Trade Office (USPTO) provides information on existing patents at its website. This database was searched for patents relating to ROVs, since that is a standard industry term. There are many patents on the individual aspects of ROV design such as buoyancy systems, wireless communication methods, and sonar processes to name a few. There are also patents on remotely controlled submersibles themselves. Three patents in particular are discussed here.

The first, patent no. 7290496 is titled “Unmanned Autonomous Submarine” [2]. This patent details the design of an entire submarine that is autonomous. It is also detailed that the sub can be controlled manually. While the design of our submersible will probably do many of the same things as the sub in question, we would not be infringing on this particular patent because our sub will not be deterministically qualified as autonomous.

The second and third patents are held by the same organization, H2EYE Limited. Patent no. 6986320 was issued in January 2006 and is titled “Remote Operated Vehicles” [2]. Patent no. 7007625 was issued approximately three months later and is titled “Location and Movement of Remote Operated Vehicles” [2]. This patent is effectively a supplement of the earlier and most likely came as a result of the organization’s design process. This organization was also issued another patent, an update to the January 2006 patent, in July of 2007. This patent poses potential intellectual property issues as we design our submersible.
Our design and the patented designs, particularly the later of the two, will likely be extremely similar. However, we do not intend to develop full scale production of our prototype. Nor do we intend to market and sell our product. Our prototype will differ from existing patents in the configuration of components and hardware. It will also differ in design aesthetics. Our prototype is a onetime project requiring us to exercise and incorporate all aspects of the design process, which inherently includes customizing a solution (developing a product) to a particular problem (market need). So naturally, as we design our submersible to serve the needs of the Annis Water Resources Institute, our sub will be designed to perform some or all of the same functions as an existing patented submersible. Thus, our sub cannot and will not be used for profit. Neither will our sub be mass produced so as to deflate the market for protected products. In the case that our design becomes very popular and is easily reproducible, an agreement with the patent holder(s) will be pursued so as to issue credit where credit is due. These actions will ensure that the rights of ROV patent holders are not infringed upon.

3.3 Market Research

Market research reveals that a small variety of remotely controlled submarines are commercially available. There are four predominant manufacturers of ROVs; SeaBotix, VideoRay, JW Fishers, and Deep Sea Engineering. The ROV solutions provided by these manufacturers are very versatile and effective. Submersibles are available in sizes ranging from the size of a small desktop PC to a large suitcase. They are operable up to depths of 3300 ft and equipped with many sensors, water sampler, video camera, and mechanical arm. Most of these come complete with a host device providing a graphical user interface (GUI) and data logging.

Our submersible will differ from existing products in the configuration of components and hardware. Our design utilizes common commercial components which are very readily available. For example, common security cameras can be used for video feedback, provided a waterproof enclosure is designed. Also, bilge pump motors, which are fully waterproof, are used as propulsion motors. These factors enable easy maintenance and the replacement of parts. As well, the fact that components are utilized from established industries, lowers cost. Additionally, our submersible will differ from existing ROVs in aesthetic design.

Since these products are so effective and capable, they are very complex, require a lot of power, and have very high cost associated with them. Our submersible on the other hand, provides significantly more simplicity, and with it provides the advantages of low power consumption and most importantly, low cost. This makes it possible for small scale institutions (such as AWRI) to utilize a ROV for educational and simple research purposes without compromising major functionality and performance. If our submersible were to be developed into a full scale production, the market for it would be small budget organizations and private enterprises.
4. Method of Approach

The senior design project schedule is broken into two major sections: feasibility study and general design followed by a detailed design, assembly and testing. During the first semester of senior design the focus of the work was on a feasibility study and the initial development of the design. In order to accomplish these tasks, milestones were set up to detail each major step along the way. Milestones for future tasks were also created.

4.1 Milestone I

The main goal for Milestone I was to establish a specific purpose for the final design of the submersible. The starting point for this milestone was to determine the type of research that the submersible would be involved in. In speaking with Calvin’s Biology department there were many applications for a design which could be used in exploring the nearby lakes in West Michigan, specifically Lake Michigan. The capabilities associated with this type of research were discussed and ideas for water sampling, CO$_2$ level readings, pH analysis and temperature measurements were developed for the initial design. The culmination of this milestone was developing a detailed project description and purpose for the SEA.

Options for potential funding were explored and contacts were made with AWRI to discuss the development of the project and the incorporation of our design with their research needs. The results of the meeting were beneficial in determining what requirements would limit the design of the submersible. More importantly, it was established with AWRI that items or capabilities which might increase prototype costs beyond the Calvin supplied budget could be covered by their institution. Any additional capabilities would have to be proposed to AWRI to determine if it would fit within the scope of their needs for research and education. The design would need to incorporate these new capabilities for any additional instrumentation or parts so that AWRI could add them at a later time.

4.2 Milestone II

Milestone II marked the decision between the design alternatives presented through the initial design discussions. One alternative discussed to complete this goal was an opened or closed hull option which would depend on the depth requirements and electronics incorporated in the submersible. Tethered communication and wireless transmission were considered and research was completed to determine the availability of technology for both of these designs. Finally, ideas for depth control of the submersible were considered, which involved a decision either to incorporate a combination of motors and ballast systems or solely a ballast system for change in depth. More details on this process are discussed later in section 5.
4.3 Milestone III

The third milestone was the completion of the mechanical design. This step of the design consisted of determining a suitable ballast system for the design parameters, selection of motors for three dimensional control, and design of the hull to achieve stability underwater. Pressure calculations were completed to determine the requirements the submersible must have and select an appropriate material for the frame. For motor control the volumetric output of water (pumping power) of each individual motor was calculated so that it can effectively control the submersible depending on the final weight and placement of each of the components.

4.4 Milestone IV

Milestone IV is the design of the control systems circuitry for the submersible. The circuitry will need to incorporate control of the motors and pumping system used for the ballast and provide a design which would effectively control these parameters for underwater movement. The design for the communication between the controller and the SEA would be established as well as video communication with the host. There also will be the incorporation of an emergency mode where if a system would fail the submersible would automatically return to the surface. A majority of the work for circuit design will need to be done after the mechanical design has been finalized. All circuitry must also be sealed from the outside environment and either an enclosed hull or other protective coating around the circuitry must be installed on the submersible.

4.5 Milestone V

The finalization of the parts list and the ordering of parts mark Milestone V. Timing is key for this part of the plan to account for long lead times, allowing for a timely delivery of a prototype.

4.6 Milestone VI

Milestone VI is initial testing of individual components that make up the complete design. A schedule for this is provided in the test matrix in Appendix C.

4.6 Milestone VII

Milestone VII completes the final assembly of the SEA. Periodic testing and re-evaluation will be necessary as the design is completed and the controls are calibrated. Therefore this will be performed in parallel with Milestone VI.
5. Alternative Solutions

5.1 Hull Options

The SEA will need to have a hull to mount the equipment and ultimately give the submersible its structure and shape.

5.1.1 Closed Hull

A closed hull is the traditional design for most submerged vehicles. This design is normally chosen because it helps protect the contents inside of the submersible, such as the motors, gear systems, circuitry, and camera inside the hull. One of the potential difficulties of this design would be constructing a watertight hull. Another design difficulty would be to design a hull that could withstand pressures the vessel would face at depths of 80 feet.

5.1.2 Open Hull

An open hull design would have relatively no enclosed areas but rather, is exposed. This design presents no difficulties in constructing a hull to withstand pressures at 80 feet below the surface. One disadvantage of the open hull design is that each component will be exposed to the elements, potentially resulting in waterproofing or corrosion problems.

5.1.3 Selected Solution

The open hull was decided to be the optimal design for this application. With the small amount of components needed to be kept enclosed (camera and electrical circuitry), minimizing the design of high pressure enclosures would simplify the overall design. The open hull design would also be more cost effective than the closed hull due to the higher material costs associated with stronger structural material, as well as the need for less overall material.

5.2 Depth Control

For the wide range of depths at which the SEA will operate, a depth control system is needed to assist the motors for diving and surfacing. A series of ballast systems were explored below [3].

5.2.1 Incremented Weighting System

To achieve relatively neutral buoyancy, an incremented system of different weights could be added to the SEA. A chart would be constructed to show how much weight would need to be added to the submersible to achieve neutral buoyancy at different depths. This weight system would achieve the goal of helping the SEA dive; however, there would be no way for this system to help the submersible in resurfacing.
5.2.2 Piston Ballast System

This system acts like a giant syringe, changing the buoyancy of the submersible when it takes on water for diving and pushes out water for resurfacing. The piston ballast does not use any valves or pumps, but rather adjusts the water level inside the ballast tank using a motor to move the head of the piston. Although this system can displace a large amount of water, this type of ballast system commonly has sealing issues around the piston head. Creating a completely water and air tight seal is nearly impossible due to thermal expansion, given the resources available.

5.2.3 Membrane Ballast System

The membrane ballast system is an extension of the piston ballast system. This uses the same principle as the piston system, changing the submersible’s buoyancy by taking in and pushing out water without the use of valves or pumps. However, this system uses a flexible membrane to help form the piston. This system improves the seal between the piston and cylinder, but it does not displace as much water as the piston ballast system.

5.2.4 Pump Ballast System

The pump ballast system uses a pump and valve to take in and push out water in diving and resurfacing. For this system, the ballast tank must be capable of withstanding high pressures that the pump creates. The ballast tank can never be 100% full of water. Using the pump ballast system, correlation between the intake and outtake of the pump and the opening and closing of the valve must be attained. A drawback to the pump ballast system is finding a small high pressure pump that can meet the requirements for necessary displacement of water.

5.2.5 Selected Solution

The pump ballast system was chosen as the optimal depth control system using the decision matrix below.

Table 1: Ballast System Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Incremented Weighted System</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>97</td>
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<tr>
<td>Piston Ballast</td>
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<td>1</td>
<td>1</td>
<td>1</td>
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<td>2</td>
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<td>99</td>
</tr>
<tr>
<td>Pump Ballast</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>132</td>
</tr>
</tbody>
</table>

With this system, creating an airtight and watertight seal between the piston head and cylinder is not necessary. Unlike a piston system, leaks in this system can more easily be traced and located. This system allows for minimal manufacturing complications, as creating a piston system might. The pump system will also be less affected by thermal expansion due to temperature differences at varying depths.
5.3 Communications

Underwater communication is much more complicated than normal methods of communication since the information must be passed through a liquid. There are various methods available to overcome this obstacle.

5.3.1 Tether

The simplest solution is the use of a tether, connecting the SEA directly to a controller unit above the surface. The tether would carry electric control and data signals to and from the submersible, and it could also be used to transmit power, eliminating the need for an onboard power source. This method has the obvious disadvantage of limiting the range of motion of the SEA. It could only travel as far from the controller as the tether would allow, and there is a high risk of the tether getting caught on a rock or tangled in weeds if the SEA is being operated around these obstacles. The control signals would also need to be strong enough to compensate for the high resistance of the long transmission lines, and electromagnetic interference becomes an issue when data and power lines are in close proximity. The tether does have a unique advantage, however, in that it can be used to “wheel in” the device if for some reason it malfunctions.

5.3.2 Wireless

The seemingly most convenient solution would be to communicate with the submersible wirelessly via electromagnetic propagation. This is problematic due to the characteristic physical differences between air and water. The key difference is electrical conductivity. Water has a very high level of conductivity when compared to air; higher conductivity means higher attenuation and more signal loss. It is also known that “attenuation increases rapidly with frequency” [4]. Thus, it is only possible to communicate wirelessly by transmitting very low frequencies at very high amounts of power. Some institutions have developed methods of transmitting data wirelessly for up to 600 ft underwater, however, the data rate for those methods are less than 16Kbps. The most developed underwater wireless communication methods are not feasible for use with the SEA because the data rate would not be sufficient for the video transmission. At best, approximately 10Mbps would be possible at distances less than one meter.

5.3.3 Audio Frequency Shift Keying

Perhaps the most interesting solution is audio frequency shift keying, or AFSK. This is a wireless communication method that uses sound instead of EM waves. It works by transmitting two sound pulses at different frequencies, with one frequency representing the binary 1 bit, and the other representing the 0 bit. A receiver would then decode this signal to obtain the original data. This is actually the same technology that was used by early modems. Since water is an excellent conductor of sound waves, data could be transmitted wirelessly across a very long range [5]. This has the inherent problem of noise pollution, which could adversely affect marine life, but the base frequencies could theoretically be set high enough so that they would be out of the
audible range of any animal. The biggest disadvantage, however, is the baud rate. This process cannot transfer data very quickly (the maximum rate is around 1200 bits per second), and rapid transmission could be crucial in effectively controlling the SEA.

5.3.4 Selected Solution

The tether was selected as the best option for communication using the decision matrix shown below in Table 2. AFSK had to be rejected since the baud rate was too low to transmit the live video feed, which is a vital component of the design. Standard wireless communication also could not be used, since the SEA needs to be able to operate up to eighty feet below the surface, and the ability to generate a signal of this strength is far beyond the scope of this project. Additionally, it is not important for the device to be able to move through caves or complicated rock structures, and so the risk of tether entanglement is of little consequence. The tether provides the simplest and most reliable means of communication that is appropriate for this project.

<table>
<thead>
<tr>
<th>Method</th>
<th>Range (5)</th>
<th>Baud Rate (10)</th>
<th>Cost (7)</th>
<th>Simplicity (3)</th>
<th>Weighted Total</th>
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<td>Wireless</td>
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<td>1</td>
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<td>AFSK</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>52</td>
</tr>
</tbody>
</table>

5.4 Video Camera Options

There are many considerations in the selection of video surveillance hardware for use on the SEA. The environment in which it will be used is a unique one. Light is refracted at the surface and as a result, underwater environments are not very illuminated. The selection of video hardware must consider variations of performance, size, construction, functionality, and compatibility. For purpose of this design, video surveillance hardware will operate on 12 Volts or less and ideally, consume minimal power. The following categories are not to be compared to each other but are instead, separate categories in which alternatives are discussed and a tentative recommendation is made.

5.4.1 Light requirements and constraints

Most small video cameras have a specification rating the camera’s sensitivity to light. The spec is measured in the SI unit “lux.” Lux is the measurement of light emittance or admittance. So for a video camera, the lower value of lux, the less light is needed to produce a clear image. For
comparison, one lux is approximately equal to one-tenth of a candela. A clear night with a full moon is equated to approximately 0.25 lux.

Common video surveillance cameras have lux ratings on the order of 0.1 lux. These are designed to be used in daylight and in well lit areas at night. Some other video cameras on the other hand, are equipped with a self-illuminating method based on infrared technology. These products are simply termed “IR cameras” and can produce a clear illuminated image in complete darkness (i.e.: a cavern or a moonless, overcast night). IR illumination is technology that came from night-vision goggles. IR illumination takes existing light and amplifies it, but “…the amplification process is not optical…but electronic” [6]. Original light in the IR band is detected and converted into an electrical signal, that signal is amplified and then converted back into a form of light which is visible to the human eye [6].

IR technology is very advantageous for the surveillance of poorly illuminated areas. As light is not always readily available underwater, the submersible would ideally be equipped with such technology. The use of an IR video camera would make it unnecessary to have a light system onboard. However, a light system will be quite simple to implement and may still be a part of the final design. Thus, a light system is still proposed as a part of the preliminary design. It is expected that with a high intensity light system, the SEA will be able to provide lighting in murky lake at night, on the order of 10 lux for a short range.

5.4.2 Size and Construction

The size of the video surveillance equipment may depend on the final size of the submersible. There exists enough variation in equipment size with sufficient performance to appropriately fit the size of the submersible. So at this point, the design of the submersible will not be constrained by the size video surveillance equipment. The tentative and approximate size of this hardware will be a variation of constructions in the range of 3”L x 3”W x 4”H.

One product in particular was recommended by AWRI. It is a waterproof IR camera which can be fully submerged; it is also rated at 0.0001 Lux. The cost of this product is approximately $500 which causes obvious problems for our budget. However, AWRI currently owns one of these units and offered the use of their unit if our budget wouldn’t support this product. An alternative video camera is an IR dome turret camera which is rated at 0.0 Lux and costs $150. The use of this unit would require building a waterproof enclosure because it is not waterproof. This unit on the other hand, provides the advantage of controlling the turret to change the field of vision without having to move the SEA. Tentatively, the IR turret camera is the proposed video surveillance unit; however a final decision will be made upon receiving more technical data from the vendor.
5.4.3 Transmission and Processing

Most video surveillance products researched thus far provide convenient video output connections in many standard video formats. This is an important factor in keeping the project feasible. It would be very difficult to implement and utilize a mere optical device while still having to develop a method for formatting the images. Having to design video processing circuitry to be onboard of the submersible would drastically complicate the overall design process.

Video processing can more easily be performed by the host device utilizing existing software. This would be supplemental design work to our project but is not proposed in the scope of design work for our project. The design of an interface management unit would include tasks such as the formatting and storing of video data, live display of the video feed and sensor data, storing of sensor data, as well as the correlation of data readings to GPS position; all on a simple GUI.

The consideration of electrical resistance will factor into the selection of wiring for the tether. The length of the tether will introduce some voltage drop between the host and the submersible. No resistance calculations have been performed thus far due to the indeterminacy of hardware specifications. Once hardware selections solidify, detailed specifications and requirements will be known, then calculations will follow, and the appropriate wiring can be selected and acquired.

EMI is a concern as it could introduce “noise” to our video signal. High amounts of current (in the range of 15 amps) traveling in power wires bundled with our video line propose a potential conflict. In effort to prevent this, twisted pair and shielded wiring will be used. The possibility of further prevention strategies will be researched and explored.

6. Preliminary Design

6.1 Structure

The structure of the submersible is based on a balance between the need to withstand pressure and to incorporate the ballast system with the other components mounted on the submersible. The open hull design was decided on to ensure simplicity of the design and avoid the potential problems associated with high pressure. The structure consists of a frame on which the different components are mounted. The ballast system will be at the center of the design and will be the largest component on the frame. The individual electrical components will be spread out on the frame as needed to ensure the center of gravity of the submersible is stabilized. Appropriate room for the instrumentation incorporated in the final design will be designed into the structure as will allow for the submersible to maintain stability and functionality. The structure will be made out of a corrosion resistant material. A detailed design drawing can be found in Appendix A.
6.2 Movement

The submersible will be controlled by a combination of three propulsion motors mounted to the frame. The largest motor will be in the rear and will provide lateral movement through the water. This will be the largest of the motors and will provide the primary forward and reverse control. Dive planes will be mounted near the motor to allow faster diving and more control over the depth and direction of movement. There will be two side motors which will perform any turning maneuvers and provide additional propulsion for the submersible. The two motors will be identical in power ratings and movement capability. Each will be affixed to a common rod which will allow for axial rotation allowing for simultaneous depth control and lateral stabilization. The common rod will be controlled by a stepper motor which will rotate the shaft according to inputs from the controller. All speeds will be controlled by the surface controller as required for the specific task of underwater research.

6.3 Host Unit

In order to easily control the motion of the SEA, the host unit must be ergonomic and simple to learn. It will contain a small, portable monitor to allow the live video feed to been viewed from the surface. It will also come with a control unit that will be able to be handled easily with two hands (Figure 1). There will be a slide switch on the center of the controller that adjusts the speed and direction of the main rear motor. On the left side, there will be a simple analog joystick device that controls the speed of the two rear motors. The right side of the device will have a unique switch that combines a slide switch with a toggle switch. The slide switch will control the pitch of the side motors, and the toggle switch will control the direction in which the side motors spin, allowing the submersible to turn. It will also contain an on/off switch with an LED indicator, and a simple toggle switch to fill or empty the ballast tank. The host unit will run off of a 12 V supply.
6.4 Video Feed

To ensure that the submersible can be controlled under water it is necessary that there be a live video feed for maneuvering under water. There will be a pressurized camera mounted on the bow of submersible accompanied by LED lights which will provide a live video stream back to the controller. The feed will be displayed on the surface via a laptop or monitor to aid the controller in the navigation of the submersible. The feed will be transmitted via tether to the controller.

6.5 Depth Control

The main means of depth control will be through the ballast tank. The ballast tank will be controlled in coordination with a depth sensor to achieve neutral buoyancy at a specific depth.
The ballast tank will initiate at the surface to dive the submersible as needed. There will be two way control of the tank so that it can be lowered or raised as needed by the controller. The ballast will provide rough depth control as it achieves neutral buoyancy. Specific control of the depth will be achieved through the two side motors. These two motors, controlled by their common shaft will be able to rotate around the axis of the common shaft so that the depth may be controlled either to increase or decrease depth.

6.6 Additional Functionality

Upon meeting with AWRI, requirements for additional functionality were discussed and options for implementing these options into the SEA design were decided upon. One option for additional functionality is to include a water sampling mechanism. AWRI also required that these water samples be accompanied by a form of GPS tracking or labeling for each of the samples gathered. This would allow for mapping of an area based on the water samples. More functionality could include pH and temperature measurements or CO₂ sensors. These additional functions would most likely be added by AWRI and the SEA design team would need only to design the submersible so that such sensors could be added later as needed for different applications.

7. Feasibility

7.1 Budget

Through initial investigation, the overall cost for this project is predicted to be around $800. A bill of materials is shown below in Table 3 with the base cost of materials for both prototype construction and mass production. About $100 has been added to our total budget for a margin of error in our cost estimates. $300 has already been promised by Calvin College, with the possibility of more, pending a written proposal. AWRI has also agreed to purchase some of our more expensive components, as they will be using them in their research.
### Table 3: Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Cost ea.</th>
<th>Cost bulk</th>
<th>Prototype Cost</th>
<th>Production Cost</th>
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</thead>
<tbody>
<tr>
<td>Bilge Pump Cartridge</td>
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<td>28.99</td>
<td>27.99</td>
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<td>52.53</td>
<td>54.56</td>
<td>52.53</td>
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<td>10.00</td>
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<td>Ballast Tank</td>
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<td>47.00</td>
<td>45.00</td>
<td>47.00</td>
<td>45.00</td>
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<tr>
<td>Props</td>
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<td>3.99</td>
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<td>0.99</td>
<td>2.10</td>
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<tr>
<td>Camera</td>
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<td>144.99</td>
<td>149.99</td>
<td>144.99</td>
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<td>3.15</td>
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<td>1.75</td>
<td>1.65</td>
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</tr>
<tr>
<td>Toggle Switch</td>
<td>2</td>
<td>9.98</td>
<td>9.68</td>
<td>19.96</td>
<td>19.36</td>
</tr>
<tr>
<td>LED (for &quot;on&quot; light)</td>
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<td>0.54</td>
<td>0.51</td>
<td>0.54</td>
<td>0.51</td>
</tr>
<tr>
<td>D-sub Connectors</td>
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<td>7.67</td>
<td>6.27</td>
<td>15.34</td>
<td>12.54</td>
</tr>
<tr>
<td>Motor Tether (6 wires)</td>
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<td>4.3</td>
<td>180.00</td>
<td>172.00</td>
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<tr>
<td>Ballast Pump Motor Tether</td>
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<tr>
<td>Servo/Stepper Motor Tether</td>
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<td>18</td>
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</table>

<table>
<thead>
<tr>
<th>Total Prototype Cost</th>
<th>Production Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>693.18</td>
<td>652.60</td>
</tr>
</tbody>
</table>

### 7.2 Schedule

In order to ensure the SEA can be tested and completed on schedule, the assembly has been broken down into specific tasks within a timeline. Final completion is set one month before the report and field tests are due, allowing for any reworking, reordering, or redesign that may set back the completion of certain tasks. A Gantt chart is included in Appendix B.

**Preliminary Tasks- Deadline : Feb 1, 2009**
- Order hull base
- Order 2 side motors, 1 rear motor
- Finalize side motor pitch control design
- Order ballast tank and pump
- Order camera
- Order lights (if necessary)

**Device Preparation- Deadline : Feb 20, 2009**
- Order necessary components for pitch control
- Order host unit components
- Order hull casing
- Waterproof camera
- Waterproof motors
- Mount the props
- Seal the ballast and connect the pump

**Early Construction - Deadline: Mar 8, 2009**
- Mount the pitch control components on the hull base
- Mount the side motors onto the pitch controller
- Mount the rear motor on the hull base

**Continued Construction - Deadline: Mar 25, 2009**
- Mount the ballast tank onto the hull base
- Mount the camera (and lights if necessary) onto the hull base
- Wire the controller unit

**Completed Construction - Deadline: April 8, 2009**
- Secure hull casing onto hull base
- Complete tether construction
- Place tether connectors on SEA and host unit
- Touch up details and add aesthetics

### 8. Conclusion

After rigorous examination and scheduling, the design and construction of a submerged environment analyst that meets all of the project objectives as proposed appears to be feasible within the allowed time frame and budget. The SEA will have 3D range of motion from a three motor system with a ballast tank. It will be able to reach a maximum depth of 90 feet, return a live video feed to the surface, and it will be capable of carrying sensors to analyze the water. It will be controlled by simple host unit via a detachable tether. On completion, the SEA will be delivered to the Annis Water Resources Institute on Lake Muskegon to assist them in their goals of research, education, and outreach, and to fulfill the project goal of improving underwater research technology to better understand this dynamic environment.

### Acknowledgements

We would like to thank the following people for their contribution in our project proposal:

**Annis Water Resources Institute:**
- Alan Steinman
- Janet Vail
- Bopaiah Biddanda
- John Koches

Rob Meyer (Industrial Consultant – GE Aviation)
Rob Bossemeyer (Team Advisor – Calvin College)
References


# Appendix C: Test Matrix

<table>
<thead>
<tr>
<th>Test</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1 Feb 15</strong></td>
<td></td>
</tr>
<tr>
<td>Basic Motor Control</td>
<td>- The motors spin forwards and backwards</td>
</tr>
<tr>
<td></td>
<td>- The speed of the motors can be adjusted</td>
</tr>
<tr>
<td>Basic Ballast Control</td>
<td>- Tank can be filled and emptied</td>
</tr>
<tr>
<td></td>
<td>- Tank does not leak underwater</td>
</tr>
<tr>
<td>Video Feed</td>
<td>- Camera can transfer live video to a monitor</td>
</tr>
<tr>
<td>Power Capabilities</td>
<td>- All the motors can be driven by PowerPack 400+ or equivalent supply</td>
</tr>
<tr>
<td><strong>Phase 2 Mar 15</strong></td>
<td></td>
</tr>
<tr>
<td>Underwater Motor Control</td>
<td>- The motors spin underwater</td>
</tr>
<tr>
<td></td>
<td>- The motors can be controlled from the surface</td>
</tr>
<tr>
<td></td>
<td>- The motors still operate the same after 24 hours underwater</td>
</tr>
<tr>
<td>Underwater Video</td>
<td>- The camera can transfer video from below the surface to a monitor above</td>
</tr>
<tr>
<td></td>
<td>- The camera still operates the same after 24 hours underwater</td>
</tr>
<tr>
<td>Motor Rotation</td>
<td>- Side mounted motors can spin 180 (or 360) degrees underwater</td>
</tr>
<tr>
<td><strong>Phase 3 April 15</strong></td>
<td></td>
</tr>
<tr>
<td>Range of Motion</td>
<td>- SEA (or hull + motors) can move forward and backward</td>
</tr>
<tr>
<td></td>
<td>- SEA can turn left and right</td>
</tr>
<tr>
<td></td>
<td>- SEA can move up and down around a point</td>
</tr>
<tr>
<td>Depth Control</td>
<td>- SEA (or hull + ballast) can surface and dive</td>
</tr>
<tr>
<td></td>
<td>- SEA can hover at a fixed depth</td>
</tr>
<tr>
<td>Host Unit</td>
<td>- SEA correctly responds to commands sent by the controller unit</td>
</tr>
<tr>
<td><strong>Phase 4 May 1</strong></td>
<td></td>
</tr>
<tr>
<td>Field Testing</td>
<td>- SEA is deployed from Annis research vessel</td>
</tr>
<tr>
<td></td>
<td>- SEA returns video from Lake Muskegon</td>
</tr>
<tr>
<td></td>
<td>- SEA is able to operate off of on-board power</td>
</tr>
<tr>
<td></td>
<td>- SEA is brought back on board the vessel</td>
</tr>
<tr>
<td></td>
<td>- SEA is able to be controlled in lake conditions</td>
</tr>
</tbody>
</table>
Appendix D: Drag Force Calculations

Appendix D: Drag Force Calculations

SEA Dimensions

\[ d_{\text{sub}} = 10 \cdot \left| \frac{0.0254 \cdot \text{m}}{\text{in}} \right| \] Diameter of SEA

\[ L_{\text{sub}} = 32.5 \cdot \left| \frac{0.0254 \cdot \text{m}}{\text{in}} \right| \] Length of SEA

\[ \text{Area}_{\text{sub}} = 2 \cdot \pi \cdot \left( \frac{d_{\text{sub}}}{2} \right)^2 + 2 \cdot \pi \cdot \frac{d_{\text{sub}}}{2} \cdot L_{\text{sub}} \] Surface Area of SEA

\[ V_{\text{ideal}} = 0.5 \cdot \left| \frac{0.3048}{\text{m/s}} \right| \] Ideal Speed

\[ T_{\text{LakeAvg}} = \text{ConvertTemp} \left( \text{F, K, 45} \right) \] Lake Water Temperature

\[ \rho_{\text{water}} = \rho \left( \text{Water}, T = T_{\text{LakeAvg}}, \chi = 1 \right) \] Density of water

\[ \mu = \text{Visc} \left( \text{Water}, T = T_{\text{LakeAvg}}, \chi = 1 \right) \]

\[ \text{Re} = \frac{\rho_{\text{water}} \cdot V_{\text{ideal}} \cdot d_{\text{sub}}}{\mu} \] Reynolds Number

\[ C_d = 2 \] Figure 15.34 pg. 601 Cengel

\[ F_{\text{drag}} = C_d \cdot \text{Area}_{\text{sub}} \cdot \frac{\rho_{\text{water}} \cdot V_{\text{ideal}}^2}{2} \] Drag Force

\[ F_{\text{drag, english}} = F_{\text{drag}} \cdot \left| 0.2248 \cdot \frac{\text{lbf}}{\text{N}} \right| \]

Prop Specs

\[ \text{Diameter}_{\text{english}} = 3 \] Prop Diameter, in English

\[ \text{Diameter}_{\text{english}} = \text{Diameter} \cdot \left| 39.37 \cdot \frac{\text{in}}{\text{m}} \right| \]

\[ A_{\text{prop}} = \pi \cdot \left( \frac{\text{Diameter}}{2} \right)^2 \] Area of Prop

\[ F_{\text{drag}} = 0.5 \cdot \rho_{\text{water}} \cdot A_{\text{prop}} \cdot V_{\text{prop}}^2 \] Velocity of Prop

\[ \dot{V}_{\text{prop}} = V_{\text{prop}} \cdot A_{\text{prop}} \] Volumetric flow rate of prop

\[ P_{\text{prop}} = \frac{\rho_{\text{water}}}{2 \cdot A_{\text{prop}}^2} \cdot \dot{V}_{\text{prop}}^2 \] Power needed of Prop for propulsion
Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]

$\text{Area}_{\text{sub}} = 0.7601 \text{ [m}^2\text{]}$

$\text{Diameter} = 0.0762 \text{ [m]}$

$F_{\text{drag}} = 0.0001389 \text{ [N]}$

$\mu = 0.000009391 \text{ [kg/m-s]}$

$\rho_{\text{water}} = 0.007868 \text{ [kg/m}^3\text{]}$

$V_{\text{ideal}} = 0.1524 \text{ [m/s]}$

$A_{\text{prop}} = 0.00456 \text{ [m}^2\text{]}$

$\text{Diameter}_{\text{english}} = 3 \text{ [in]}$

$F_{\text{drag,english}} = 0.00003123 \text{ [lbf]}$

$P_{\text{prop}} = 0.0003865 \text{ [W]}$

$T_{\text{LakeAvg}} = 280.4 \text{ [K]}$

$V_{\text{prop}} = 2.782 \text{ [m/s]}$

$C_d = 2$

$a_{\text{sub}} = 0.254 \text{ [m]}$

$L_{\text{sub}} = 0.8255 \text{ [m]}$

$Re = 32.43$

$\dot{V}_{\text{prop}} = 0.01269 \text{ [m}^3\text{/s]}$
Appendix E: Submerged Pressure and Ballast Tank Sizing Calculations

Pressure Submerged at 80 Feet Below the Surface

\[ P_{\text{surface}} = 101325 \quad [\text{Pa}] \quad \text{Surface Pressure} \]

\[ g = 9.8 \quad [\text{m/s}^2] \quad \text{Gravity Constant} \]

\[ \rho = 999.9 \quad [\text{kg/m}^3] \quad \text{Density of Water} \]

\[ h = 80 \cdot 0.3048 \cdot \frac{\text{m}}{\text{ft}} \quad \text{Maximum Depth of Submersible} \]

\[ P_{\text{depth}} = P_{\text{surface}} + \rho \cdot g \cdot h \quad \text{Pressure in Pa} \]

\[ P_{\text{depth, eng}} = P_{\text{depth}} \cdot 0.000145038 \cdot \frac{\text{psi}}{\text{Pa}} \quad \text{Pressure in PSI} \]

Ballast Tank Sizing Calculations

\[ m = 4.5 \quad [\text{kg}] \quad \text{Estimated weight of SEA (10 lbs)} \]

\[ F_{\text{buoyant}} = \rho \cdot g \cdot V \quad \text{Buoyant Force Calculation} \]

\[ \rho_w = 940.5 \quad \text{Density of water at temperature } 10^\circ C \]

\[ F_{\text{buoyant}} = m \cdot g \quad \text{Buoyant Force Equation for neutral buoyancy} \]

\[ V = \pi \cdot R_{\text{ballast}}^2 \cdot L_{\text{ballast}} \quad \text{Volume of Ballast Tank} \]

\[ L_{\text{ballast}} = 20 \cdot 0.0254 \cdot \frac{\text{m}}{\text{in}} \quad \text{Length of Ballast Tank} \]

\[ R_{\text{eng}} = R_{\text{ballast}} \cdot 39.37 \cdot \frac{\text{in}}{\text{m}} \quad \text{Radius of Ballast Tank, English} \]

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

\[ F_{\text{buoyant}} = 44.1 \quad [\text{N}] \quad g = 9.8 \quad [\text{m/s}^2] \quad h = 24.38 \quad [\text{m}] \]

\[ L_{\text{ballast}} = 0.508 \quad [\text{m}] \quad m = 4.5 \quad [\text{kg}] \quad P_{\text{depth}} = 340264 \quad [\text{Pa}] \]

\[ P_{\text{depth, eng}} = 49.35 \quad [\text{psi}] \quad P_{\text{surface}} = 101325 \quad [\text{Pa}] \quad \rho = 1000 \quad [\text{kg/m}^3] \]

\[ \rho_w = 940.5 \quad [\text{kg/m}^3] \quad R_{\text{ballast}} = 0.0531 \quad [\text{m}] \quad R_{\text{eng}} = 2.091 \quad [\text{in}] \]

\[ V = 0.0045 \quad [\text{m}^3] \]