The WASP: an Atonomous Surface Vessel for the University of Alaska

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***Abstract* - The vision of the Autonomous Surface Vessel program is to develop an instrumented boat capable of robust, automatic sampling of oceanographic data at specific locations and depths in estuary and coastal waters. The objective of the WASP project was to develop an initial prototype of such a system including software, physical hardware and electronic components. The physical structure includes pontoons, vertical supports, and a platform housing the vessel's power source, onboard electronics and payload. The onboard electronics control the movement and functionality of the vessel and the payload of scientific instruments are attached to a winch for taking readings at depth. Also, the user interface developed for the wireless communication and control of the vessel is internet based allowing the user to control the vessel anywhere in the world. This prototype will be integrated and tested in Elkhorn Slough during the Summer of 2005 as part of an SCU-MBARI project. The work performed to date has been critical in the development of the ASV concept which is expected to lead to an operational system deployed in the Kasitsna Bay Laboratory in Alaska and other national estuaries.**

I. INTRODUCTION

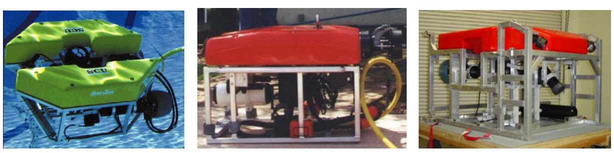
A. Santa Clara University Robotics Systems Laboratory

Santa Clara University's (SCU) Robotic Systems Laboratory (RSL) conducts a low-cost, aggressive, integrative research and education program in intelligent robotic systems. Initiated in 1998, the centerpiece of this program is a set of yearly undergraduate design projects in which teams of senior students completely design, fabricate, test, operate, and manage high-quality robotic systems for performing a variety of scientific investigations. Experimental systems include numerous spacecraft, underwater vehicles, terrestrial rovers, unmanned aircraft/airships, industrial manipulators, and astronomical telescopes [1].

Once operational, these robotic systems are used by undergraduates, graduate students, and professional researchers to perform compelling science missions and to demonstrate advanced technology; over the past five years, RSL has developed and/or executed more than $2,000,000 of such sponsored work. Specific missions have included studies relating to marine archeology, coastal ecological studies, space-based photography, space environment characterization, satellite formation flying and constellation control, and autonomous operations. Collaborators and sponsors for these missions include a variety of government agencies (the National Science Foundation, the National Oceanographic and Atmospheric Agency, the National Aeronautics and Space Administration, the U.S. Air Force, etc.), corporations (the Lockheed Martin Corporation, Globalstar LCC, etc.), academic institutions (Stanford University, the Massachusetts Institute of Technology, the University of Texas at Austin, etc.), and non-profit entities (the Monterey Bay Aquarium Research Institute, the California Space Grant Consortium, etc.).

The development and use of these robotic systems serves as the keystone for the integrative nature of the SCU program. Overall, the mixing of engineers and scientists across a variety of educational levels and from a multitude of organizations creates a particularly stimulating environment for technical education, engineering innovation, and scientific discovery. Furthermore, the availability of multiple operational robots in several domains offers unprecedented opportunities for low-cost experimental engineering research exploring novel subsystem technologies, multi-robot systems and teleoperation techniques.

Undersea Vehicles and Instrumentation: The development and operation of undersea robots and their technical subsystems is one of the most successful aspects of the SCU robotics program. Previously developed and now operational systems include two tethered Remotely Operated Vehicles (ROVs), Triton and Nautilus, each rated for 300-meter depth operation. Additional systems currently in full-scale development include the SCU-designed Mantaris ROV (a 6 Hp tethered vehicle designed for 500-meter depth) and an Odyssey-class Autonomous Underwater Vehicle (AUV) which is being re-engineered for operation to 500-meter depth. Student-developed instrumentation for the ROV's includes a suction sampler, a simple robotic gripper, and an undersea docking port for deploying and retrieving tool sleds at depth.



(a) (b) (c)

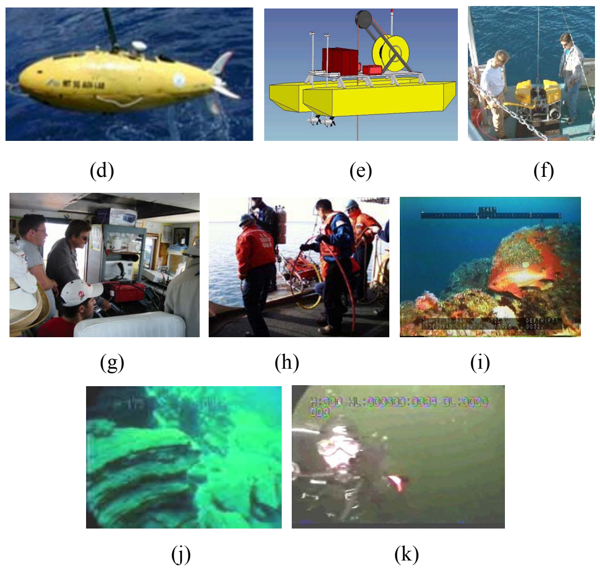


Fig. 1. SCU Underwater Robotic Activities: (a) The RSL-designed Triton ROV, operational to 300m. (b) The RSL-designed Nautilus ROV, operational to 300m. (c) The RSL-designed Mantaris ROV, commissioning in Summer 2005, rated to 500 m. (d) Odyssey-Class AUV being re-engineered by RSL, commissioning in Summer 2006, rated to 500 m. (e) The RSL-designed Bronco ASV, proof-of-concept operations in Summer 2005. (f) Students deploy Triton ROV in Lake Tahoe from the R/V LeConte. (g) Students pilot and operate the ROV for scientists during a deployment. (h) Students deploy ROV in arctic for an archaeology mission from the USCG R/V Polar Star. (i) ROV video data from a fisheries research deployment in the Channel Islands. (j) ROV video data from a geology research deployment in Lake Tahoe. (k) ROV video data from ROV-diver test in Monterey Bay.

RSL's operational ROVs are routinely deployed along the California coast and in Lake Tahoe in support of a variety of science, technology and education missions. Over the past five years, RSL personnel have engaged in collaborations and operational deployments with numerous world-class researchers to include scientists and technologists with the NOAA Undersea Research Program's West Coast and Polar Regions Undersea Research Center, NASA Ames Research Center, the U.S. Coast Guard, the Monterey Bay Aquarium Research Institute (MBARI), the National Marine Sanctuary, Moss Landing Marine Laboratories, the U.S. Geological Survey, Scripps Institution of Oceanography, and several partner academic institutions.

Scientifically, RSL personnel and systems have supported a variety of research investigations to include biological and fisheries research, geologic investigations, and archaeological expeditions. From an engineering research perspective, RSL personnel have used the systems to explore a range of technologies such as underwater three-dimensional imaging, advanced robotic manipulators, and advanced navigation/teleoperation strategies. Educationally, undergraduate student design teams play a vital role in the development of these systems as part of SCU's interdisciplinary senior design project program. Underclass students also learn to maintain, operate and deploy these systems as part of an established marine operations course sequence. Graduate students use these systems as experimental platforms for conducting engineering projects in several established classes (ocean engineering, robotic teleoperation, advanced mechatronics) and through thesis research. Overall, the program supports a robust outreach effort that has served more than 1500 high school students over the past two years. References [2-26] review many of the science, engineering and education activities of the SCU underwater robotics program since 1998.

B. *Scientific Drivers*

Alaska is known for its dramatically changing tides and abundant marine life migrating to and from its bays and coastal areas. Kachemak bay, along the south-west coast, extends from the Pacific Ocean to Anchorage.

Along this area there are numerous species of animals that migrate up the bay including sea otters, harbor seals, sea lions, porpoises, a variety of whales, several species of ducks and birds, fish and shellfish [27]. Within the Kachemak Bay is Kasitsna Bay (K-Bay), a small ¼ mile bay protected by the Kenai Peninsula. The National Oceanic and Atmospheric Administration (NOAA) had taken an active interest in the area and had founded the Kasitsna Bay Laboratory through the University of Alaska Fairbanks (UAF). UAF offers several diving programs as well as marine biology programs at the K-Bay Laboratory. The facility consists of resident quarters, dry and wet laboratories, several research vessels and a floating dock, completed this past year. Researchers are currently studying kelp forests, crab and fish populations, and the effect of UV-B exposure in sea-urchin larvae to mention just a few [28].

C. *Project Overview*

The vision of the project was to develop a research vessel that is capable of robust, autonomous sampling of oceanographic data at specific locations and depths in estuary and coastal waterways. To date the specific goals include the development of an initial prototype of such a system. In pursuing this objective, our major contributions have been a structure, including pontoons, vertical struts, a platform and the connecting apparatus. This supported a winch for deployment of scientific instruments, the power source for the vessel, and the electronic components that controlled the movement and functionality of the vessel. Integration and testing which is currently in progress as part of an SCU-MBARI project. Although our work has been limited to prototyping, these accomplishments have been crucial to evolving the ASV concept for automated, cost-effective estuary monitoring.

D. *Project Objectives and Requirements*

The capabilitys requested by the UAF were quite specific, but by designing it to be adaptable, the vessel can be applied in a wide variety of settings, for many different scientifc goals. It must be able to traverse a ¼ mile bay, making at least 12 stops for deployment of scientific payloads (e.g. a CTD). This was interpreted into specifications for at least 8 hours of power. The large power draws were from propulsion and the vertical deployment systems.

It must be able to operate in saltwater conditions with some wind, waves, and currents. The design of the vessel needed to withstand Force 3 sea conditions as defined by the Beaufort Wind Force Scale [29]. This describes wind speeds of 7-10 knots, waves of 2-3.25 feet height, with "large wavelets, crests begin to break, scattered white caps" [29]. Wind and waves can cause the vessel to tip and it can create problems for measurement integrity. The design was constrained to not have platform displacement amplitude larger than two feet.

In addition to the weight of the vessel itself, the vessel must be able to carry a payload of scientific instruments weighing up to 200 lbs, a combination of which could be mounted on the topside structure or lowered into the water. The flotation subsystem needed to balance the weight of the boat and the payload weight.

Using some type of navigation system it must to be able to determine its location with at least ±10 feet of precision while station keeping and taking readings. A wireless data uplink allowed communication and provided status updates to the user at a remote location. The controllers on board needed to sense the current location and automatically steer and propel the ASV towards the desired location.

The ASV must also be shippable. The access to Kasitsna Bay is very limited, so the unit must be able to be shipped on a 737 cargo plane. The maximum size of a cargo container was 9 feet by 7 feet for the base with 7 feet vertical clearance.

E. User Scenario

The system was set up so that anyone with internet access, and the proper authorization, could control the vessel and implement mission plans. After picking each location, the program prompts the user to determine the depths at which to take measurements and the type of measurements to take at each depth. When the mission plan is completed, the commands are sent through the internet to the server in the K-Bay Laboratory. The operator of the ASV deploys the ASV from its docking station and activates the system. The commands are then sent wirelessly to the ASV and read in through the onboard controllers. The controllers communicate the commands and the propulsion is turned on or the vertical deployment system can be operated. The status of the boat, the power levels and the completion rate of the mission are sent back and displayed on the screen.

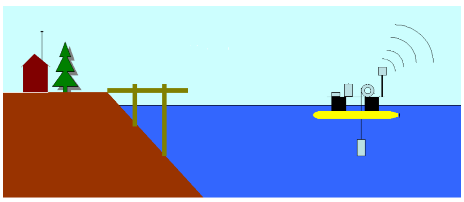


Fig. 2. User scenario for the ASV

Using the Graphical User Interface (GUI), the user will be able to input the mission plan by picking points on the map or by typing the coordinates. A real-time uplink showed the user the current status including location, mission progress, battery life and overall health of the system, as well as allowed the user to modify the mission plan or even operate the ASV in a manual mode using the onboard video link. Once the ASV completed the mission, it returned to the dock where the operator secured the vessel and recharged the power system. All scientific data was uploaded to the shore computer via the wireless link as well as a detailed report of the mission. If the ASV will be used several days in a row, it can be stored in the water; however, it was recommended that in order to reduce the effects of corrosion and extend the life of the ASV that it should be removed from the water when not in use.

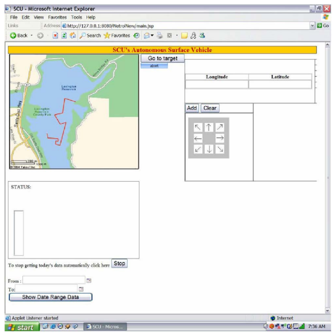


Fig. 3. Prototype GUI for the ASV

G. Key System Issues

In order to meet the needs of the customer, we had several options for the vessel: ROV, AUV or ASV. There were several key issues to consider including the integration of each subsystem, reliability of the system, manufacturability, cost, power consumption of all electrical components, flotation of the vehicle, and stability, static and dynamic balance, and the overall weight and size of the system. These issues, combined with the weather conditions and the input of the UAF's School of Fisheries and Ocean Sciences, led our team to choose an unmanned surface vehicle instead of an ROV or an AUV.

When determining what type of vehicle to utilize, trade offs were made corresponding to our key system level issues. Comparing an autonomous surface vessel, autonomous underwater vehicle and a remotely operated vehicle, the ASV would not require attachments on a submerged hull, it required fewer navigation motors, and it was easier to statically and dynamically balance (especially with two hulls). It was also easier to maintain equilibrium while taking measurements, the onboard instruments were easier to install and access, movement was not limited by a tether, the GPS was running constantly and without an accompanying vessel to relay the signal, and the above surface and sub surface measurements were taken simultaneously. However, the ASV required a vertical deployment system to lower the sub-surface scientific instruments and the overall system was heavy, possibly heavier than either the AUV or the ROV would have been.

One of the main concerns with using an AUV was that when the vessel dove to take measurements, the GPS signal faded. One of the requirements voiced by the scientists during the interviews used to determine customer needs was to have constant contact with both the on-shore computer and the GPS signal. Also, keeping engineering principles in mind, the design of the ASV needed to minimize the amount of environmental impact. With a constantly active GPS signal and the onboard video link, the whereabouts and any potential obstacles in front of the boat were known and the possibility of avoidance increased.

The final design of the ASV was a Small Water-plane Area Twin Hull (SWATH) design. Similar to a catamaran or standard pontoon boat, a SWATH vessel has two pontoons set wide to increase stability, but unlike the standard pontoon boat, the SWATH's pontoons are completely submerged 6 to 10 inches below the surface, and are connected to the main deck by vertical struts. This design increased the stability of the vessel by decoupling the boat from the oscillation due to the waves. This was especially important when the instruments were deployed because oscillations of the platform changed the depth at which the instruments were reading from, and can cause high stress on the cable. Having the pontoons spread out helps to keep the center of buoyancy and the center of gravity move closely aligned, reducing the tendency of the vessel to flip over. We decided to name the ASV the WASP, or Water-Analysis Surface Platform.

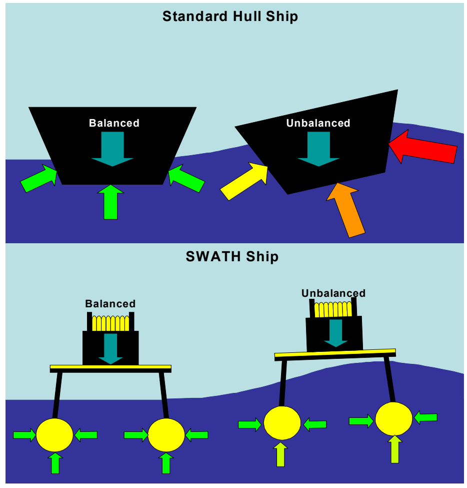


Fig. 4. Standard Hull Vs. SWATH Design

F. *Functional Analysis*

The data or electrical flow between the user and the vessel as well as the command flow from the microprocessors to the various components can be seen in the functional diagram in Fig. 5.

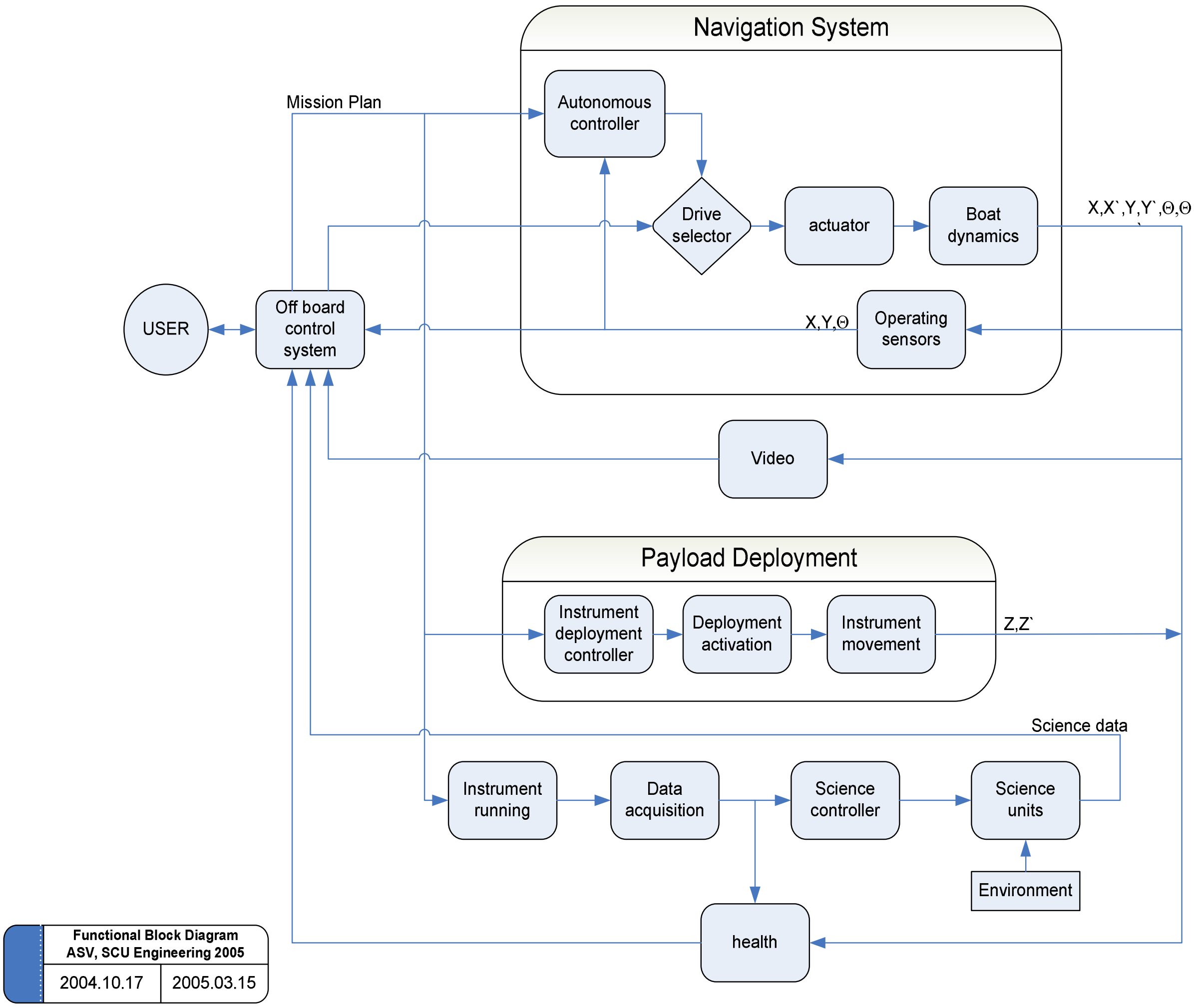


Fig. 5. Functional Diagram of the ASV

II. SYSTEM TECHNOLOGY

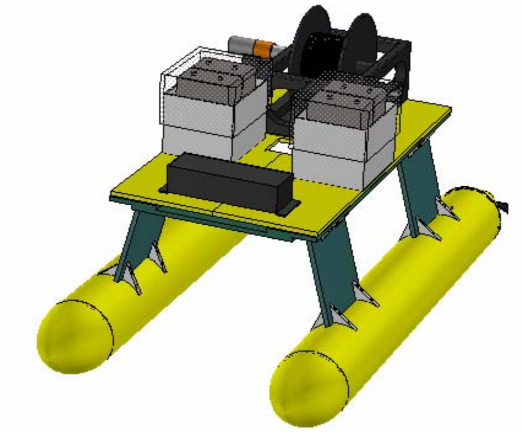


Fig. 6. Current Design of the ASV

A. Systems-Overview

The entire ASV was broken down into discipline-related sections: Mechanical, Electrical, and Computer systems. The mechanical systems deal with the physical appearance and functionality of the ASV. The electrical systems control the movement and data acquisition of the ASV. Finally, the computer systems create the human interface between the ASV and the user. Due to the limited space constrainst we will be focusing on just a few of the subsystems within each system. Refrence [30] gives an indepth description and analisys of the first year of the project's development.

B. Systems-Mechanical

The mechanical systems are comprised of a flotation subsystem, power subsystem, propulsion subsystem, and a vertical deployment (or instrument deployment) subsystem. These subsystems control the overall movement of the ASV and the instruments that are deployed.

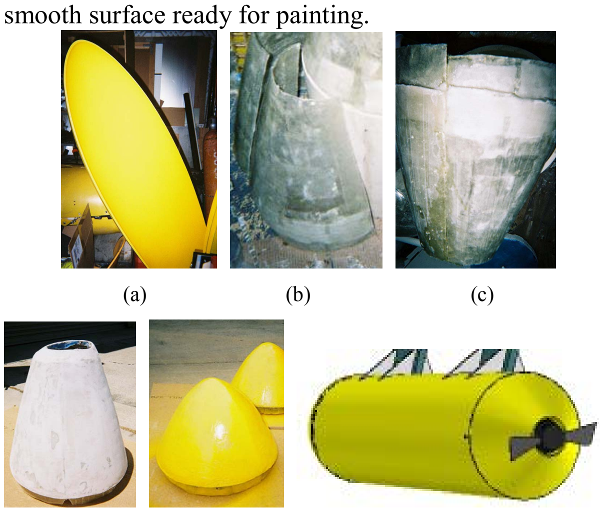
1) Flotation Subsystem

In order for our ASV to operate, it was vital for the vehicle to stay at the surface. Some type of flotation or buoyancy system was decided upon based on a variety of selection criteria. The design team brainstormed many potential solutions for flotation ranging from containers filled with air to a variety of materials less dense than water. Listed are the most important functional criteria from most to least importance: stability, buoyancy, complexity, versatility, reliability, strength, and size (when broken down for shipping). After determining the criteria, each design solution was evaluated according to the criteria and ranked for compliance. The design solutions for the flotation subsystem: Inflatable Pontoons, Fishing Boat Base, Semi-Submergible, Foam Filled Pontoons, and PVC Tubing with Fiberglass End Caps.

The final design selected for the pontoons can be seen in Fig. 6. Knowing common diameters of PVC in the construction industry and calculating the approximate amount of water needed to be displaced, we chose a 15 inch diameter pipe that was cut to 8 feet in length. The shape of the end caps were modeled after an existing AUV shell that had a rounded nose and thrusters protruding out of the end. In the SWATH design, the pontoons are submerged and the platform was raised above the water. The pontoons are designed to ride six to ten inches below the surface. By submerging the pontoons, the stability of the craft was increased because of the decoupling of the vessel from the wave motion. Unfortunately, to keep the pontoons submerged when the instruments are deployed, a dynamic (or active) ballast system is needed. This system has been designed, but will not be fabricatied untill a later date.

Fig. 7. CAD drawing for pontoon design

The process of manufacturing the flotation subsystem included sizing the PVC, fiberglassing the end caps, pouring the foam inserts, painting and finishing all parts, and assembling the pontoons. To size the 15 inch PVC pipes, the mass budget was set, and the required buoyance was obtained. From this calculation they were cut to 8 foot lengths. To get the optimal shape for the end caps, an existing AUV shell was used as a mold. A novel idea when creating the end caps was to use a section of PVC at the base, where the end cap was designed to connect with the piping of the pontoon, and mold the fiberglass to the AUV and over the PVC. This created a surface that fit securely into the PVC and made mounting the final end caps easier. Each end cap was constructed of two halves and fiberglassed together. The surface was sandpapered and filled to create a smooth surface ready for painting.



(a) (b) (c)

(d) (e) (f)

Fig. 8. Process used to create end caps: (a) existing AUV shell used as a mold, (b) end caps were created in halves, (c) halves were joined, (d) end caps were sanded and filled, (e) end caps were painted, and (f) a CAD drawing of pontoons with thrusters mounted

2) Propulsion Subsystem

Because the ASV has to take measurements at several locations, it needs a drive system. The different options for this subsystem were ranked by how well they scored based on several criteria; the most important was thrust followed by reliability, and power consumption. Several different options and configurations for the ASV's propulsion system were a Structure-Mounted Gasoline Motor, Pontoon-Mounted Electric Motors, and Platform Mounted Electric Motors.

The solution we chose is pontoon mounted electric motors. The thrusters that were purchased were Minn Kota Electric Trolling Motors. These provided 55 pounds of thrust each and draw 25 Amps of current. The motors, without the shaft that led to the electric steer control, are 4 inches in diameter at the widest and 11 inches long.

The thrusters chosen to drive the ASV were modified Minn Kota Electric Trolling Motors. They had a shaft enabling mounting on a surface approximately two feet above water as well as fins along the motor for better hydrodynamics. However, because the thrusters were embedded in the pontoons, the shaft and the fins were removed. The wiring for the motor ran through the shaft; therefore the cut area was sealed with epoxy to prevent flooding.

To mount the motors into the pontoons, a 4 inch acrylonitrile butadiene styrene (ABS) pipe was used. See Fig. 9. The pipe was cut to size and a section was cut out for the protruding shaft section and wiring to slide in. A hose clamp was placed around the mount and the motor to secure it in the mount. The protruding shaft helped to keep the motor from spinning within the mounting. To mount the ABS pipe into the pontoon, two ¼ inch diameter all-thread rods were bolted through. Finally, the end caps were filled with foam to add extra support for the thrusters.

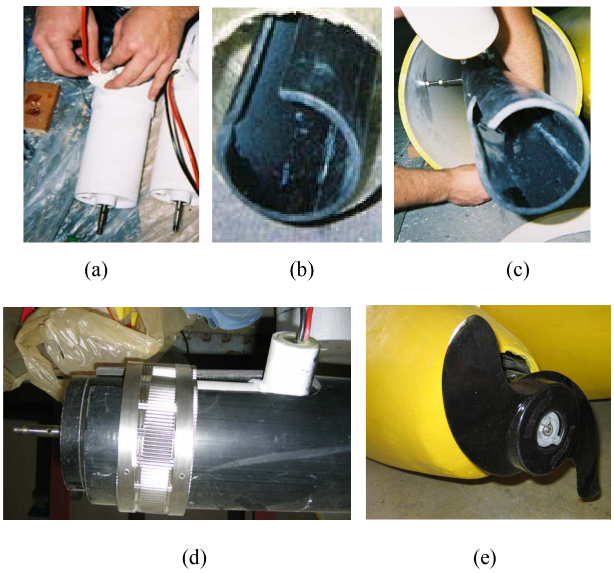


Fig. 9. (a) filling the cut shaft with epoxy, (b) slot cut out from ABS for mounting thruster, (c) bolts holding mounting in pontoon, (d) thrusters mounted, and (e) end cap mounted

3) Structural Subsystem

During the preliminary design stage, the design solutions for the structure were diverse, but the primary function is to create a surface to mount all equipment of the various subsystems and to connect this platform to the flotation. Criteria for selection included strength, rigidity, weight, manufacturability, cost, time, and simplicity. The design solutions for the structure were: Angle Iron Frame, Bent Steel Tubes or Honeycomb Aluminum platform and vertical struts.

The design chosen was the Honeycomb Aluminum Platform and Vertical Struts. The platform dimensions are 6 feet 8 inchs by 3 feet 8 inches and the vertical struts are 1 foot 6 inches by 1 foot 8 inches with a 15 degree angle. Two 13 inch wide strips run from bow to stern and four 11 inch wide strips run from port to starbord to support the platform. The fiberglass grating consists of two section 1 foot 9 inches by 6 feet 8 inches, and is bolted on top of the aluminum plates for mounting components. By using the aluminum only as a support and the grating as the actual platform, the surface area is decreased, allowing more air and water to pass through instead of impacting the platform and tossing the vessel. The CAD drawing of the final design for the structure can be seen below in Fig. 10.

Fig. 10. CAD drawing of final design for structure

The use of vertical struts constructed of the aluminum plates coincided with the SWATH design. The vertical struts were designed to be partially submerged. The integration of the vertical struts to the platform and to the PVC pontoons required connectors or clamps. These clamps were designed to be approximately 3 inches by 4 inches with a 1½ inch cross section. Before manufacturing the clamps out of ultra-high molecular weight (UHMW) plastic, a finite element analysis (FEA) was performed. The CAD drawings for the vertical struts and the clamps can be seen in Fig. 11.

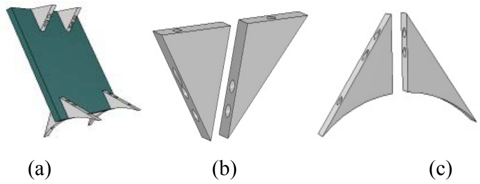
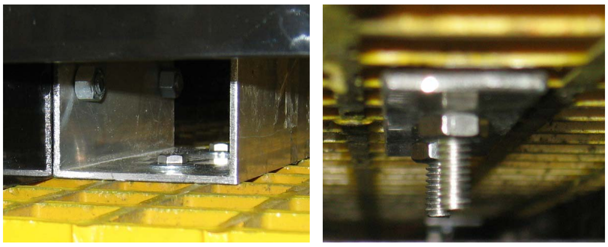


Fig. 11. CAD drawing of (a)vertical struts with clamps attached, (b) top clamps, and (c) bottom clamps

The structure was constructed of honeycomb aluminum plates. They were cut to size using a band saw and the edges were finished with a filler to water seal the material. Each piece was finished with a protective paint. To bolt through the honeycomb, a ½ inch hole was drilled and a ¼ inch inner diameter bushing was adhered within. For mounting of all components, ¼ inch stainless steel bolts and nuts were used along with stainless steel washers or flat stock.



(a) (b)

Fig. 12. Mounting bracket for (a) topside and (b) bottom side

Because the bottom clamps needed an arc-shaped surface to mount on the pontoons, the manufacturing process was more complicated than expected; therefore the clamps were cut using a water jet at . Top and bottom clamps attached to the vertical struts and the platform can be seen in Fig. 13.

(a) (b)

Fig. 13. (a) UHMW clamps fastened to vertical struts (b) access panel location

One issue considered was how the clamps were going to be fastened and how the end caps would be bolted down once the foam filled the pipes. To solve this, panels were designed to be cut out of the pontoons to grant access to bolts and nuts holding together the end caps and the clamps. Location of access panels can be seen in Fig. 13.

Knowing the ASV will be deployed in a salt-water environment, the materials selected needed to be marine-grade corrosion resistant. Such materials are stainless steel, marine grade aluminum and plastics. The pontoons are made of PVC, a plastic used in plumbing, and fiberglass. All clamps are cut out of ultra high molecular weight plastic known for its strength and rigidity. The bolts, washers and nuts used to secure the clamps and the end caps were all made out of stainless steel. The vertical supports are made out of honeycomb aluminum plates. The outer aluminum plates are made of anodized aluminum and surround the inner honeycomb structure which is made of non-anodized aluminum. To protect the inner aluminum structure from permeation by salt water, protective adhesive filler was applied to the edges. This adhesive also created a safer surface for handling by covering the sharp edges.

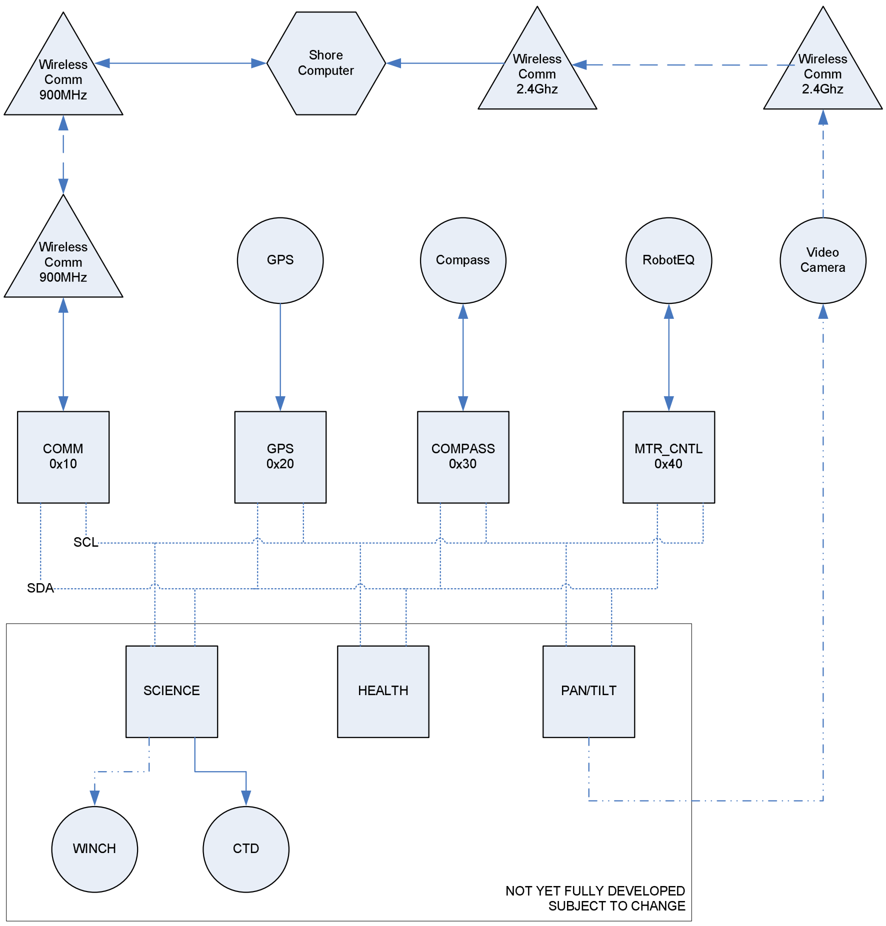


Fig. 14. ASV Component Block Diagram

C. Systems- Electrical

The electronics on the ASV employed common bus distributed avionics architecture with each subsystem being controlled by its own microcontroller. This approach was used for a couple of reasons. It allows for the construction of abstract pieces that can be added, removed or upgraded depending on how the project evolves before its completion and allows groups in future years to work on one system independently without having to know the specifics of the entire project. The component block diagram can be seen on the previous page in Fig. 14.

A distributed, avionics architecture breaks the components of a system into function specific subsystems. These subsystems each do their own task and work together to create a complete system. Some configurations to connect these systems together are: the star, the single bus or the multiple bus architectures. In a star architecture, one master device connects to each subsystem. This system works well as long as none of the subsystems need information from each other; if this is the case, a method of information forwarding must be developed to handle cross subsystem communications. Devices on a single bus system, such as I2C, will facilitate a multi-master architecture that allows for cross system communication. For this application, I2C was chosen over other multi-master setups such as SPI or CAN, because it is simple and does not need additional hardware or modification of existing systems to expand the overall system.

Each of the subsystems in the system block diagram was represented by a square and each contain their own microcontroller. Each of the controllers was connected to the I2C bus and most have another device connected to its UART.

D. Systems- Computer

The WASP has been designed to be controlled remotely via the internet either by a realtime pilot or by a supervisory operator. RSL's NETROL system is being used to provide this software architecture. NETROL uses a realtime streaming data server in order to relay commands and telemetry between applications executing on the shore station computer and the remote operator's computer. The shore station application simply provides a data bridge between the internet connection and the multiple radio links with the boat. The operator's application allows joystick/keyboard/GUI commands to be sent to the boat and displays the boat's camera video and telemetry via the GUI. The NETROL architecture is routinely used for a variety of RSL robotic missions ranging from realtime piloting of ROVs, land rovers, and airships to the supervisory control of spacecraft. Testing of the NETROL system shows across a variety of networking configurations and between numerous geographical locations shows typical round trip delay times of less than a half second (for joystick-based commands and black and white video suitable forpiloting) [31].

III. CONCLUSION

A. Evaluation of Design

The design changed throughout the first year and we are confident in our final design: the WASP. Because the flotation system is submerged, the change in water height does not affect the stability of the boat as drastically. The amplitude of the oscillation of the depth of the instruments is also dampened and the thrusters are constantly submerged. The use of the honeycomb aluminum kept the structure strong and light. Also, by mounting all components onto plastic grating, there is a large amount of adjustability in placement. The use of Atmels will prove easy to learn and continue working with. By using basic languages like Java, the software is easy to adjust if any project specifications are changed and it is compatible with most computers.

B. SCU-MBARI Project

One of our team members, Paul Mahacek, is currently working for the Montery Bay Aquarium Research Institute. In this ten week internship he is working on analising the dynamic response of the ASV. By generating waves and noting the response of the system at different angles, we can determine the most effective positioning and orentation for both driving and stationkeeping.

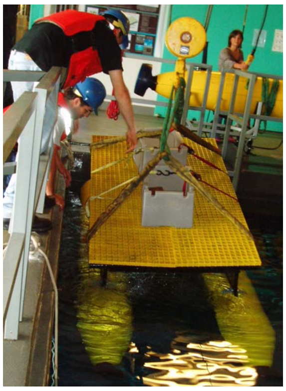


Fig. 15. ASV testing currently in progress as an SCU-MBARI project.

B. Future Work

Although we accomplished most of the objectives set forth, there is still more to do to meet the complete requirements of the customer. For the mechanical subsystems, a dynamic ballast system should be added. Our idea is that there are sections in the pontoons that contain several pumps that can control the amount of water contained in that section. This allows the ASV to remain more stable in rougher sea conditions.

Although we estimate the batteries on board will give the required amount of hours of operation, a generator system should be considered. We anticipate that the scope of the project will increase and with it, an increase in the length of time the ASV will be operational. The generator will add more hours and enable that requirement to be fulfilled without changing the power subsystem.

In order to deploy instruments, three conditions must be fulfilled. First, the wheel that guides the tether from the level wind to the instruments and keeps a safe radius of curvature needs to be fabricated and mounted. This wheel will need to drop the instruments through the center of the ASV and ensure that the instruments rise completely out of the water. The second wheel needs to be attached to the level wind to keep the tether from rubbing against rough edges. Because the edge of the winch is close to the entrance of the instruments, the first wheel needs to be mounted at a steeper angle than optimal. A problem arises when the tether tends to rub against the locking mechanism of the level wind. The second condition that must be fulfilled is a protective cage for multiple instruments. This cage should be light yet strong in order to protect instruments in case they come in contact with a hard object, yet light enough to not create an unbearable load on the tether. The cage must support the various instruments that the scientists require and should be designed for easy removal and installation of new instruments in the case of repairs or upgrades. Finally, a guide for the instruments is desired for periods when the instruments are retracted and the boat is in motion. The instruments will tend to sway in windy conditions, with swells or waves, and with general motion. This guide will reduce stressing the tether and reduce error in the deployment of instruments.

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