

Workhorse AUV – A cost-sensible new Autonomous Underwater Vehicle for Surveys/ Soundings, Search & Rescue, and Research

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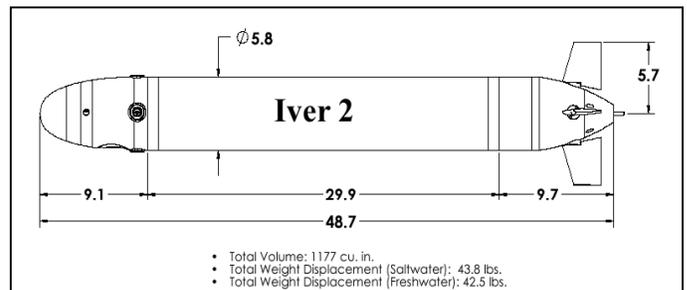
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Abstract - The need for lower-cost AUVs to enable routine Survey and Sounding missions with a greater reliance on technology, rather than crewed workboats and expensive on-site labor, has been recognized for some time. High quality, proven electronic and electromechanical components, developed for tangential industries such as robotics, factory automation and recreational boating, now offer a wide variety of commodity-priced solutions ready for applications in traditionally sophisticated AUV missions. Commercial Maritime applications for targeted sensor functionality such as forward looking and side-scan sonar have also yielded an array of low cost sub-system components ideally suited to basic missions in the field of near-coastal hydrographic surveying. Priced appropriately, and readily available with defined physical and software interfaces, these components open the door to the development of a low-R&D, simplified Workhorse AUV. OceanServer Technology has created such an AUV by selecting commercial grade components, repeatable manufacturing techniques, and intuitive operator interfaces designed to reduce the cost of rudimentary data collection in shallow (< 200 ft) waters.

I. INTRODUCTION

We approached the AUV electronics as a system integration challenge, and the hull structure as a reliability and manufacturability challenge. In both cases we dissected the AUV ‘System’ into component parts, examined the state of the art, and selected low-risk components with proven performance in comparable applications. For electronics, we viewed the AUV as a ‘submersible’ PC, based on Microsoft Windows XP™ due to its lead in stable device drivers, and then spent virtually all of our software development time designing and coding a Underwater Vehicle Control program (UVC) and Mission Planning Software (MissionP) program that would layer on top of Window™, and present a function GUI interface to the AUV Operator. For the hull and control surfaces, we ‘adopted’ the Myring Hull Contour [1], which has proven to be an efficient hydrodynamic design, with an added benefit of offering cylindrical shapes that yield easily-manufactured hull components using numerically controlled (NC) machine tools. By focusing on these elements as independent sub-systems,

each with a defined set of functional requirements and a defined interface, opportunities to use readily available industry standard components, materials and assembly techniques became possible. As subsystems, many of these items are way up the curve of feature functionality and product quality, and way down the cost curve. Adopting mechanical and electronics components that are commodity items in their intended application, has transferred the low-costs, high volume quality, and innovation of design inherent in these off-the-shelf commercial-grade items, to the new AUV in a way that isn’t normally possible in the specialized, low-volume scientific arena. Increased attention could then be placed on reducing risk and the cost of unique system items not available in the general commercial market. In aggregate, this approach offered the potential of yielding a reliable, Cost-Sensible Autonomous Underwater Vehicle, with surprising functionality. We code named the first potentially marketable Workhorse AUV as “Iver 2”.



Gross Hull Dimensions for Iver 2 AUV

II. LIKELY MISSIONS

The initial AUV development was targeted at creating a simple, functional, robust tool for use by private sector contractors focussed on collecting hydrographic and environmental survey data in near-coastal areas. Bathymetric surveying was originally considered the most likely application. Harbors, rivers and developed port facilities, with depth requirements of far less than 200 feet, comprise a sizable portion of the surveying business, perhaps 28% [2], and present a moderately challenging physical environment for AUV

operations. Additionally, in the post 9-11 world of enhanced interest in sub-surface security that is increasingly encouraged by US Coast Guard mandates, the interest in physically inspecting bulkheads, ship hulls and all nature of underwater structures expands the is dangerous and costly, and often requires a lead-time notice to arrange. If a low-cost, man portable, simple-to-use AUV with side scan sonar and video capture capability existed, it could need and opportunity for technology-assisted data collection methods in the near-coastal waters. These charting, basic hydrographic, and now security and surveillance missions are primarily conducted by small, local businesses who are focussed on cost-efficiencies in both tools and methods as a means of differentiating themselves from competition. Additionally, putting divers in the water be a great first tool in search and rescue or other marine survey missions where soundings are needed.

III. DESIGN OBJECTIVES

Viewing the AUV as a ‘truck’ to carry sensors, with a submersible Personal Computer to log data and ‘drive’ the AUV, helped to keep things simple, and to keep our development team focused on radically improving the cost dynamics usually associated with the historically tiny market for multipurpose small AUVs. By focusing on the likely missions, and more specifically on the likely higher-volume missions, unnecessarily complex and costly elements of the AUV could be re-spec’d to accommodate available commercial high-volume components.

After discussing potential applications with front-line contractors, the following minimum specifications/ goals for system and component functionality were developed.

A. Displacement

If the vehicle can be made small enough, it can be deployed and retrieved by a single person, either from shore or from a small boat. The US Navy has a minimum sized AUV (UUV) category called ‘Man-Portable’, defined as less than 100 lbs. displacement, but we see that as far too large for the sensor load and duration of a useful near-coastal vehicle [3]. Our displacement target was set at <50 lbs.

B. Weight

Size and weight necessarily sync up in a neutrally buoyant vessel, determining the ease of physical handling by the operator. With sensor and vehicle electronics of a few pounds and sensor payloads of a few pounds more, the current ‘small’ AUVs are far larger than needed. Even considering the improved stability of slightly larger vessels, the trade-off of handling ease, and reduced power consumption and associated complexity, favors minimizing weight.

C. Battery Power

Re-chargeable high-performance batteries, preferably with ‘charge state status’ that can be monitored in real-time to optimize vehicle in-service time, or to assist in prioritizing missions.

D. Mission Duration

A Run time without re-charging of greater than 8 hours to cover a typical workday without service.

E. Speed

3 - 4 knots (1.5 -2m /s) for surveying.

F. Simple Navigation

GPS, Compass, ded (deduced) reckoning, with acoustic fixes possible for special operations.

G. Vehicle Control

Enhanced low-speed control (better system than traditional fins) for use at slow speeds or in confined spaces.

H. Operating Depth

100 - 200 feet, targeted at harbor, coastal and lake waters.

I. Acquisition Cost

Low acquisition cost - standardized, simple, mass-producible design. Contractors have historically frowned on using ROVs / AUVs for cost and complexity reasons. Assuming potential market volume is elastically tied to price, AUV must be at a price point well under \$50,000 per unit.

J. Operating Cost

Low operating cost - functional, robust, operator maintainable, to encourage multiple-vehicle operations as force-multiplier (Networking or Swarming)

K. Sensor Payload

Integral sensor support for Compass, Side scans Sonar, Echo sounder, Pressure transducer, Low-light cameras, Local Telemetry (Wireless Ethernet).

IV. DESIGN CHARACTERISTICS

A. Electronics

A full featured low-power (X86) CPU Computer and other functional modules in PC104 form factor (3.6” x 3.8”, plus perimeter for cabling) minimizes the internal envelope while still using commodity components.

Commercial devices such as cameras and digitizers (from the Surveillance Industry), Radio Links (from office Wi-Fi) Echosounders (from recreational boating) and many other useful devices all have small outlines, standardized serial data outputs and minimal power requirements. Most add-on devices have full driver support in WindowsXP, whereas other operating systems have only a limited selection, including Linux.

Batteries and power management modules. OceanServer already produces a variety of Batteries and Battery Controllers in the PC-104 format. These were designed for embedded OEM applications, that are often housed in small or irregular enclosures.

B. Hull Configuration

When a complete set of solid models for the system

components was manipulated in SolidWorks™, a cylindrical vehicle hull, with an internal diameter of 5” to 6” was achievable. The selected inside diameter (ID) of 5.5” allows enough flexibility for varying battery and electronics combinations without including undue extra space that would require additional ballast in minimal vehicle configurations.

The length of the center tube, which houses the batteries and the electronics needed to be slightly over two feet in length for a vehicle that met all the design objectives. This length can be adjusted longer or shorter based on the battery power required or optional sensor configurations, without affecting the bow or tail sections.

The bow and tail sections were designed to comply with the Myring Hull Contour. This approach yielded an over-all length of 48 inches (less propeller), and a volumetric displacement in saltwater of just under 44 lbs (20 kg.). This is an easily handled size, and well within the weight objective for a ‘Man-Portable’ AUV.

V. FUNCTIONAL COMPONENTS

A. Battery Power

A scalable battery power system based on the OceanServer MP-08, DC-023 and DC2U-1V was designed into the vehicle. These components allow an integrator to add rechargeable Lithium-ion battery power to any device with very little engineering effort. The subsystem has integrated smart battery chargers and manages all of the safety policies for the Lithium-ion battery packs.

A new Lithium-ion Smart battery pack, the BA95HCL-FL, that is long and skinny, was introduced by OceanServer to improve the use of space in the cylindrical center tube of the vehicle. The new pack, containing 12 each, 3.6 volt, 18650-size cylindrical rechargeable Lithium-ion cells, provides 96 watt hours of power, is 0.8 inches x 2.25 inches x 11.75 inches in size, and weighs 1.45 lbs.

The power subsystem creates the required 24 VDC for the propulsion motor using one super high-efficient DC2U-1V Voltage Regulator Module. To supply the CPU and sensors with regulated 3.3 volts, 5 volts, +12 volts and -12 volts, the system incorporates one DC-023 converter module.

All regulated voltages are derived from the Li-ion battery packs nominal voltage of 16.0 – 11.5 volts DC by super-efficient converters (up to 98%) to minimize excess heating which can only be removed from the vehicle by thermal convection through the hull skins.

The base vehicle will contain 6-8 of the Smart battery packs, for a total power of < 760 Watt Hours. This will power the propulsion motor and likely sensors for over 10 hours, which exceeds the targeted time goal.

Recharging of the batteries can be completed in 3.5 hours with an external 18 volt DC source, derived from AC, or a Ship’s 24 volt power.

B. Propulsion

A high-efficiency Brushless DC motor is used to power the vehicle. The motor has an integrated motor control electronics element, and was developed for a high-volume, high-reliability commercial application. It runs on 24 Volt DC, and consumes under 20 watts of power when propelling the vehicle at about 3 knots.

C. Vehicle control

Fin: Four Airfoil fins, computer generated to a NACA 0012 design profile, are used for the basic control of Yaw, Pitch and Roll. These control surfaces are independently driven by four linear actuators, to allow the vehicle control software to split the vertical and horizontal planes for active attitude compensation of varying amounts of roll tendency induced by the propeller at different speeds. This ‘active roll compensation’ is a feature of the mission control software, based on input from 3-axis accelerometers contained in the digital heading compass/ attitude sensor.

Bow Thruster: The bow section of the vehicle includes a ‘bow-thruster’ of similar design to those used increasingly throughout the Marine Industry to control boats and ships in tight quarters. This very small bi-directional pump provides enough force to turn the vehicle at zero velocity. This feature enables the vehicle control software to supplement the forces applied to the fin surfaces at low speed, which significantly improves maneuverability, and thus allowed the mechanical designers to minimize the surface area of the fins and still meet the design objectives.

Center Tube Equipment Rack: The vehicle’s CPU module, disk drive, sensor control modules, GPS, WiFi link, digitizers and power subsystem are mounted to an independent equipment rack that can be operated outside of the vehicle when cabled to the bow and tail section and any sensor payloads. This simplifies user configuration, and allows for accurate physical alignment of this relatively heavy component. The rack is approximately three inches shorter than the center tube, and once initially positioned and fixed in place, can be moved +/- one inch within the tube to slightly change the center of gravity for the vehicle, and thus change the relationship between the center of gravity (CG) and the center of buoyancy (CB). Even small changes in the ‘for’ and ‘aft’ CG/CB relationship have proven to enhance the vehicles ability to dive or return to the surface.

The center tube has independent o-ring sealed plates at each end to protect the expensive electronics from water damage caused by a failed seal between the hull sections or within the bow or tail sections. Less than \$500 of water-sensitive components resides in the bow or tail, and these can be removed and replaced easily with minimal hand tools.

Fin-less control: Future development will focus on using these two ‘supplemental’ vehicle control methods to replace the fins in a simplified AUV design.

D. Sensors

The focus of the new development was on the vehicle 'truck', rather than on the sensor payload. The assumption was made that the End User will select appropriate sensors beyond those required to control the vehicle. A variety of proven small, low-power sensors, with serial data outputs, are available (YSI, RDI, Nortek, Airmar, TriOS, Chelsea Instruments, Falmouth Scientific, B-Tech, Benthos, and others).

The initial spec-compliant vehicle includes the following sensors:

- Side scan sonar, dual frequency, 300KHz/ 800 KHz
- Echo Sounder (Height off Bottom)
- Pressure Transducer (Depth from Surface)
- Cameras (IR Low-light, or Low-light color, both video capable)
- Differential GPS (One foot antenna)
- Compass (Includes attitude sensor)

Electronics:

The Underwater Vehicle Control software is incorporated into the MissionP software, which runs on a low-power X86 CPU, under the MS Windows XP™ Operating System. The base CPU runs at 1Ghz and has 512 MB systems memory, and an 80 GB SATA Disk, which primarily support data logging for the onboard sensors. The Battery/ Power Subsystem contains its own microprocessors at several levels, which enforce redundant safety policies, and provide management data to the event monitoring features of the Underwater Vehicle Control program.

The power consumption goal of the design, for the computer and electronics load, was 20 Watts in a typical 3-knot survey operation.

Communications:

The primary method for loading missions and retrieving log data is via a wireless connection when the vehicle is on the surface. The AUV is equipped with an IEEE 802.11G Wireless Ethernet transceiver for a 108 MB/s data path to a transceiver up to 600 feet away on the support vehicle. Low-cost data disks, with capacity of <160GB can log more data than the vehicle will collect in a typical day, so the need for real-time transfer is eliminated in most cases, in favor of a high-speed file transfer once the Iver 2 has completed a days work.

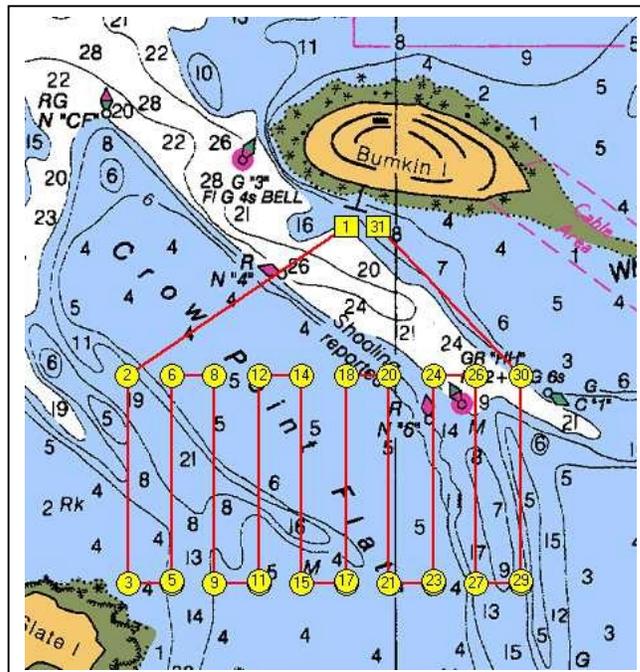
Alternatively, the vehicle can support an acoustic modem, or even a satellite telemetry system such as an Inmarsat C or a Globalstar satphone link, though these methods are considered beyond the requirements of the initial Iver 2 missions.

VI. SOFTWARE

The software suite for the Iver 2, consisting of the Underwater Vehicle Control program and the mission planning MissionP software, are written in Visual Studio, layered on top of Windows XP™, and are designed to be easily extensible to meet applications needs. The MissionP planning software presents an intuitive GUI that allows the operator to design

missions quickly, and extract completed data files for end-of day post processing. The primary function of the MissionP software is to collect sensor data and organize it in an intuitive way for future sorting and analysis.

The Underwater Vehicle Control program directs the Iver 2 movements by way of a mission file that contains the (Latitude/ Longitude) waypoints as well as the commands and parameters for each waypoint. The program uses a standard chart data file in NOS/GEO format and allows the user to plot geo-referenced missions using NOAA charts. These raster charts can be purchased from several online companies including www.thecapn.com Softcharts.



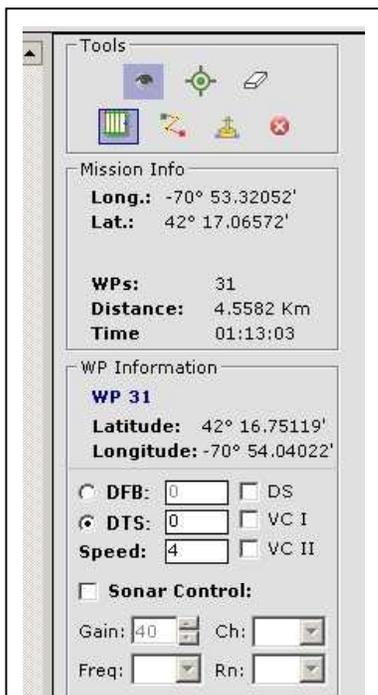
Screen shot showing mission planning feature

The MissionP planning software allows for the creation of waypoints that can be dragged around the screen, to create routes or lawnmower sweeps of an area. The control panel lets the user select the vehicle operating parameters such as speed and depth, and to control the sensor instruments such as the video cameras and the side scan sonar data collection rate.

Large surveys can be pre-designed using the MissionP planning software, which creates a series of instructional files that can later be loaded onto the AUV(s) and executed. The operator can graphically view the whole survey, or divide it into smaller missions, partitioning the work between several runs of a single vehicle or between several Iver 2 vehicles operating simultaneously. Large surveys can be designed and accomplished more quickly. The software allows the operator to integrate data from multiple runs or vehicles, and to open an existing mission file for editing and updating.

The MissionP planning software also allows for the placement of acoustic surface buoys on the chart in the survey

area, and will integrate the position and time schedule of collected data into a common mission file format. All data points are shown in LAT/LON coordinates when editing. After highlighting a waypoint on the screen with the PC Mouse, the operator can delete it, edit its location by dragging it to a new location, or insert a new waypoint. The waypoint data for operating parameters can also be seen in the control box and parameters can be easily edited. This includes the side scan sonar parameters or photo/video parameters for this waypoint.



Screen shot of Sensor Configuration Screen

The MissionP planning software creates an actual mission data file that can be uploaded or downloaded as images to/from the Iver 2 vehicle. The commanded mission, as well as the actual LAT/LON track that the vehicle ran on while operating, is graphically presented on a chart of the survey area. The vehicle logs the video data from up to two cameras and this data can be viewed and located by closest image to this LAT/LONG on the map. This feature makes it easy to correlate video images when conducting a search or survey.

VII. SYSTEM TESTING

Hardware and software testing is independently ongoing to validate design assumptions and firm up the intended specifications. Initial tank-tests and simulated missions run in protected free-water have validated many aspects of the initial Iver 2, while highlighting areas for further improvement. The goal of making the Iver 2 robust enough for integration into the harsh environment of the real world, and insuring a long service life, justifies continued exercise and thorough fixes for the issues that arise during validation.



Photo of Iver 2 prototype during free-water testing

VIII. ECONOMICS AND CONCLUSIONS

The business model for the sale/ distribution of the standardized base Iver 2 AUV ‘Truck’ is focussed on supporting or partnering with Systems OEMs and/or Service Providers who have the operational expertise and on-site resources to deploy the vehicles in real world applications. For Iver 2 to become commercially viable, it must do simple tasks in an intuitive way for a reasonable service period, and be maintainable and/or repairable by the personnel and resources that are on the job site. The initial entry must ‘work as advertised’.

Advanced or specialized features can be considered in the future, but market viability almost certainly depends on the current vehicle achieving the design goals specified at the beginning of the project. However, since much work has been done over the years in the areas of vehicle control, surveying techniques, intelligence-based navigational algorithms, underwater docking, underwater data transfer and recharging, and multi-vehicle swarming, the Iver 2 was developed to readily accept data from existing control programs and map these commands to the on-board systems.

The Underwater Vehicle Control Program and the MissionP planning software have been in development and validation for 30 months. The Iver 2 hull, a follow-on to a tiny (22 inch, 14 lb.) experimental Iver 1, has been in development for 18 months.



Photo of the original Iver 1 vehicle during tank testing

The target price for the Iver 2 AUV with basic navigation and data-logging functionality (without side scan sonar) is \$15,000 to \$20,000 in OEM volumes. This low price reflects the developers' intent to have Systems-level OEMs and VARs purchase the basic Iver 2 vehicle, and then add their value in the applications space to form a complete system-level solution. The developers are anxious to identify early adopters (research, commercial or military) who are willing to participate in ruggedizing the Iver 2. Availability is planned for late CY 2005.

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