Design Challenges of a Next Generation Small AUV

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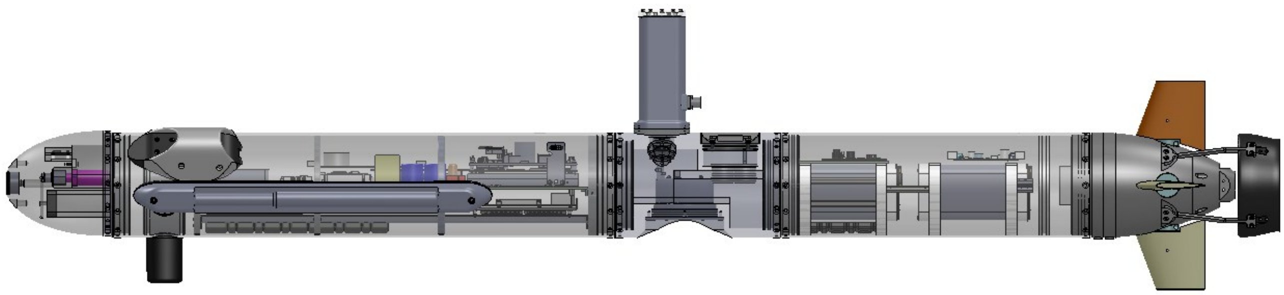

***Abstract*—The Iver3 AUV is a next generation Lightweight AUV system based on hardware and software proven in the Iver2 AUV that has now been operational in the field for several years. Many of the design challenge result from the very small hull with an inside diameter of 108mm or 140mm. The Iver3 design goals included increased battery system energy, increased propulsion power while reducing drag, and reduced electrical and magnetic noise interference – all packaged into a small modular hull structure.**

The resulting Iver3 incorporates a custom battery sub-system design in a dedicated hull section that allows the operator in the field to replace depleted batteries with a fully charged second battery section in minutes. This custom Li-ion battery sub-system, coupled to custom DC-DC convertors, provides super high-efficiency power generation. It can be fully charged in half the time as the Iver2 battery design and a second battery hull section can be changed in the field in minutes between missions. The Li-ion packs provide 150% of the energy density of the Iver2 by using the latest cell technology. The Iver3 battery cluster design allows the system to be classified as NON-HAZARDOUS GOODs, avoiding customary US DOT and IATA restrictions, and simplifying shipment as air freight on UPS, FEDEX, etc. All of these improvements fit in the original 147mm OD hull and a new smaller 114mm OD hull.

The design goals and the resulting component specifications of Iver3 AUVs are reviewed.

Keywords*—*AUV; UUV; sonar; small underwater vehicle

I. Introduction

The OceanServer Iver2 AUV platform has evolved and improved over the last several years of its productions. The next generation platform design was started over a year ago and has led to the Iver3 AUV platform. The redesign was a 'ground up' effort incorporating all of the proven Iver2 hardware options and software, with the operator feed-back from thousands of field operating hours. The effort focused on improving the system packaging scheme, and redesigning some critical system components in the latest technology.

The Iver3 platform comes in two hull diameter variants, 114mm (4.5") and 147mm (5.8"), named the Iver3-450 and Iver3-580 respectively. The smaller vehicle has been running in field test for the last 3 years waiting for appropriate sonar and DVL technology to shrink to fit this tiny hull. The larger 147mm hull is the existing Iver2 standard dimension. The Iver3-580 maintains the same tube and tube interface to make the transition simpler.

The most important design goal of the Iver family of AUVs is to keep the displacement weight as low as possible while meeting the design requirements. The displacement weight grows proportional to the square of the hull radius. The vehicle weight grows very quickly as the hull gets roomy enough for standard electronic systems. Table 1 shows the displacement weight vs. hull outer diameter for a 1.5m long vehicle. The Iver3-450 with a very small 114mm diameter hull would weigh 15 kilograms while the 147mm diameter hull will weigh 26 kilograms. In contrast a vehicle with a 190mm diameter hull would weigh 44 kilograms.

TABLE I. WEIGHT OF A 1.5 METER LONG VEHICLE VS HULL DIAMETER

Hull Diameter (mm)	Vehicle Weight (kgs)
114	**15**
147	**26**
190	**44**
305	**111**

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533	**340**

The benefits of being small and light come in many areas. The logistics become one man and no boats with a resulting low operating cost and fast operational tempo. Very light vehicles such as the Iver3-450 cost two orders of magnitude less than very large vehicles to purchase, giving them a manageable cost for insurance during operations. Another non obvious feature of very low mass is that the vehicle is not a 'hazard to navigation' for other vessels operating in the area, nor is it likely to sustain significant damage if struck by a passing boat.

A. Platform Design Goals

The design goals for the Iver3 platform that differ from the Iver2 are summarized in the following section.

I. VEHICLE MODULAR PACKAGING SCHEME

The Iver3 designs have a new hull structure that provides a logical partitioning of the system components.

- Sensitive electronics such as compasses and gyroscopes should be in the front of the vehicle.
- Sonar and other electronics should be toward the front and near their transducers with clean wire routes between the devices.
- Electro-magnetically noisy devices, such as switching power supplies, should be moved toward the back of the vehicle along with magnetic objects such as battery packs.
- The vehicle should break into two parts for shipping in very small reasonably sized cases, <50 pounds each.
- Packaging should support field removable disk drives for extracting at least 256GB of sonar data in seconds and replacing it with an empty device.

II. BATTERY SUBSYSTEM

The battery system of the Iver2 is being modernized using custom controllers and smart battery packs incorporating the highest energy density li-ion cells.

- Increase the energy density by 50% and improve the total capacity in Watt-hours by 50%
- Reduce battery to controller wiring by attaching the battery controllers directly to battery packs
- Support field swapping of battery bays with fully charged spares
- Create a single NMEA string for monitoring battery status.

III. MAIN CPU SPECIFICATIONS

The Iver2 CPU is a semi-custom design based on the Intel Atom Z530 single processor chip. The Iver3 platform should build a CPU that has forward looking specifications.

- Improve disk capacity and performance by 300% while removing the cables
- Increase the CPU performance by 200% (dual core) and main memory by 400%
- Support high speed native IO; 10/100/1000 Ethernet, USB 3.0
- Provide passive cooling in a smaller footprint

IV. PROPULSION MOTOR AND CONTROLLER

The Iver2 system uses an integrated smart motor and controller. The goal of the Iver3 system is to design a custom smart motor controller module that can be used across the full family of Iver3 vehicles and motors.

- Design a single motor controller module that can drive a range of brushless DC motors from 50-250 watts.
- Support NMEA strings for commands and reporting motor status and RPM in real time.

V. SMART LEAK DETECTOR

Design a very small low powered circuit that can measure the resistance of several locations and detect leaks with a low false positive rate.

- Provide an accurate measurement of water present at several sensors to help avoid any false leak reports.
- Operate on very low power (1mW) supporting a master detector and other modules reporting distant leaks via a single shared wire.
- Report status to the host in a NMEA style message.

VI. MECHANICAL IMPROVEMENTS

There are several general considerations to make the Iver3 perform better than the Iver2 that need to be considered.

- Reduce the drag of the hull and appendages to increase mission duration.
- Improve the shaft sealing for propulsion and fins to reduce the service schedule.

B. Platform Design Results

Details of the changes to the AUV system that were adopted following the design process, are discussed in the following section.

I. VEHICLE MODULAR PACKAGING SCHEME

The Iver3 platform will be offered in two diameter hulls, Iver3-450 (114mm OD) and Iver3-580 (147mm OD). A design goal of all Iver3 platforms is to be one man portable so the displacement and resulting weight are critical factors. The weight of a typical Iver3-450 is in the 15 kilogram range and the Iver3-580 is in the 26 kilogram range. The Iver3 battery system supports swapping out a discharged pack with a spare pack. The spare packs can be charged independent of the operating AUV in about 4 hours.

Typical payloads include very sensitive electrical equipment such as interferometry sonar that benefit from quiet environments. In the Iver3, noise reduction is accomplished by the modular nature of the Iver3 design. Devices such as motors and DC-DC converters that generate radiated and conducted EMI noise and battery packs and motors that generate magnetic fields are placed in the back of the vehicle. Radios and DVLs are placed in the mid-section, and sensitive electronics and sensor are located in the front section. The nose cone (bow section) is for the most sensitive devices, compasses and FOG gyros, both very negatively affected by magnetic noise.

The five modular sections of the Iver3 are;

- Nose cone; compass, gyro, INS
- Front section; electronics are mounted in this tube section with sonar transducers entering the hull forward to avoid picking up switching noise.
- Mid Section: Antennas, user access port for sonar disk and charging power – also keyboard and monitor access for software install or de-bug.
- Battery Section: This section holds all of the small smart battery packs. The DC-DC switching supplies and motor controller is housed here. Filtered DC is bussed to the front section. The motor controller is mounted here.
- Tail: This includes the propulsion motor, prop shaft and seals, and the servos/shafts/seals for the fins/control surfaces.

The Iver3 AUV is broken down into two sections between the Mid and Battery sections for shipping. The modular cable scheme automatically disconnects the battery packs for shipping. The two sections fit into small rugged cases that weight less than 60 pounds. The Iver3 systems support the 2013 IATA guidance for shipping lithium ion battery based systems (UN 3481) that allow properly labeled Iver3 cases to be shipped as air packages on carriers such as FedEx, UPS, and DHL.

II. Battery Subsystem

In order to meet the requirements of the battery system we had to select a new battery pack based on the latest 3.4AH li-ion cells. We developed the BC1123 next generation battery controller module that attaches to a pair of battery packs. The function of the controller is to manage all safety, charge and discharge functions, and provide status reporting for 32 parameters from each battery pack. In a system with 12 battery packs we use 6 of these controllers. The controllers operate in a network arrangement where the last controller sends the NMEA status strings to the AUV's main computer.

- Each battery pack provides 14.4V, 99Whr, at a 8A discharge rate and meets UN IATA shipping rules.
- Each BC1123 dual battery controller charges from 24V DC, and has detailed control parameters to limit charge.
- Each AUV will have a spare Battery Section that can be charged away from the vehicle and swapped for a discharged Battery Section between missions in the field.

Figure 1 Battery Controller and two battery packs

III. Main CPU Specifications

The Iver2 is based on an Intel Atom Z530 (Haswell) processor with a single core. For the Iver3, we chose the Intel N2600/N2800 processor (Cedarview) which provides a dual core processor at about the same power consumption. The NM10 express chipset provides the PCIe bus, serial ATA disk busses, USB 2.0 ports and a DDR3 memory interface that supports 4GB of main memory. The largest form factor that would fit in our smallest vehicles is the PICO ITX measuring 10cm x 7.2cm, which is 20% smaller than the PC/104 form factor.

The extra I/O required by the Iver3 system, mainly 16 serial ports, a pair of USB 3.0 port, and the C8051 supervisor processor, were added to the PCIe bus along with a set of connectors that let the CPU plug directly into the system backplane with no wires. Detailed specs include:

- mSATA solid state disk supporting up to 500 GB of very fast storage.
- 18 serial ports (RS232, TTL, RS485)
- Eight USB 2.0 ports and two USB 3.0 ports
- Native 10/100/1000 Ethernet
- CPU subsystem power consumption of less than 10Watts

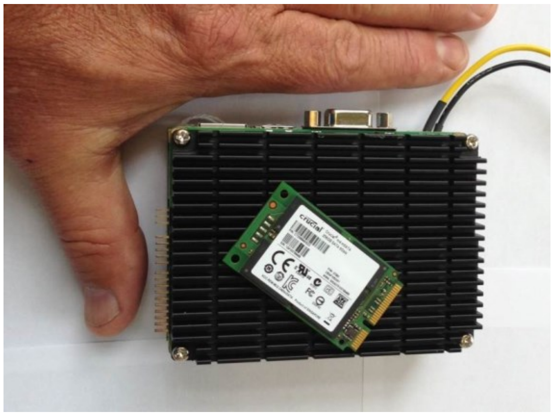

Figure 2 – Main 2 Core CPU and 256GB mSata SSD

IV. PROPULSION MOTOR AND CONTROLLER

The Iver2 system uses an integrated smart motor and controller. A new motor controller design was created for the Iver3 to allow greater flexibility in selecting a correct motor for each platform. The new smart motor controller connects to any brushless DC motor with hall effect sensor and drives the motor. The motor controller operates from a 48V DC input supply and a 5V logic supply. The controller can provide 10Amps @ 48V for about 500W peak power to the motor, continuous power is rated at 250W.

The motor controller communicates with the system via NMEA strings that report the commanded velocity and the measured RPM of the shaft along with error status such as hall sensor failure or overtemp conditions.

A custom propulsion motor was designed for the Iver3-580 vehicle that delivers 180 Watts maximum power. The motor can be built in a larger stack providing 360 Watts of power for special applications where high vehicle speeds are required.

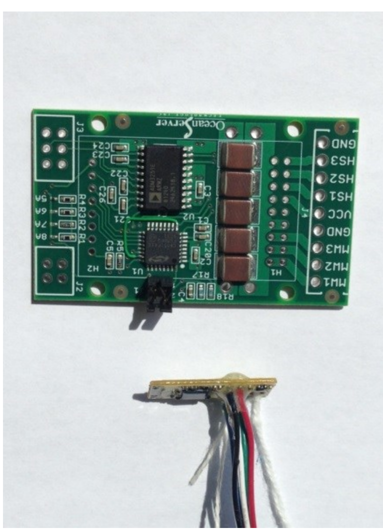

Figure 3 Smart Motor controller and Leak Detector

V. SMART LEAK DETECTOR

The smart leak detector module is based on a C8051 microprocessor that draws under one mili-Watt of power. It measures the resistance between four sets of gold pads to detect if a fluid is present. The firmware is configurable to set thresholds for reporting a leak. The device is very robust and accurate.

The smart leak detector is connected to the AUV main computer via a serial link and reports a custom NMEA-like message every second with the error status. This allows the system to know that the sensor is connected and reporting status.

The leak detector can also operate in slave mode, allowing several additional leak sensors to be placed in the system. The master will report the slave status in the standard NMEA message.

VI. MECHANICAL IMPROVEMENTS

The most significant mechanical changes between the Iver2 and Iver3 platforms have been to the design of the pressure vessel. The list of major changes are:

- Nose: Mounts the compass, pressure transducer, gyros and INS. This is the area least influenced by noise and magnetic disturbances.
- Front Section (Forward Tub): This section is used to house all of the electronics - mounted on a mid-plane circuit board.
  - This eliminates 90% of the cable wiring used on the Iver2 system.
  - The sonar transducers mount on the outside and sensitive cables enter the vehicle in the front (away from switching noise) and directly plug into the sonar control board.
- Mid-Section: This section has the antenna, and the access bulkhead for user I/O ports.
  - The top feature is the sonar recording disk is in this area and can be swapped out in seconds taking 256GB of data off the vehicle.
  - The vehicle charging port is in this section and supports up to 400W of input DC charge power.
  - Access to attach a monitor and keyboard/mouse is provided for operations such as operating system update.
- Battery Section: The battery section can be removed by the user. In many cases a spare tail and battery bay is purchased. These can be charged away from the vehicle and used to swap out a spent battery after a completed mission.
  - This hull section includes all of the switching power supplies and provides filtered DC power in a variety of voltages to the rest of the vehicle.

- Tail Section: Contains a selection of new Brushless DC motors and propellers matched to the application.

C. Conclusions

The Iver3 goal was to create a top down re-design of the Iver2 AUV system that added improvements to the Iver2 system in many areas. The goal of moving to a new power and packaging design without increasing the over diameter of the hull proved to be the most challenging. The momentum of smart phone designs has driven all of the electronics to new levels of tiny sizes with very high quality and reliability expectations. The Iver3 was executed very quickly meeting or exceeding all of our performance and capacity goals.

In the design process we took great care to move the design parts and technologies that worked well forward and only change things that the risk outweighed the benefits. One example is the CPU design; we used the same PCIe serial port controllers and driver that have been running on the Iver2 CPU for 4 years and just moved the hardware block forward to the latest Intel Atom CPU member. This overall strategy

The greatest challenge in building AUV's in the 15-50 Kg ranges if convincing sonar manufacturers to build control electronics in this very small envelope. We now have system from four sonar manufacturers integrated into these very small hulls including three bathymetric sonar systems. The Iver3 family of systems has exceeded our design goals across the board.

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