

Hardware Architecture for a Modular Autonomous Underwater Vehicle STARFISH

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Abstract- The use of Autonomous Underwater Vehicles (AUVs) in various research, commercial and military applications has significantly increased in the recent years. Most AUVs available commercially tend to be complex and very expensive. With advances in recent technology, sensors with new functionality or lower cost substitutes have become available. Most existing AUV platforms do not facilitate easy integration of new or upgraded sensors. A solution to this problem is to have a modular AUV system with changeable payload sections capable of carrying different sensor to suite different missions. Modular AUVs are exceptionally useful in group mission scenarios with different AUVs carrying different sensor payloads. By having a team of modular AUVs, payloads can be easily interchanged between the AUVs to configure the team for various missions. Modular AUVs require their sections to be electrically and mechanically compatible with one another.

At the Acoustic Research Laboratory (ARL) of the National University of Singapore (NUS) we have built one such modular open-architecture AUV called STARFISH. It has both software as well as hardware modularity. The hardware architecture for STARFISH has been designed to achieve a common electrical and mechanical interface between the different sections thus providing a plug and play capability between them. A general electrical architecture has been defined for all AUV sections in order to achieve electrical modularity. Employing this general architecture, individual sections have been tailored according to their functionality. The architecture has been implemented by using a combination of micro-controllers and single board computers which communicate over Ethernet. A distributed power architecture has been defined to allow AUV sections to contain power sources. STARFISH has a power management unit which manages the power distribution, charges batteries and provides emergency power cut offs. By using Ethernet and a common power bus system a common electrical interface between the AUV sections can be achieved. STARFISH also has advanced emergency safety systems consisting of leak sensors, emergency micro-controller capable of operating a GPS/GSM device, a pinger and a strobe.

In this paper we describe the detailed architecture of the electronics system for STARFISH AUV. The benefits of modular hardware and its advantages in developing and integrating newer sensor payloads with the base AUV are shown. The modular electronics system for STARFISH AUV has been implemented and currently being tested.

I. INTRODUCTION

Over the past few decades AUVs have matured from research and experimental vessels to commercially available systems. Commercially available AUVs are expensive and complex. Most AUVs are single hull systems with centralized electronics. With advancement in technology, newer sensors have been developed for a variety of operations which can be integrated in AUV systems. With single hull AUVs it is not easy to integrate newer and upgraded sensors without making significant changes to the mechanical and electrical systems. This has given rise to interest in modular designs for AUVs.

Modular AUV structures in hardware as well as software have significant advantages. Modules for different sensors can be made and interchanged to configure the same basic AUV for different missions. With a team of such modular AUVs, configurable sections can allow the user to setup the team for different group missions as per requirements. In case of failures, individual sections can be easily replaced and debugged, which significantly reduces down time.

At the Acoustic Research Lab (ARL) of the National University of Singapore (NUS), a open-architecture modular AUV “STARFISH” is being developed [1]. It is a multi-section AUV with individual sections being electrically and mechanically modular but compatible. Mechanical compatibility has been achieved by using a locking teeth system. Electrical compatibility has been made possible by having a standard communications interface and power interface between sections. A standard AUV electrical section is capable of individually acquiring and processing data from the sensors in the section. A section also has total control over the actuators attached to it. Different sections of the AUV can communicate with each other over Ethernet. Most communication takes place using raw Ethernet packets as this is extremely light-weight and can be implemented on micro-controllers without a TCP/IP stack [2]. A centralized single board computer in the AUV’s central section runs the configuration server which provides the Micro-Controller Units (MCUs) in different sections with initial configuration for the sensors. The computer also runs a logging server to which the MCUs log the acquired data. The single board computer also runs the positioning, navigational and command and control algorithms in the AUV. In order to provide compatibility between modules, a power distribution architecture has also been defined. Sections which have

batteries contribute to a central power pool from which power is distributed to electronics in all the sections of the AUV. STARFISH also has a number of safety systems in case of emergency.

In this paper we describe the electronics and power architecture developed for STARFISH and elaborate on its implementation in STARFISH. We also describe the advantages of such an architecture with examples of its use in STARFISH.

II. BACKGROUND

Most existing commercially available AUVs and research AUVs that exhibits modularity design are generally large in size, such as Hugin [3] and Urashima [4]. Electronics components and systems are sealed in multiple watertight hulls and interconnect through a number of underwater cabling. Such design methodology utilizing multiple watertight housings is difficult to employ in small AUVs. AUVs like REMUS [5] offer small size and a semi-modular structure which is configurable in the factory but not in the field. Another such small size AUV is Maya [6] which is not modular. Having a modular AUV design with a base vehicle and inter-changeable mission-dependent payloads will greatly reduce cost. Modular hull design also allows quick replacement of malfunctioning hardware and debugging. The use of multiple AUVs in group missions is also rapidly becoming a reality. Another commercially available AUV - GAVIA [7], offers a wide range of sensor payloads which can be attached to the base AUV. However most commercial AUVs are not open architecture.

Modular AUVs need to have a standard electrical interface between modules. Also the number of interface lines is to be kept minimum for ease electrical wiring and development of newer payload sections. The architecture discussed in this paper has been used in STARFISH AUV to achieve electrical compatibility between its sections and to provide ease of development for newer modules.

III. THE STARFISH VEHICLE

The STARFISH AUV is a torpedo-shaped small AUV as shown in Figure 1. The basic AUV is 1.7 m in length and the final length can change depending on the payload sections attached. A typical payload section is 0.25 m in length. The AUV has a diameter of 0.2m. The AUV is marginally positive buoyant, enough to keep the RF communication antenna above water surface during surface operation.

STARFISH is a modular AUV. Each section of the AUV has a standard mechanical interface for inter-module connection. The mechanical interface consists of a custom designed interlocking teeth arrangement to provide mechanical rigidity and two piston O-rings for water tightness.

STARFISH has three basic sections consisting of the Nose, Tail and Command, Control & Communications (C3) sections. In addition to this, the AUV has additional payload

sections which can be added or interchanged as per mission requirements. For better navigational accuracy, the STARFISH AUV has an optional advanced navigational payload section which houses the Doppler Velocity Log (DVL) for better vehicle velocity estimate.

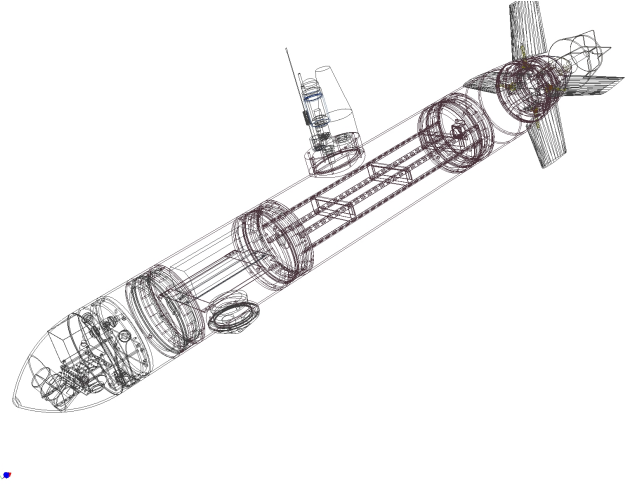


Figure 1. CAD drawing of STARFISH

The AUV uses a single main thruster for propulsion providing thrust up to 10 kg. The thruster is water cooled and connects to the hull through an underwater connector and is rigidly held by a clamp. Four control fins driven by servo motors are used for yaw, roll, pitch and depth control. A Forward Looking Sonar (FLS) is used for obstacle avoidance. The AUV also carries a number of positioning sensors which include an altimeter and a depth sensor. For navigational purposes, the AUV has an Inertial Measurement Unit (IMU), a compass, and a GPS receiver.

The nose contains two tubes for ballast weights to trim the AUV for optimum buoyancy and weight distribution. In case of emergency, these weights can be dropped by opening a hatch held by an electromagnet. The AUV is powered by a pool of Lithium Polymer batteries. The batteries, which contribute to most of the AUV's weight, are located at the lower half of the hull section in order to lower the centre of gravity and improve the meta-centric height. This provides good roll stability.

We can communicate with the AUV using the Acoustic Modem. When at the surface, Wireless LAN can be used for short range communications and a GSM link can be used for long range communications. The vehicle contains a number of leak sensors placed at key locations in the hull. If triggered, the AUV is powered off and an emergency battery is used to power only a small group of emergency devices like GPS/GSM, Pinger and Strobe. These devices enable the AUV to send its coordinates to the operator to aid in search and recovery.

The various sensors and actuators are distributed across sections based on their functionality and operational requirements. This is supported through the use of a distributed hardware and software architecture.

IV. ELECTRONICS ARCHITECTURE

A. Architectural Overview

A distributed electronics architecture has been designed and implemented in the STARFISH AUV. It defines a common section architecture as a guideline for implementing the electronics within each section. It also defines a common interface for electrical interconnectivity between sections. The interactions between sections are governed by the DSAAV software architecture [2].

1) Common section architecture

The common section architecture allows each section to have externally and/or internally mounted sensors and actuators. Individual AUV sections should be capable of acquiring data from the sensors connected to them, processing it and making the processed data available to the rest of the vehicle. Sections also have control over actuators integrated in them and provide software services for the rest of the vehicle to access actuators or sensors.

Each AUV Section has its own set of power converters which generate the necessary voltages required by the sensors and actuators from a central power bus. This allows a single voltage common bus to run through every section in the AUV. Individual AUV sections may or may not contain batteries. However it is recommended that each section carries nominal 48V Li-Po batteries with enough energy supply for its own consumption and optionally cater additional energy to supply pool that distributes power to the entire vehicle.

It is recommended that each section is neutrally buoyant and has a low central of gravity.

2) Common section interface

Electrically the sections are interfaced through a common hybrid connector containing low voltage signal contacts as well as high current power contacts. The common interface specifications define a power bus, an Ethernet backbone and a leak sensor bus. The power bus consists of three high current lines - a battery line, an electronics line and a ground line. The first connects all the battery packs into a common energy reservoir while the later supplies power to electronics from the reservoir. The Ethernet connection provides common communication platform in normal operation between the sections and between the various electronics modules. The leak sensor bus connects the outputs of all leak sensors across sections and triggers a power cut off when a leak is sensed.

3) Software architecture

The DSAAV has been implemented on STARFISH using Ethernet as the backbone [2]. Raw Ethernet packets are used to avoid the overheads of TCP/IP. DSAAV is a four-layer architecture. The bottom-most layer (IComms) provides an unreliable messaging service over the Ethernet communication backbone. The higher layer, called the RPC implements the remote procedure call semantic and uses the IComms

messaging service. The third layer consists of framework and sensors/actuator services implemented over RPC. These include core services like the health monitoring, logging and configuration. It also comprises of hardware drivers for sensors and actuators. The top layer contains the high level algorithms in the AUV for positioning, communication and command & control.

The DSAAV software architecture supports plug-and-play operations. The configuration server stores initial start up configuration of all sensors/actuators. The data logging server logs information from all the sensors and actuators. Algorithms running on various processors through out the AUV get data from the sensors over Ethernet through a Remote Procedure Call service (RPC).

B. Basic AUV Section

Every section of the AUV is capable of acquiring data from its sensors and controlling the actuators housed in it. Each section has a few basic electronics components to realize modularity. It has a MCU to communicate with the sensors over standard communication interfaces like RS232, SPI or I2C etc. The MCU acquires data over these interfaces and makes it available to the rest of the AUV over Ethernet. The MCU board also has an onboard temperature sensor to monitor temperature.

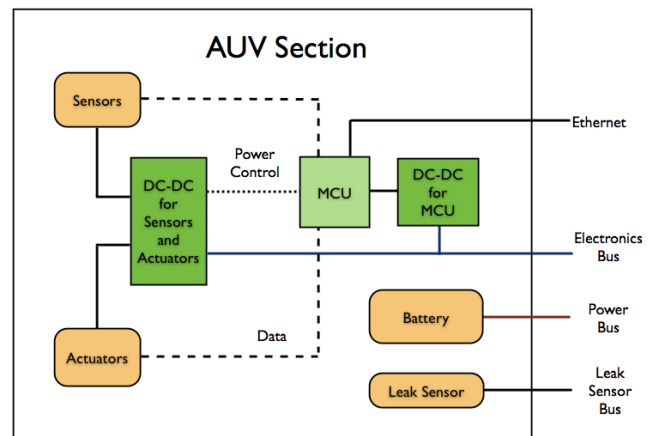


Figure 2. Basic AUV section

Each section has a set of isolated DC to DC converters which convert power from the main bus to voltage levels required by the sensors and actuators in that section. This provides electrical isolation between battery packs and electronics. The MCU runs on a separate DC to DC converter which does not have a control line and is powered up as soon as the AUV is switched on. The MCU has control over all the remaining DC to DC converters and provides proper power on and off sequences. Power supply blocks with COTS DC to DC converters and opto-isolated control logics have been designed for this purpose. The ability to control power allows the MCU to cut off any sensor or actuator in case of malfunction or to conserve power. Each section has a leak sensor which connects onto a central leak sensor bus. The different

components that are part of the basic AUV section are shown in Figure 2 and described below.

1) Micro-Controller Units

The MCUs used in STARFISH are based on the STR9 ARM core. A custom designed MCU board with support for 100 base-T Ethernet, I2C, SSP and UART interfaces has been developed. MCUs have on-board temperature sensors. The MCUs can be programmed over JTAG. A system for programming the MCUs over Ethernet has also been implemented to avoid having to dismantle the AUV section to update MCU code.

2) PC-104s

PC-104s may be used in sections that require computationally intensive processing. The central C3 Section has a PC-104 running Linux to process the data for AUV Navigation, Command & Control and Positioning. The PC-104 runs the configuration server and the logging server. The command & control software on the PC-104 communicates with the MCUs in different AUV sections and runs the mission. Missions can be changed and uploaded over Wireless LAN.

The PC-104 also runs a Health Monitor which checks the health of MCUs and other sensors/actuators connected to the AUV. This is useful in detecting malfunctioning components. Depending on the severity of a problem, a necessary action can be taken.

3) Ethernet Communications

In order for the different sections of the AUV to communicate, Ethernet is used as the standard interface. The use of Ethernet helps to keep the number of interface lines between sections to a minimum. Four lines are required for the Ethernet interface. As Ethernet is differential and is connected through a transformer it does not require common grounding between sections for data communication. This helps prevent formation of ground loops reduces electrical noise.

C. Power Architecture

The AUV uses Lithium-Polymer batteries as its main power source. The total power capacity of the base AUV is 1.3 KWh. The architecture is shown in Figure 3. Customized curved battery packs are designed to conform to the lower part of the AUV hull section. Each pack contains 13 cells with nominal operational voltage of 48V. The batteries have a short circuit protection system and a over-current protection system.

The AUV has two main buses which runs through all sections. Batteries in different sections get connected to a common bus when the sections are interlocked together. Power from all the AUV sections is available on a single 48V DC battery line. The electronics line runs through all AUV sections connecting the electronics from different modules.

The power switch consists of two high current relays controlled by control logics with a latch. A magnetic switch is

used to trigger the latch, which powers on the system by connecting the power bus to the electronics bus (see Figure 4). Apart from the magnetic switch, it can also be triggered by MCUs or the leak sensors during emergency situations. All AUV sections obtain power from the electronics line once the relay is switched on. This in turn powers up the MCUs and PC-104s in all the sections. The MCUs then power on the individual sensors in each section as necessary.

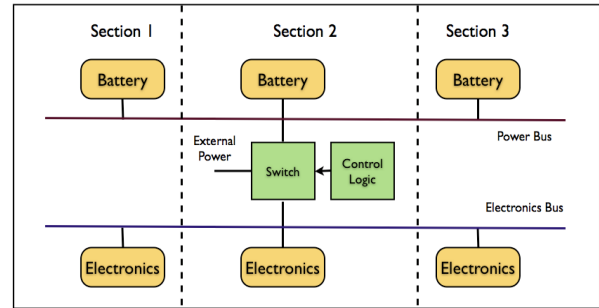


Figure 3. Power architecture

In each sections, isolated DC to DC converters convert the power into individual 5V, 12V and 9V DC as required by the sensors and actuators in that section. The DC to DC converters can be powered on or off by the MCUs through isolated digital control lines.

As all the batteries are connected on a single bus, they can be charged together. While charging, the power switch connects the batteries located in the hull to the external charger through a tether. A charge protection circuit prevents the electronics from being powered up accidentally during charging by isolating the power and electronics bus.

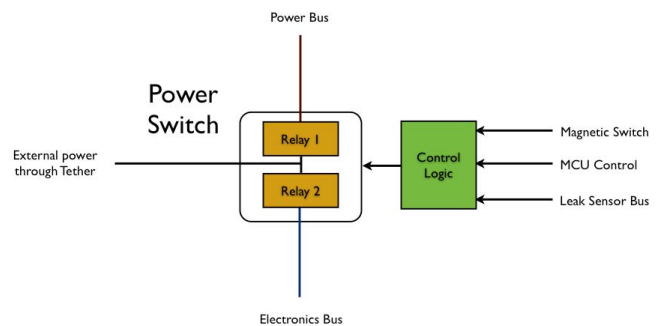


Figure 4: Power Control Logic and Switch

The charger provides a current of 15A at peak to the batteries. A positive temperature resistor, connected in series with every battery pack, prevents individual batteries from taking in excessive current in case one of the battery packs fail. A one-wire protocol driver on the MCU can be used to read the battery status of individual packs.

V. STARFISH SECTIONS

The STARFISH AUV currently has three basic sections and one optional payload section. The common section architecture has been implemented in all sections. The detailed architecture for the individual sections is described in the following sub-sections.

A. Nose Section

The Nose section has a dry and a wet compartment. The wet compartment is flooded and houses the FLS, altimeter, pressure sensor and emergency release magnet (Figure 5). These wet end sensors and actuator are connected to the electronics in dry nose sections through a wet-mate underwater connector.

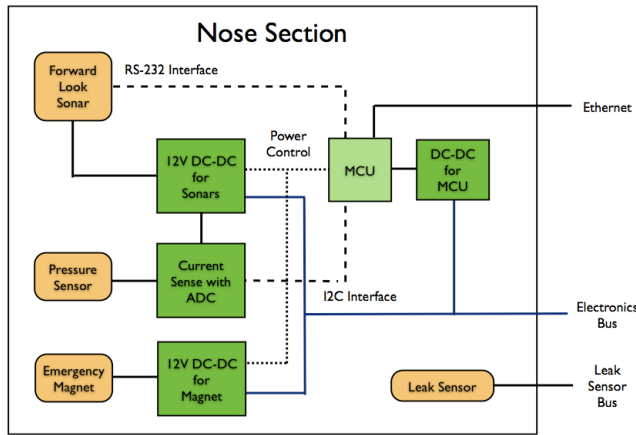


Figure 5. Nose Section Components

The dry section of the nose has been developed using the standard AUV section architecture. It has a MCU which acquires the data from the sensors. The FLS and the altimeter communicate over a RS-232 interface to the MCU. The depth sensor has current output which is converted into a digital reading by a Analog to Digital (ADC) circuit after being signal conditioned by current sense amplifier. The digital output is read by the MCU over a I2C interface from the ADC. The Nose section contains three DC to DC converters, with an always on 5V converter powering the nose MCU. The MCU then powers up a 12V DC to DC converter for the sonars and the pressure sensor as well as a separate 12V supply for the magnet hatch for emergency weight ballast.

Upon power up, the MCU gets the configuration for the sensors from the configuration server. In case the configuration server fails to communicate with the MCU, it configures the sensors with default settings. The Nose section contains a leak sensor connected to the leak sensor bus which runs throughout the AUV. A leak triggers the power control logic unit in the C3 section to cut-off the AUV's main power. This greatly reduces the risk of the electronics being shorted due to the water leak.

A power cut-off causes the electro-magnet holding the hatch that prevents emergency weight ballast from falling to

lose its magnetism. This hatch located in the nose cone wet section opens and the lead pellets are released to enable an emergency ascent to the surface.

B. Command Control and Communications (C3) Section

The C3 section is more complex (Figure 6) and can be logically divided into two groups although both are physically located in the same section. The first group consists of electronics that runs in normal operation while the second group consists of electronics that needs to be active even under emergency situations.

The first group of electronics includes a PC-104 which is the main computer where most of the computationally intensive algorithms such as positioning, navigation, command and control, communication run.

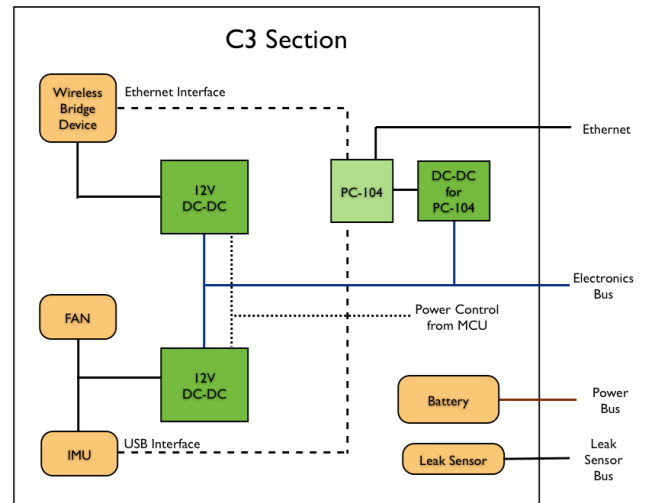


Figure 6. C3 Section Components

Within this group there is also a WiFi bridge that connect the Wireless LAN to the internal Ethernet backbone. This allows us to communicate with different Ethernet nodes within the AUV over the Wireless LAN. It is useful for uploading mission files and for diagnostic purposes when the AUV is on the surface. The wireless bridge is powered by a 12V DC to DC converter that can be powered off when it is not in use, such as when the vehicle is at depth.

Two Ethernet switches are located in the same group, providing the necessary link from all the Ethernet devices to the communication backbone. A number of simple navigational sensors. It consists of an IMU that interfaces with the PC-104 through the USB port, and an electronics magnetic compass that interfaces to the C3 MCU which is part of the second group of electronics. A fan is used to circulate the air internally to aid the heat transfer between PC-104 and the aluminum hull that acts as heat sink. The electronics is supplied from a set of 12V supplies controlled by the C3 MCU. The power for all the electronics within this group is drawn from the main battery pool.

Unlike other sections in the vehicle, the second group of the electronics contains a number of devices that are powered by an separate emergency battery (Figure 7). The emergency battery is kept charged from the main battery (power bus) during normal operation of the AUV. A reverse charging protection circuit that prevents the main battery from being charged by this emergency battery. The C3 MCU controls power to all the devices within both group except itself, Ethernet switches and PC-104.

The second group of electronics contains a GPS/GSM module, acoustic pinger, and a strobe light. The GPS/GSM module runs from a 12V DC to DC converter and communicates with the C3 MCU over a RS-232 serial interface. The pinger and strobe are powered by a 9V DC to DC converter. They can be powered on or off individually by the C3 MCU as required. The pinger is powered on in emergency situations while the strobe can be powered on during low light and night deployments.

During emergency the power bus and the electronics bus are isolated and the PC-104 is powered off. The MCU , GPS/GSM module, strobe light and pinger remains on as they are powered from a separate emergency battery. This group of electronics is located at high within the hull along with the emergency battery, making it less likely to be in contact with water in case of hull leaks. The C3 also has a leak sensor as all other sections.

A major portion of the AUVs batteries are housed in the C3 section. They get connected onto the power bus on assembly.

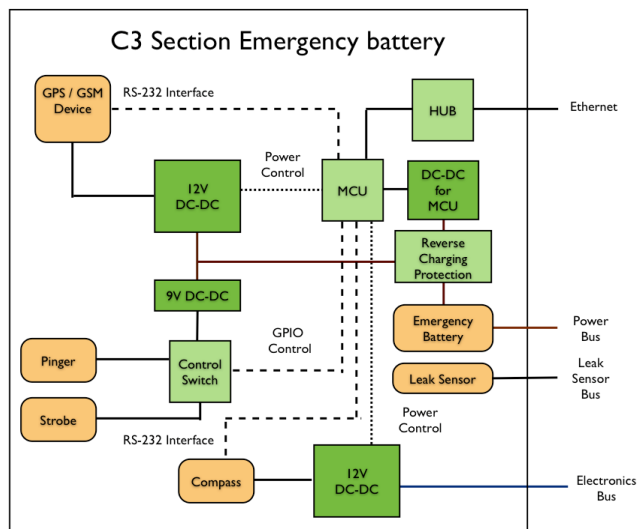


Figure 7: C3 Emergency Components

C. Tail Section

The tail section electronics consists of a MCU, four servo motors, a main thruster, battery packs, and a number of DC to

DC converters (Figure 8). The four servo motors can be controlled individually by the tail MCU which generates the necessary PWM signal. The servos are powered from a separate 5V DC to DC converter whose power is controlled by the MCU. The thruster is powered from a 500W DC to DC converter which can convert any input voltage from 37V to 75V to a 48V constant voltage output. This ensures a smooth thruster operation even in case of low battery. 12V instrumentation power required by the thruster is provided by another supply which is also controlled by the MCU. In case the thruster malfunctions the MCU can cut it off by disabling the power. The thruster requires an analog voltage level for speed control. This is generated by an Digital to Analog (DAC) circuit connected to the tail MCU over a I2C interface. The Tail MCU runs the basic drivers for managing the thruster and fins for AUV operation.

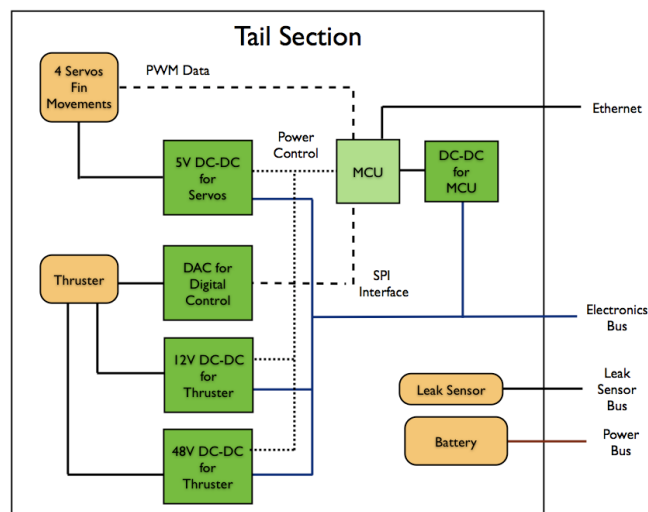


Figure 8. Tail Section Components

The tail section also has a leak sensor which is connected to the leak sensor bus once the AUV is assembled. The batteries in this section get connected to the power bus and contribute power to the central power pool. The batteries are not directly connected to the thruster.

D. DVL Payload Section

Payload sections are sections that provide optional sensors, actuators, new functionalities or additional power sources to the basic AUV configuration. Here, we describe a payload section providing advance navigational capability. The same basic AUV section architecture is employed in designing the advanced navigational payload for the STARFISH AUV (Figure 9).

This payload contains a Doppler Velocity Log (DVL) unit used to measure the AUV velocity with respect to sea bottom. The DVL module is easily interfaced into the existing base AUV system through the standard hardware and software interfaces.

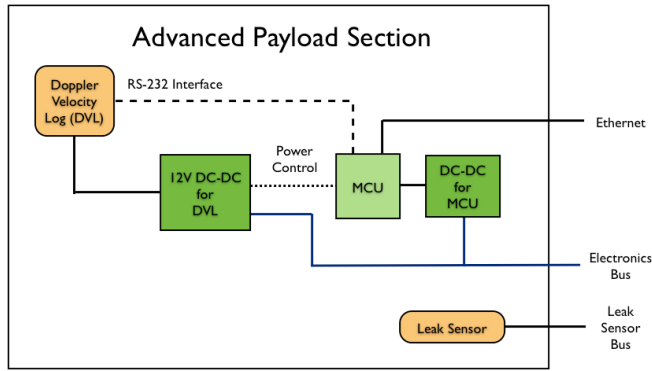


Figure 9. Advanced payload Section components

The DVL section has a MCU which communicates with the DVL electronics over a RS-232 serial interface. The MCU receives the DVL configuration over Ethernet from the configuration server and programs the DVL over the serial interface. The data acquired from the DVL is available over the Ethernet to any other AUV section. The DVL can be powered on or off as required by the MCU. The DVL section also has a leak sensor which gets connected to leak sensor bus of the base AUV.

VI. SAFETY SYSTEMS

STARFISH contains safety systems which are an important part for safe operational of the AUV. Every module in the AUV becomes a part of the safety system once the system is assembled.

E. Emergency ballast

The wet end of the AUVs nose section has a emergency ballast module. It consists of two tubes with lead pellets. The tubes can hold 1 kilogram of lead pellets which are held by a magnetic hatch. During emergency, the power to the magnet can be cut off either actively by the MCU or the power cut from the main electronics power bus. This releases the weight pallets which instantly reduce weight causing the AUV to surface.

F. Leak sensors

Each section of the AUV has a leak sensor. All the leak sensors in the AUV are connected to a common leak sensor bus once the AUV is assembled. In the presence of water in the hull, the sensor provides a logic signal to the power control logic unit which then cuts off the AUV power by isolating the power and electronics bus mentioned in section IV-C. This powers off all the electronics except the emergency electronics group and drop the emergency weight ballast.

G. Emergency battery and GPS

Loss of power causes the lead pellets in the nose section to drop and the AUV to surface. Upon disconnecting the AUVs main power, an emergency battery is used to keep the

emergency electronics in the C3 section alive. This includes the C3 MCU, the GPS/GSM module, the pinger and the optical strobe. After an emergency ascent, the GPS/GSM device notifies a programmed phone number the latest GPS position. The emergency battery is charged from the main batteries during normal operation. It is only drained when the main battery pool is cut-off, hence ensuring enough energy to maintain an emergency communication link.

H. Emergency Strobe and Pinger

The emergency pinger under normal AUV operation is powered off both to save power and reduce acoustic noise to other sensors. In an emergency state, the pinger is powered on by the MCU in the C3 section to send out 37.5 kHz pings at regular intervals. The pinger can be used to locate the AUV underwater and retrieve it if the vehicle is entangled and unable to surface on its own. The strobe is useful during night operations of the AUV for spotting it under low lighting conditions. The strobe can be powered on by the MCU in the C3 section whenever necessary.

I. Health Monitor

The C3 PC-104 runs a health monitoring service which acquires health status from MCUs and other sensors at regular intervals. A failure in any of the AUV sections can easily be detected and the mission can be aborted if necessary. The control logic can be made to trip the central power and release the lead weights in the Nose section if necessary.

VII. ADVANTAGES

A distributed architecture has provided the design team with great flexibility to move functionality across different platforms, replace sensors and reconfiguration the system. This resulted in cost, time and resources saving. This is mainly due to the modularity and common distributed architecture that has been designed and implemented not only at sections level but also to the component level. Since the architecture reuses components which are common to different sections, electronics components and PCB boards can be mass produced both to reduce cost and provide spares for quick repairs whenever there is a failure.

The use of a distributed architecture both for hardware and software has allowed quick and easy reconfiguration of the system. Because of the standard electrical interfaces, and common components employed across the vehicle, sections or even modules within section can be easily added, removed, and replaced as and when required. One example from actual scenario is when we decided to reduce the number of PC-104 used from two units in the initial design to one unit in current design. We were able to move the IMU and Compass connectivity not only from one PC-104 to a different PC-104 module, but also from PC-104 to MCU platform with minimal effort.

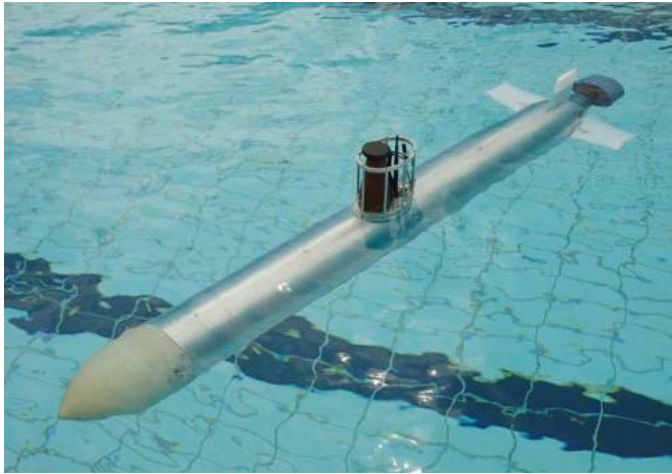


Figure 10. STARFISH AUV

Replacing sensors across different vendors is also easy. For example, when we were required to upgrade the compass to a higher specification unit, the modification required only involved replacing the DC to DC converter and plugging in the new compass. A change in the compass driver on the PC-104 was required to handle the protocol for the new unit. Later, the new compass was connected to the MCU instead of the PC-104. This change was easily accomplished by simply moving the driver to the MCU.

Another good example is during the initial stages of testing, trimming was a problem with the AUV as it was tail heavy. The number of batteries in the tail section had to be reduced. Due to a common power bus architecture it was easy to remove battery packs within minutes. We also tried interchanging the DVL and the C3 section positions for better trim in the AUV configuration and could do it with ease due to electrical compatibility between sections.

As the architecture is open and simple, it can be used to develop newer payload sections for the AUV. This ensures that the newer sections are compatible with the base AUV system and also provide the necessary power and safety systems required by the payload section when assembled with the base AUV. In the development of the advanced navigational payload of the AUV, the architecture was followed. This made its design and implementation fast and easy. A new side-scan section is currently being designed for the AUV and also follows the basic architecture for its electronics.

VIII. FIELD TRIALS

Numerous trials have been conducted in the swimming pool and a lake environment with the STARFISH AUV (Figure 10). It is currently being tested at a local reservoir for dive control. The command, control and navigational algorithms are also being tested for path planning and way-point navigation. Through a large number of trials, the hardware and software architecture have been shown to be reliable and flexible. We expect that the AUV will be

undergoing open sea trials by the end of Q3-2008. Newer payloads are now under development for different mission objectives to be demonstrated in 2009.

IX. CONCLUSIONS

In this paper we have described the distributed hardware architecture designed for the modular AUV STARFISH. Sections of the STARFISH AUV were designed and implemented by using this basic architecture and tested in swimming pool and a fresh water reservoir. Modular hardware architecture has been proven to have many benefits and provides an efficient way of designing, maintaining, and operating a modular AUV.

As each AUV section is independent it is possible to debug hardware and software problems with ease without having to disassemble the other sections. By having standard components, malfunctioning electronic components can be replaced with minimum effort. It also allows the user to change existing components with few electrical and software changes. This architecture provides an easy and standard layout to design new AUV sections for different sensor payloads. Standard communication interface and power bus architecture allows different sensor modules to integrate with the base system. It has proven to be very useful in the implementation, testing and maintenance of the STARFISH AUV.

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