Design and Development of AUVs for cooperative missions

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Abstract

In project Small Team of Autonomous Robotic Fish (STARFISH), we are building a team of low-cost Autonomous Underwater Vehicles (AUVs), each with different capabilities and being able to accomplish a particular mission collectively by sharing information. A team of AUVs has distinct advantages over a single complex AUV in terms of fault tolerance, redundancy, simultaneous multi-point spatial sampling, and better overall communications to mother-ship. Data from multiple AUVs are fused to perform localization and navigation and eliminate the need for expensive navigational equipment on each AUV. Command and control is done in a distributed fashion. Underlying this team behaviour is a robust networked communications system which primarily uses locally developed highly optimized modems underwater and radio communication when on the surface.

AUV test platforms allowing us complete autonomy over their design specifications and control were required to constitute this team. Existing AUV competency from the open literature along with novel ideas have been incorporated to achieve the final design of our AUVs. The entire AUV has been designed to be modular from a mechanical, electrical and software perspective so that additional, payloads such as Doppler Velocity Log (DVL), Conductivity-Temperature-Turbidity-Depth (CTD), Side-scan etc. can be included with ease. Standard electrical interface between modules offers the required flexibility in terms of development of additional modules. Additional sections can be included without affecting the final design provided they are self sufficient in terms of battery life and neutrally buoyant.

These AUVs will serve as a test platform to demonstrate cooperative behaviour which would enable us to perform complex tasks such as surveying, tracking and target re-acquisition effectively along with the testing and development for the allied technologies such as localisation, positioning, control etc that are required for cooperative behaviour. Group behavioural aspects along with the design details of such AUVs are presented in this paper.

1. Introduction

At Acoustic Research Laboratory (ARL), we are exploring the use of a network of autonomous distributed systems for underwater missions. We are currently building a team of small low-cost Autonomous Underwater Vehicles (AUVs) to help us test group behaviour. The use of a team of AUVs provides many advantages over a single complex AUV [1]. To achieve team coordination, communication is a critical requirement. With ARL's expertise in underwater acoustic communication [7], our team of AUVs will be able to operate in warm shallow waters effectively. Research is also being carried out in areas of Underwater Networking, Command and Control, Control Systems and Positioning & Localization towards achieving a successfully integrated team of AUVs.

Tapping into the existing AUV technology [3,4,5], we have designed a platform which offers us complete flexibility with regards to overall structural design, testing custom designed software algorithms. Additionally various payloads such as CTD, DVL, Side-scan, Bow thruster, Bow planes can also be included. Thus, the resulting team of AUVs will have varying capabilities by including different payload sections.

2. Overall Hull Design

The overall hull profile is taken from the Myring's equation [2] for a *torpedo shape.* It was further verified by modeling in GAMBIT + FLUENT CFD tools with approx. 500,000 elements using the k- epsilon solver. In order to reduce the hydrodynamic drag further the number of protruding components is kept to a minimum.

The entire design of the AUV is modular and the hull is Ø0.2m in diameter with length restricted from 1.45 to 2m depending on the optional payloads. The resulting fineness ratio of the AUV hull varies from 7 to 10.

The AUVs comprise of the following sections as in figure 1:

- Nose cone Section
- Command Control and Communication (C3) section
- Tail section
- Optional Payload Section

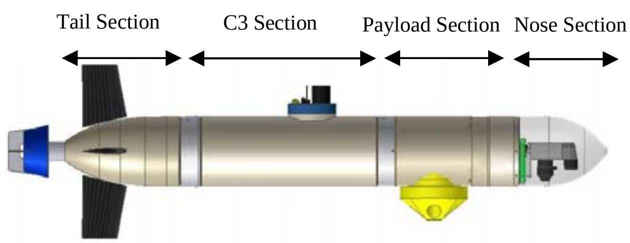

Figure 1: AUV rendering

These individual sections are then interconnected by means of a custom designed interlocking teeth arrangement and made water tight by using a double piston o-ring seal.

The Starfish AUV offers approx. 40kg of buoyancy and weighs approx. 34.5kg in air. Provision for ballast weights up to 4.5kg is made to adjust the buoyancy as required. Additional payload sections can be included provided they do not change this buoyancy criterion.

Vehicle Parameters	Details
Total Hull Length	1450mm to 2000mm
Outer Hull Diameter	200mm
Shape	Slender Ellipsoid
AUV Dry weight	34.5 kg
Hull Material (C3 & Tail Section)	Aluminium Alloy 6061
Nose Cone	Delrin®
Propulsion	Single DC Motor
Depth Rating	100m

Table 1: AUV Specifications

2.1 The Nose Cone Section

This section comprises of wet and a dry sub section and is 0.4m in length. The wet section has a parabolic profile, 0.3m long, made out of an acoustically transparent material and is free flooded.

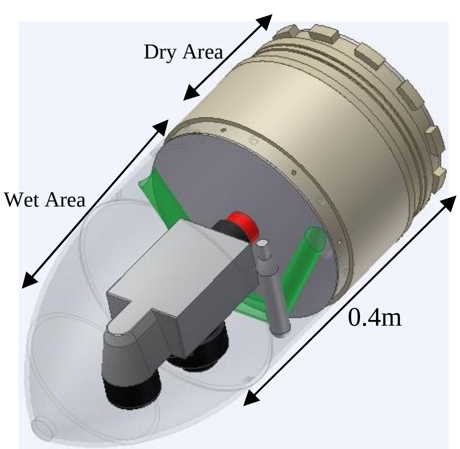

Figure 2: Nose Cone Section

The Nose Cone has a dual purpose of providing a hydro-dynamically designed fairing for minimizing drag and an acoustic aperture for the altimeter, obstacle avoidance sonar and pressure gauge which are all mounted within this section.

A custom designed emergency ballast and trimming mechanism is provided in this section and caters for a total of 1kg of trimming weights. These weights can be dropped in case of an emergency to provide enough buoyancy for the AUV to return to the surface.

2.1 C3 Section and Communications tower

This centrally located section is approx. 0.65m long and holds the Communications tower. This section has an internal ballast chamber for coarse trimming of the vehicle buoyancy.

The position of the ballast weight can be varied in order to obtain the C_G of the entire system along the same vertical axis as that of the vehicle C_B. Batteries and the ballast weights are placed as close to the bottom as possible to allow for maximum separation between the C_B and C_G to achieve better stability. This section houses the command, control and communication PC along with related sensors and controllers.

The communication tower houses antennas for GPS, wireless LAN, GSM Modem and an Acoustic Modem transducer. A bulkhead

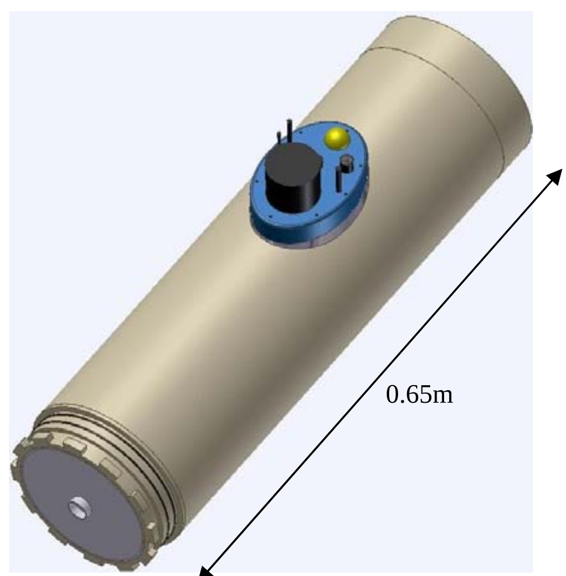

Figure 3: C3 Section

connector is provided on the tower for wired LAN and for providing power to the AUV externally for tethered operation. A strobe is also provided on the tower for identifying the AUV when it surfaces.

2.4 Tail Section

The tail section is most important in terms of minimizing the hydrodynamic drag and therefore has a longer taper than the nose cone. Externally, it holds the control surfaces and grips the main forward thruster by a cage arrangement. This section too is partially flooded for providing water cooling to the main thruster.

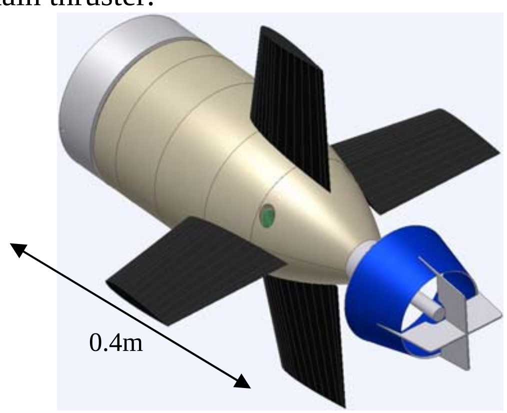

Figure 4: Tail Section

Fins are controlled individually by using servo motors. They are designed to meet the well proven NACA 0012 axi-symmetric profile with a relatively large span of 0.115m x 0.15m translating to 11 N lift at 5° angle of attack with a 0.1 N drag at a cruising speed of 3knots.

A buoyancy trimming mechanism is also provided in this section for fine trimming of the AUV.

3. Electronics and Software Architecture

The AUV is designed to be modular from a mechanical, electrical and software perspective. A hardware module is a standalone electronic module with a standard interface as depicted in the figure 5.

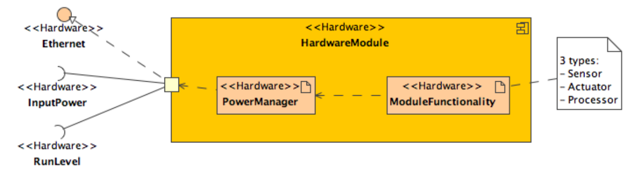

Figure 5: AUV Module

A section consists of multiple modules. Individual sections are interlinked together by the Ethernet backbone, Power bus and the Run level bus.

Each module connects to other modules via an Ethernet interface. It draws power from a common bus and selects its own activity level based on the Run level bus which indicates the AUV running condition.

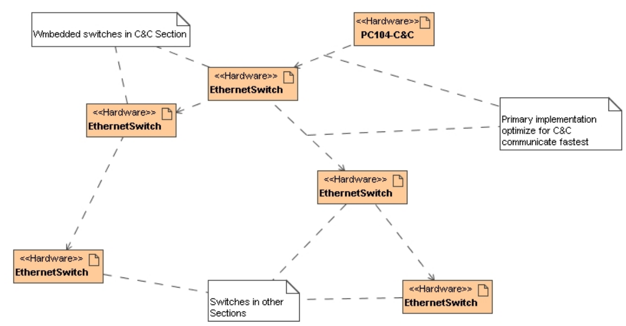

Figure 6: AUV Ethernet Communication

The AUV core software runs on a PC 104 with self complied embedded Linux which is located in the C3 section. Other sections of the AUV have microcontrollers which are connected to the main PC 104 via an Ethernet backbone.

Although heavy weight protocols like TCP/IP could have been used to implement communication between nodes, these protocols are likely to be too heavy for the MCU. Instead, the AUV implements a lightweight Ethernet datagram protocol for reliable communication between nodes.

4. Power System

The AUV has a total battery capacity of

1.35kWh with Lithium Polymer (Li-Po) as primary energy source. A 48V power rail runs all along the length of the AUV. In each section the voltage is converted as per requirements using highly efficient DC to DC converters.

A 1-Wire protocol for battery capacity monitoring is implemented. At present batteries are charged externally but a provision for internal charging has also been made.

5. Networked Communications

For successful AUV team operations, the importance of communication and networking cannot be over-emphasized. Underwater communication mainly relies on acoustics, and is characterized by high latency, low data rates, and significant Doppler and multi-path effects which lead to high bit error rates. When on the surface, AUVs can use radio communications. Requirements for AUV networks also include managing high level of mobility, energy efficiency, reliable message transfer etc.

The primary device for point-point communications underwater is the ARL acoustic modem based on OFDM [6]. It can achieve error free physical layer data rates up to 15 kbps at 1 km range in the highly noisy and shallow local waters of Singapore, where COTS modems fail to achieve good performance. In the modem physical layer, high degree of coding including repetition, convolution, Golay and Low Density Parity Check (LDPC), Viterbi decoding and packet detection optimized for non-Gaussian noise etc, ensure highly robust communications

Positioning information will be carried in each packet to enable co-operative localization and navigation. The importance of co-operative behaviour and the need for robust communication link to achieve the goal is discussed in the next section, with a hypothetical scenario.

6. Example Mission

Consider a hypothetical scenario where a mother-ship enters unknown waters and needs to conduct a survey. Instead of deploying a single complex AUV with navigational, imaging and communication capabilities we adapt a distributed concept having a team of AUVs each with a different capability carrying out the survey by cooperation.

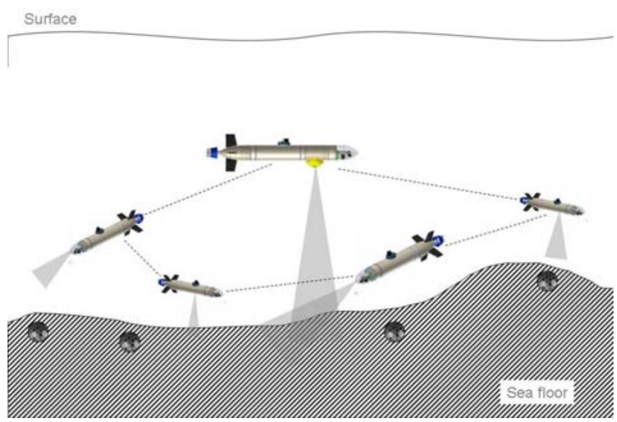

Figure 7: Mission Scenario

The Navigational AUV is used to get better positioning information for the team. The other AUVs use their sensors to search for possible threats (mines). As there are multiple AUVs searching at the same time we have a spatial sampling advantage of the search area thereby reducing the overall time required to scan by a single AUV. In case, one of the search AUV fails the mission need not be aborted and is continued by the remaining AUVs thereby adding redundancy and improving the system reliability.

Scenario 1
Positioning information can be exchanged between the Navigational AUV and search AUVs via robust communication links as discussed above so that the search AUVs can correct their position estimates and the team can have a much better positional accuracy.

Scenario 2
As soon as the search AUV detects a threat it

relays the information to the AUV team and also gets its accurate positioning information from the navigational AUV.

Scenario 3
In case the positioning AUV fails the mission may still be carried out by collective navigational accuracy of the remaining team.

7. Future Work

Future payloads such as USBL, INS etc. may be included later for improved navigation.

Fuel cell payload may be a possibility for future long term missions and feasibility study currently being carried out.

Bow planes and different thruster configuration for hovering operations or vector thrusters may be implemented for other mission specific operations.

8. References

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