MODULAR LOW LOGISTICS AUVS IN COMMERCIAL SURVEY APPLICATIONS

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Abstract

Advances in the capability of low logistics autonomous underwater vehicles have provided a level of operational capability that was impossible to achieve with earlier man portable systems. Fully modular, low logistics AUVs with offshore survey capability were first deployed commercially in the mid to late 2000s. By the start of 2013 there were several fleets of vehicles being operated by professional survey organisations in various locations around the world, in depths from a few metres to 1000m. This paper reviews the experience in the offshore oil and gas sector in the last five years with a focus on the impact that low logistics have had on AUV survey operations. A greatly increased flexibility and capability is seen in many aspects of survey tasks using low logistics AUVs: the ability to mobilize from vessels of opportunity, small boats or even shore; ease of transport; flexible launch and recovery and rapid deployment. This flexibility when combined with high quality survey grade sensors make low logistics AUVs a powerful tool for gathering high quality survey data. The additional benefit of low logistics systems is the associated cost reduction when compared to traditional means utilizing ROVs, tow bodies, or even larger AUVs. The flexibility and benefit of a modular system capable of conducting a variety of survey tasks through a suite of available sensors; and the ability to upgrade modules or add novel sensors will also be explored.
The discussion is illustrated using examples from survey work in the Caspian Sea, UK North Sea, Gulf of Mexico and South China Sea using Gavia Offshore Surveyor AUVs (Teledyne Gavia, Iceland).

Introduction

Advances in modularity of low logistics autonomous underwater vehicles (AUVs) have provided a level of operational flexibility that was impossible to achieve with the mainly monolithic systems available in the late ‘80s and ‘90s. Fully modular low logistics AUVs with offshore survey capability were first deployed commercially in the mid to late 2000s [THS 2008] [OI 2010]. By 2013 there were several fleets of modular vehicles being operated by academic, military and commercial organisations in various locations globally, providing survey data for engineering tasks in depths up to 1000m [USH 2011].

Background

Modularity has resulted in a greatly increased flexibility in many aspects of the AUV survey task. This paper reviews the advantages of a fully modular AUV design concept, drawing on experience in the offshore oil and gas sector in the last 5 years of commercial operations using the Gavia Offshore Surveyor AUV from Teledyne Gavia (Reykjavik, Iceland).

The Gavia AUV system was developed by Hafmynd Ltd. of Reykjavik, Iceland (now Teledyne Gavia ehf) in the late 1990s [UUVS 2002]. It was the first commercially available fully modular vehicle system and the first compact AUV capable of deep-water operations [ATUV 2004]. The Gavia base vehicle (figure 1) is a mobile sensor platform that can be configured on-deck for a particular task or operating conditions by the addition of one or more sensor, navigation, or battery modules, which are attached to the vehicle and locked in place by means of a unique twist-lock system, shown in figure 2.

Figure 1: The Gavia AUV base system showing the fully modular configuration. From right: Nose, battery, control and propulsion.

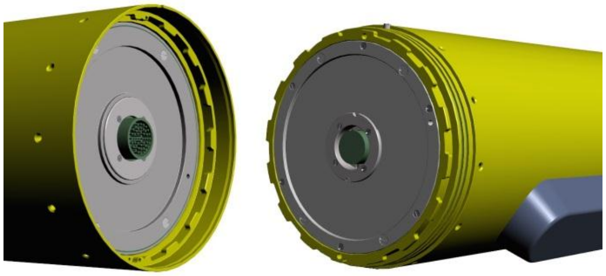

Figure 2: The Gavia twist-lock and central connector system (carrying Ethernet, signal lines and power). The 1000m-rated pressure hull is in yellow.

The Gavia modules consist of a cylindrical 20cm outside-diameter pressure hull which are attach to the adjacent modules via a double O-ring seal and central connector, so a built Gavia has a single rigid torpedo-shaped pressure hull and an electrical bus running throughout the AUV.

In this paper an attempt is made to define the concept of 'full modularity', then the impact of a fully modular architecture is discussed from the perspective of the various stakeholders in the commercial subsea survey sector.

Defining Modularity

There are various degrees of modularity, and the concept of 'full modularity' in the context of AUV design is difficult to pin down. One way would be via a use-case; full modularity implies that the mission defines the AUV on a per-mission basis, and that any elements not required for the mission can be left onshore. Another requirement for full modularity is interoperability of modules: any build of the same AUV can carry any of the modules, and modules can be interchanged between AUVs. In this context full modularity also implies field-swappable modules rather than an AUV that can be built-for-purpose in the workshop. Full modularity also implies that the AUV can be broken down into functional units (physically and/or conceptually), with well-defined boundaries between units and an easily identifiable point of interface (physical, electronic and in software architecture).

This definition of full modularity, implemented in the Gavia AUV, leads to a vehicle which is hard to describe even in general characteristics: the number of modules used on a particular mission defines the AUV length and mass; the number and type of battery modules determines the endurance; and the sensor capabilities depend entirely on what modules are chosen. Even characteristics like depth rating need to be defined on a per-module basis; a 1000m-capable base AUV could be fitted with a sensor module which has transducers only rated to 500m – this then becomes a 500m-rated AUV. In the case of the Gavia, the base vehicle consists of the following modules: nose, battery, control module, and propulsion, as shown in figure 1. This is 1.8m long and weighs less than 50kg. A fully equipped Gavia with inertial navigation, multi-beam, side scan, sub-bottom profiler and dual batteries can be over 3.5m long, and weigh more than 120kg in air (figure 3 shows some different configurations). As an aside; the hull diameter of 20cm and neutral buoyancy ballasting means that a Gavia weighs roughly π kilos per 10cm length.

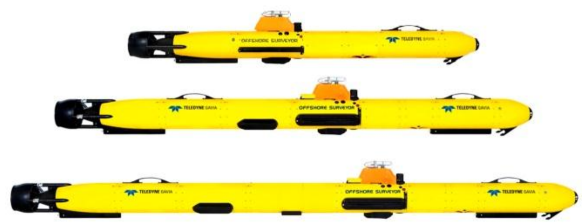

Figure 3: Same Gavia AUV, three different missions:
Top; Configured for INS-navigated side-scan debris-clearance survey (single battery, 5 hour endurance).
Middle; Hydrographic mapping configuration (long endurance): dual batteries, side scan (with transducer faring) and GeoSwath swath bathymetry.
Bottom; Geophysical survey configuration: as middle, plus sub-bottom profiler.

One key aspect of full modularity is the modular nature of the software and firmware running the AUV. This can be achieved by tight definition of the electronic and data interfaces between software and hardware modules. The implementation of this in the Gavia is described in more detail in a later section.

Limited partial modularity (for example exchangeable batteries, or factory-swappable payload sensors) gives some advantages, especially in systems that are dedicated to specific tasks and where operational flexibility is not an issue. In the commercial offshore sector greater flexibility is often required, especially where new technology developments (in sensors, batteries, and computer power) are constantly changing the game.

Manufacturer's Perspective.

AUV manufacture, like much of offshore industry equipment supply, is not mass production. Small volume (less than several 100 per year) in any industry means that design and manufacturing have to be fast-reacting and flexible. Technologies can change rapidly, and component obsolescence is a regular occurrence. A fully modular AUV design allows rapid changes of design in individual hardware and software modules. A design change in one module does not affect any others, as long as the physical, electrical and data interfaces are consistent. This means that design for batch-building of systems is a lot easier, without locking-in old technology, and builds can be transferred to production rapidly, avoiding the 'multi-build prototype' trap that is often seen in low-volume manufacturing. The modularity of the physical build (as shown in figure 4) therefore leads to easier incremental improvements and also an ability to rapidly adopt new technologies.

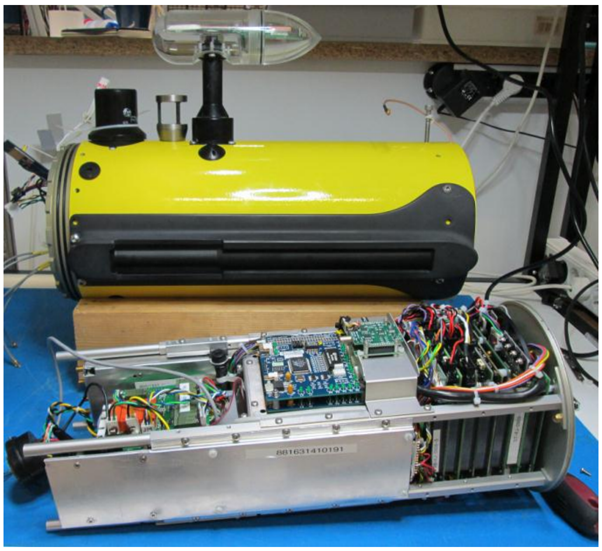

Figure 4: A Gavia module being assembled, with the electronics rack in the foreground. This physical module contains various modular sub-systems: the 900kHz/1800kHz side scan option (Marine Sonic Technology Inc.); AUV command & control computers; communications systems (WiFi, acoustic modem , Iridium); sound velocity sensor; temperature and pressure sensor.

In the design process modularity also allows specialisation and outsourcing. Well-controlled interface definition documents specify the available and required physical, electronic and data interfaces, so additional sensor modules can be designed off-site and tested against simulated inputs (or inputs derived from logs of AUV missions). Behaviourally complex simulators and test beds are also straightforward to implement.

Software Engineer's Perspective

The AUV software is a large part of what makes a successful vehicle. In a modular system with well-controlled software and hardware interfaces the code implementation, maintenance and improvement is much easier to manage than in a monolithic AUV.

In the wider computing industry standards exist for a range of interface protocols. A good example of a working modular concept in this context is the office Ethernet network. Each machine (laptop, desktop, storage server, printer) is connected via standard Ethernet communications protocols, so the addition of units or upgrading is straightforward. The Gavia AUV makes use of this Ethernet modularity and extends it using standard message-brokering services for inter-module communications. In essence the core elements of a Gavia AUV form an Ethernet-connected network of embedded computers (one or more per Gavia module) each running programming language(s) of choice (C++, Python, C and more). These embedded computers are driven by XML scripts for both system configuration and on-mission operations. Payload computers in each module (one or several) also have their own IP addresses on the network so can be readily accessed externally for test and configuration via wireless or wired local area network (LAN) when the AUV is on the surface. The Ethernet network and standardised messaging means that payload modules running on different computers (i.e. various flavours of embedded Unix or Windows) can be easily added to the network.

A well–defined standard communications interface means that Gavia operating software does not need to be aware of the details of the messaging mechanisms used to communicate with or activate a module, or even where the module is located (i.e. on the same or different physical Gavia module). To the payload module's software the interface with the Gavia is also independent of what programming language it is implemented in, its physical location, or any other aspect that is not reflected in the interface definition.

The philosophy of a well-defined and controlled interface between agents is key to the software and firmware modularity in the Gavia AUV. In monolithic AUV systems a significant percentage of programming and test effort is required to qualify interfaces with other software components. Issues arising in monolithic systems include problems with backwards-compatibility, lack of expandability, and the scaling of inter-operational testing with the number of modules. The standard communications also interface allows much easier modelling and simulation. For example testing of new software can be carried out in a simulated AUV environment (possibly using recorded communications messages from real mission logs), saving resources and speeding up the development process. Application specific capabilities and new reactive behaviours can be added by introducing specialist crewmembers.

The Gavia control software also adheres to the modular philosophy, using a crewmember architecture (figure 5). In the Gavia Control Module (and also possibly distributed on other modules around the AUV) an artificial crew operates the vehicle, consisting of individual crewmembers communicating with each other and the surface operator using standard interfaces. Mission plans are submitted to the crew in a flexible Extensible Markup Language (XML) scripting language that allows the specification of both fixed and dynamic paths. The XML script is generated by software on the mission planner's laptop or desktop computer, typically using a map-based graphical user interface (GUI).

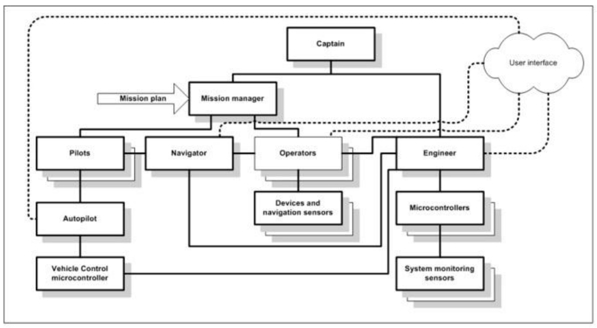

Figure 5: The Gavia crewmember architecture.

One concern is the time co-ordination of the various parts of a distributed modular architecture operating a real-time system. The hardware and software modules are distributed across a local network where the communication may be over Ethernet including network bridges. Ethernet delays are possible, but data timing often needs to be highly coordinated (for example the timing of data from the roll sensor and the sonar ping time need to be matched to sub-millisecond accuracy in order to avoid bathymetry artefacts). Common timing is achieved on the Gavia by a separate hardware time synch system based on the 1 Pulse Per Second (PPS) signal. On the surface the global positioning system (GPS) in the AUV provides a PPS output which drives a logic line running throughout the AUV. The PPS rising edge is defined to be the start of each second. The specific date/time/second of each PPS edge is communicated via a *time* message (pseudo-ZDA) over multicast Ethernet roughly 50ms after the PPS edge is generated. The PPS edge provides a common event throughout the AUV, and the ZDA provides the time of the event, allowing each module to synchronise its internal clocks with the GPS time. When submerged and out of GPS contact a similar scheme is followed, with the PPS edge and ZDA message being generated by an internal clock on the AUV.

Perspective of the AUV Buyer

The investment required to set up a commercial AUV survey unit is significant. Modularity allows an easier route in, where a base AUV can be procured on the basis of a small series of contracts, with the payload sensors for each contract being hired in on a per-job basis. This allows a wider customer base to be served without requiring a fleet of one-size-fits-all AUVs. As experience is gained in AUV operations further modules can be acquired to expand the in-house capability when investment becomes available.

Modular sensor packages also allow the buyer a choice of technologies, enhancing the competition in the sensor markets, and allowing the operator to choose a sensor to suit their client's preferences. Specialist service providers can choose the modules to suit their speciality, without losing the ability to expand into new areas at a later date.

Operation Manager's Perspective

Modularity allows the survey provider to offer only those sensor packages that are relevant to a specific job, while allowing the use of additional modules if extra capability needs to be demonstrated. The AUV can be assembled-for-purpose and designated to a mission but the capability is not locked in and dedicated to only one mission (an example is shown in figure 6). The concept of 'designated not dedicated' on a per-mission basis is also important in the military sector, although that is not the focus of the current paper.

Figure 6: Gavia AUV configured for an offshore survey, with swath bathymetry, camera, side scan and INS/DVL navigation. Photograph: NCS Survey Ltd, Aberdeen UK.

A physically modular form factor allows ease of transport and ease of stock control. With the Gavia AUV the modules pack into moulded cases (Peli-cases) weighing between 15kg and 30kg, and a typical packing list would have 10 cases including surface equipment (figure 7). These cases can even be transported as check-in luggage on commercial passenger aircraft for extremely rapid deployment worldwide (apart from the Li-ion battery modules which are classed as dangerous goods). Battery modules are interchangeable, so if a mission is likely to be required in an area a set of batteries could be sent ahead (or hired locally).

Figure 7: AUV modules ready for shipping.

Modular construction also has an impact on maintenance. This can be planned on a per-module cyclic basis, with a replacement used while each module is in maintenance, resulting in no loss of AUV capability. Lifetime replacement cycles can also be planned on a per-module basis, so the survey company will eventually have an all-new AUV with no loss of capability and a manageable spread of costs.

Field Surveyor's Perspective.

Once the AUV is built in the required configuration it can be treated like a monolithic system. The well-defined modularity of the software allows the control protocols to be well-defined, enabling higher level software tools to be implemented for AUV management and control. The Gavia interface is map-based, and allows survey patterns to be drawn, AUV mission parameters to be defined, and sensor parameters to be set-up, all from a single interface (the Gavia Control Center software, running on a separate laptop connected to the AUV via LAN). The Control Center also has tools for system checks, initiating self-test modes, and quality checks of collected data. Third party alternatives to the Control Center are available using the same AUV interface protocols, a different GUI, and additional mission-specific functionality.

During commercial operations a client's requirements can change, and frequently work extensions are required based on the field charts produced daily. If this work requires a different set of capabilities then new sensor module could be flown in and attached to any Gavia AUV already in the field (as shown in figure 8[ST 2013]).

In the event of damage or component failure a modular construction allows rapid removal and replacement of the failed unit in the field, with minimal disruption to operations. If the failed unit is not part of the base vehicle then operations can be continued with a reduced capability until the module is repaired or replaced.

Figure 8: The Gavia AUV development system (gold modules) fitted with a production Benthos ChirpIII SBP (yellow module), on trials with UTEC Survey.

Training Provider's Perspective.

From the training and capability viewpoint the modular constriction allows AUV-specialist and payload-specialist roles to be sensibly divided in the operations team. Training and personnel development programmes can also be modular, to match the system and software divisions.

Hardware Developer's Perspective.

In the rapidly changing technology of the offshore survey industry there is a constant potential that a new game-changing sensor, battery, propulsion or control technology could appear. Development of a new module with this capability is likely to be easier than integrating it into a monolithic system.

In the Gavia the common module interfaces allow newly developed modules to be fitted to existing AUVs, so the potential market for a newly developed module encompasses all the operational Gavia AUVs. This reduces the risk for hardware developers and encourages the rapid deployment of new technologies. For example, side scan systems from Edgetech (West Wareham, MA) and L3-Klein (Salem, NH) were recently being investigated for integration into Gavia modules; it took just 20 days from order to sea-trials to get the first images (figures 9 and 10).

The separate payload module with well-defined physical, electrical and data interfaces allows off-AUV sensor development and test, accelerating implementation of new (sensor/computer/battery) technology. Pressure-rated end-caps can also be attached to sensor modules allowing in-water tests (typically pole-mounted over the side of a vessel of opportunity) without committing an AUV to the development effort. This allows rapid prototyping and test prior to trials on the AUV, and for operating companies their AUV technology can be updated without loss of capability.

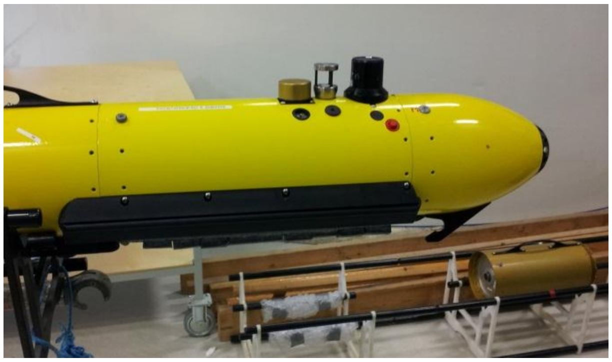

Figure 9: The Klein 3500 side scan integrated in a Gavia test module, ready for sea trials.

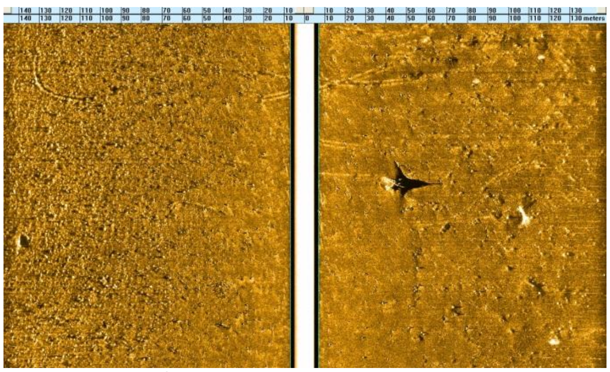

Figure 10: Data from the Klein 3500 side scan on the Gavia test module, after just 20 days integration. Frequency: 900kHz, horizontal range shown: 140m.

A Long-Term Perspective

In a fully modular system the lifetime replacement can be gradual and near-invisible to the AUV operations team. Modules can be replaced piecemeal at the end of their useful working lives or when superseded by new technologies. As a result an AUV bought today could be in continuous use for decades: in 15 years none of the current modules would still be in use, but there would have been no loss of capability in-between and there would be no requirement for a major re-equipping or re-training programme. In addition the technology in the AUV would still be relevant to changing survey markets.

Conclusions

AUV modularity has a plethora of benefits to a range of stakeholders. These benefits have now been realised in a commercially available low-logistics AUV, the Gavia Offshore Surveyor, which is capable of carrying out engineering-quality surveys in the offshore survey industry. The Gavia modular design allows the integration of new hardware and software modules with minimum effort and the plug-and-play module interfaces presents the necessary mechanical, electrical and software interface to allow straightforward integration of new modules. The Base Vehicle serves as a common platform for a variety of AUV applications with its specific capabilities defined for each mission by the modules chosen.

Recognising those benefits several offshore survey companies have invested in the technology and are offering AUV survey services in a variety of offshore scenarios. Typically an offshore company will operate a fleet of AUVs in order to gain the benefits of scale in the office (marketing, planning, mission support, data processing, and back-office). Modularity provides the flexibility that such commercial activities require, while allowing the delivery of a mission-dedicated package using a suite of sensors suited to the client. In the longer term the ability to implement a modular through-life maintenance, upgrade and replacement strategy means the lifetime of an AUV could effectively be as long as the product family.

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