Expanding the Small AUV Mission Envelope; Longer, Deeper & More Accurate

Thomas Hiller, Arnar Steingrimsson
Teledyne Gavia ehf,
Kópavogur, Iceland

Robert Melvin
Teledyne Benthos,
North Falmouth, MA, USA

***Abstract*— Small, man-portable AUVs now carry out engineering and geophysical survey tasks where previously boat-mount, towed or ROV-mounted sonars would have been required. The commercial use of low-logistics AUVs in the offshore survey industry is expanding rapidly, with several companies now operating small survey AUVs worldwide. This paper describes some of the advances in vehicle and payload technology which have enabled the uptake in commercial survey roles such as pipeline inspections, rig move surveys, harbor inspections and environmental work. Modular AUV design has enabled the continued expansion of the small-AUV envelope of operations: extending time on-site with field-swappable batteries; enhancing deliverables with multi-sensor configurations such as swath bathymetry and sub-bottom profiler; and enabling longer mission durations with multiple battery configurations. One limitation to AUV operations has been the accuracy of navigation during extended submerged missions. This has led to the development of subsea position aiding techniques such as inverted USBL to improve in the accuracy of longer missions and deeper water surveys (up to 1000m). Current AUV system performance and capabilities are illustrated using examples of side scan, swath bathymetry and sub-bottom data from a widely used low-logistics survey AUV, the Gavia Surveyor.**

***Index Terms*— AUV, seabed, survey, bathymetry, side-scan**

I. Introduction

Small, low-logistics Autonomous Underwater Vehicles (AUVs) owned by commercial organizations are becoming an increasingly important asset in many subsea survey and inspections roles, delivering engineering-quality survey data with high productivity and low logistics costs [1]. In the last decade there has been a significant increase in the capability of the small AUV with advances in navigation, propulsion, control, and compact sonar payloads. A range of oceanographic and geophysical survey instruments can be found on small AUVs including bathymetric mapping sonars, side-scans and optical cameras. Data quality from these sensors now satisfies engineering and geophysics requirements in a wide range of survey tasks.

Improvements in vehicle reliability have also helped drive system acceptance: the small AUV is now capable of extended field operations over multiple days with a variety of beach and boat launched missions to shallow, mid and deep (1000m) survey sites [2].

In many tasks the small AUV can be a cost-effective alternative to a boat-mount, ROV-mount or towed sonar. In deep water surveys the AUV enables the surveyor to get a suite of high resolution sonar instrumentation close to the survey site using a low noise, stable platform, with none of the cable handling and logistics hazards of a large ROV or deep tow system. The small vehicle size and low logistic requirements also confers specific advantages where low disruption, high asset safety, or access to hazardous areas is required.

Many of the developments in applied small survey AUV technology have been driven by the oil and gas industry. Small AUVs are now frequently used around oil and gas installations inspecting the seabed for debris and scour without the need to suspend production, and in pipeline monitoring. A limiting factor in the mission duration has been position drift in the inertial navigation systems (INS) that can be used in small AUVs. Extending the mission envelope to enable longer surveys to deeper sites while maintaining positioning quality has been a major challenge. Developments in acoustic aiding techniques such as inverted ultra-short baseline (iUSBL) positioning have started to address these challenges.

Throughout this paper AUV capability is illustrated using examples from the Gavia Offshore Surveyor AUV (from Teledyne Gavia ehf), a widely used low-logistics 20cm diameter commercial survey AUV (figure 1).

II. The Gavia AUV

The Gavia is a fully modular AUV that can be rapidly assembled in the field in various mission-specific configurations (see figure 2). The Gavia Base Vehicle consists

Fig. 1: Gavia Surveyor AUV configured for bathymetric survey.

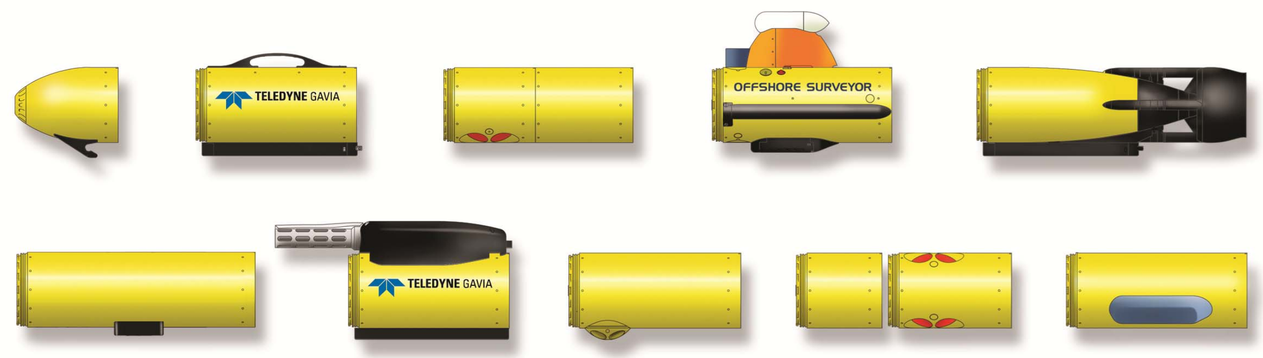

Fig. 2: The Gavia Surveyor AUV showing typical modular payloads. Clockwise from top left: nosecone, battery, DVL/INS (Kearfott T24), control with GPS, propulsion, GeoSwath, ADCP, Autotracker, DVL/INS (Kearfott T16), battery with CTD, sub-bottom profiler.

of a nose-cone, battery, control unit and propulsion unit. This configuration includes a GPS for surface positioning, wireless LAN for communications, and Iridium satellite link for over-the-horizon messages. In the base vehicle a three-axis magnetic compass and 360° orientation sensor provides input for basic vehicle control and dead-reckoning capability, although the dead-reckoning accuracy is usually not sufficient for commercial survey specifications.

The Gavia Surveyor AUV, as deployed for commercial surveys, has additional positioning and sonar sensor modules. This configured will include: a differential-ready GPS receiver; a SeaNav T24 INS (Kearfott Corporation, Little Falls, NJ); a Teledyne WorkHorse 1200 Doppler Velocity Log (DVL) (Teledyne RDI, Poway, CA); and a Keller 33Xe depth sensor (Keller-Druck, Winterthur, Switzerland). For data acquisition the Gavia can be fitted with side-scan sonar, wide-swath bathymetric sonar and/or sub-bottom-profiler modules. In a typical survey configuration the vehicle is 2.7m long and weighs less than 80kg. All data examples in this paper were collected using Gavia Surveyor AUVs in various configurations.

III. Extending the Mission Duration

Compact propulsion and battery technology helped the development of small AUV systems, and these proved popular for research and some military applications. Until recently they did not have a role in the offshore survey industry due to the limited endurance, shallow depth rating and restricted payload, as well as concerns about the vehicle reliability. Advances in propulsion and battery technology along with reductions in size and power consumption have greatly extended the small AUV mission duration and reliability, and improved vehicle designs have extended the depth of survey operations to over 1000m.

The Lithium-Ion battery packs used in the Gavia battery modules can now provide suitable mission duration for many commercial surveys tasks. This can be extended for deeper surveys by configuring the vehicle with two battery pack modules. This enables durations of over 8 hours with 4 knot survey speed while operating an array of sensors. The modular nature of the Gavia AUV also means that depleted battery modules can be exchanged in the field in a few minutes, allowing a fast turn-around between missions.

IV. Positioning The AUV During Longer Missions

A key enabling factor in the commercial utility of the small AUV survey has been improvements in the quality of the vehicle positioning. The survey platform must be accurately positioned in three dimensions for the sensor data to be useful for engineering purposes. In the small AUV this has been realized using an inertial navigation system aided by a doppler velocity log and high accuracy depth sensor.

The INS/DVL/depth sensor combination can provide positioning suitable for engineering survey and inspection tasks over tens of minutes, with survey data quality that is equal to that collected from boat-mounted or towed platforms. Long term errors in the sensors result in a position error that grows with time. The size of the position error depends on a number of factors, including water depth, water currents, and survey layout; a typical error figure is 0.05% of distance travelled [3]. At AUV operational speeds this error will exceed typical survey positioning requirements in less than an hour. This is sufficient for short missions but is significantly less than the AUV battery endurance. Practices have been developed to extend the accuracy, for example in shallow waters by surfacing to correct the position drift using a GPS fix, and this has enabled the use of small AUVs in many engineering survey roles [4].

Surfacing for a GPS fix is not practical in deeper water missions, and there is also likely to be a time during the dive to the survey site when the DVL will not be in bottom lock, resulting in a large INS position drift. In order to expand the AUV envelope of operations to deeper water other methods of subsea position aiding are required. Typical options are a boat mounted USBL system or a long baseline (LBL) array, and these are both now available integrated with the Gavia positioning solution.

A novel modification to the USBL technique is the 'inverted' USBL (iUSBL), where the azimuthal and vertical angles to a boat-mounted transponder are estimated by a system mounted on the AUV (rather than the boat). In standard USBL a directional transceiver is mounted on the vessel and is used to determine the range and angle to a transponder on the AUV. A surface vessel is a high noise, dynamic environment, which reduces the achievable accuracy of the solution. Once the range and angle has been calculated on the vessel, this will need to be communicated with the AUV via an acoustic message. Errors are also possible in the synchronization of position updates with the AUV's navigation sensor messages.

The iUSBL solution measures the range and bearing from the AUV and not from the surface. This allows the use of highly accurate INS sensors on the stable low-noise AUV platform for angle estimation. The USBL fixes can also be corrected in real time using the AUV sound velocity sensor information. The positional information obtained by the on-board USBL system can then be fed into the INS solution with the appropriate weighting to maintain navigation accuracy during extended duration surveying. The tight integration of the iUSBL directional transponder with the AUV systems allows it to be closely coupled with the AUV INS, simplifying system calibration and time synchronization, and allowing highly accurate depth sensor correction. Having the USBL transceiver permanently mounted on the AUV in the iUSBL configuration also offers operational advantages, reducing issues with installing a through-hull or over-the side USBL transceiver and eliminating errors from offset measurements. The iUSBL solution is implemented in the Gavia AUV using the Teledyne Directional Acoustic Transponder (DAT-900, Teledyne Benthos, North Falmouth, MA). Trials of this improved navigation solution were carried out in summer 2012 and the results will be released in late 2012.

V. PAYLOAD TECHNOLOGY

A range of oceanographic and geophysical survey instruments can now be mounted on the AUV, either integrated in the control module or mounted in a modular self-contained payload section. This includes depth mapping sonars, imaging side-scan sonars and optical cameras.

An important development in the capability of the small AUV was the integration of a bathymetric mapping sonar. High frequency (500kHz) ‘interferometric’ sonars are often used in boat-mounted hydrographic surveys in shallow water. Compact versions became available for mounting on the Gavia AUV from 2006, and they now are regularly used in commercial AUV surveys. Examples of data from the 500kHz GeoSwath Plus sonar (Kongsberg GeoAcoustics) shows the bathymetric mapping capability that can be achieved (Figure 3). A typical mapping mission will provide full coverage bathymetry over a 1 square km area in about 5 hours. Backscatter data is also recorded, allowing both bathymetry and side scan maps to be produced from one sonar system.

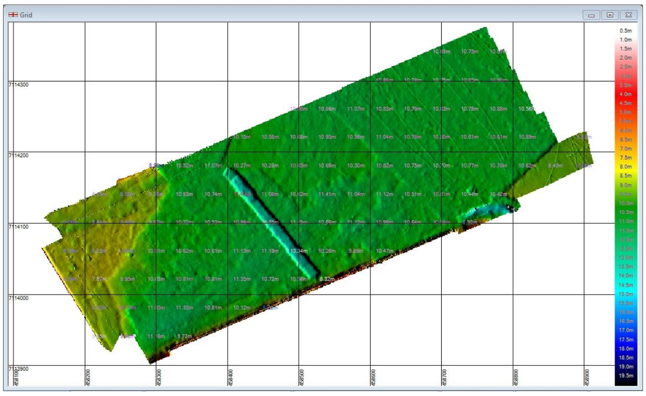

Fig. 3: A high resolution bathymetric survey of a 250m x 700m harbour basin collected by a Gavia Surveyor AUV.

A Gavia AUV will typically be supplied with a side-scan sonar for large area seabed imaging, mounted in the control module. Various side scan systems have been integrated with the Gavia; for example the dual frequency 900kHz/ 1800kHz Marine Sonic sonar (Marine Sonic Technology Ltd, White Marsh, VA); the 900kHz has an effective maximum range to either side of the AUV of 40m, the range at 1800kHz is only 10m but it generates higher resolution images (Figure 4).

For optical investigation of targets a downward-looking camera can be deployed. The camera installed in the Gavia nosecone records color images at a resolution of 800 x 600 pixels, with illumination that is provided by an array of LEDs. Black and white photos can be taken at a higher resolution of 1,600 x 1,200 pixels. At a fly height of 4m above the seabed each photograph images a 4m x 3m area, suitable for identification and classification of targets and debris.

Sub-bottom profilers (SBPs) are a very recent addition to the small AUV toolkit, with the first systems being deployed in 2011. The small AUV size puts a limit on the SBP transducer size and as a result the power and frequency range available.

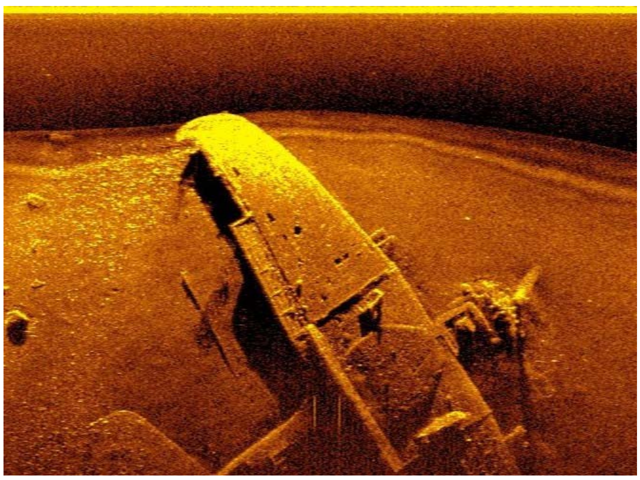

Fig. 4: High resolution side-scan sonar data of sunken second World War aircraft (15m wingspan).

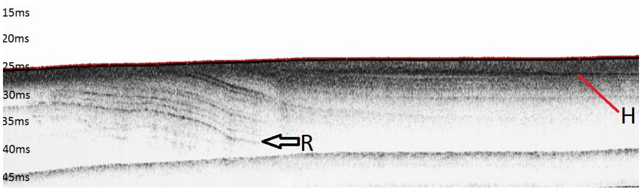

Fig. 5: Gavia AUV SBP data showing horizontal layering, H, and dipping reflectors, R (300m line shown).

Currently the Gavia AUV can include the CHIRP-III SBP (Teledyne Benthos, N. Falmouth, MA) operating in the 14 kHz to 21 kHz frequency band. A four element array is used to narrow the beam pattern and provide penetration of a few meters depending on seabed conditions (Figure 5). One of the strengths of running a sub-bottom profiler on an AUV is its ability to find buried pipes and other man-made structures. The small footprint from a low flying AUV, compared to a ship mounted system, combined with the strong return results in superior positional accuracy.

VI. Increased Automation

One limitation of an AUV survey is that there is no person in the loop to react and adjust mission objectives. This often means that the vehicle will need to be recovered and data analyzed between legs of a mission. To address this problem 'autonomous mission management' systems are being developed which enable the vehicle to react to survey data while on-mission. An example is the SeeTrack AutoTracker module (SeeByte Ltd., Edinburgh, UK), developed for aiding AUV pipeline inspections. This uses the side scan sonar data in order to track a subsea pipeline at the optimal survey offset; a Gavia AUV has successfully surveyed 31km of pipeline in 90 meters of water during a single mission [5]. Further enhancements in autonomous mission management capability are being developed to include autonomous selection of targets of interest and autonomous planning of target investigations.

VII. CONCLUSION

The man-portable low-logistics survey AUV can now perform survey tasks traditionally conducted from a vessel, towed system or ROV, with lower logistics and deployment costs. The ability of a small AUV to access hazardous areas, provide cost-effective force-multiplication, and acquire higher resolution data from deeper water has proven attractive in commercial survey work. As a result small-AUVs are becoming accepted in the oil & gas, engineering and marine environmental sectors, where they are seeing extensive use in pipeline surveys, rig scour, debris clearance and harbour engineering surveys.

Commercial drives have led to requirements for longer, deeper missions while maintaining survey accuracy. Modular AUV design and reduced sonar power consumption has enabled longer endurance, but during an extended mission the DVL-aided INS position solution will drift beyond operational requirements. The use of subsea positioning techniques such as iUSBL increases the accuracy of the navigation solution by providing direct subsea position aiding to the INS in real time. This is particularly useful in small AUVs that are capable of extended deep water missions, such as the 1000m rated Gavia Surveyor AUV in the dual battery configuration. Subsea positioning solutions such as iUSBL have the potential to greatly increase the envelope of operations for the small AUV in commercial survey work, with a low impact on operational logistics.

References

[1] McMurtrie A., "The Efficiencies of Low Logistics Man-Portable AUVs for Shallow Water Surveying", presented at Oceanology International, March 2010.

[2] Trembanis A., Patterson M., and Hiller T., "Exploring Coral Reef Sustainability With New Technologies", Hydro International, vol. 12 no. 7, pp 10-15, Sept. 2008.

[3] McEwen R., Thomas H., Weber D., Psota F., "Performance of an AUV navigation system at Arctic latitudes", IEEE J. Oceanic Engineering, vol.30 no.2, pp 443 - 454, April 2005.

[4] Hiller T., Reed T.B., Steingrimsson A., "Producing Chart Data from Interferometric Sonars on Small AUVs", International Hydrographic Review, no.6, pp43-50, Nov.2011.

[5] Tena I., "Fugro Breaks World Record for Low Logistic AUVs Using SeeByte Software", SeeByte Ltd press release, June 2011.

Approved for public release by Teledyne Benthos FAL1227, 08/27/12.