Positioning Small AUVs for Deeper Water Surveys Using Inverted USBL

Thomas HILLER, Thurne Hydrographic Ltd, Norwich, UK
Arnar STEINGRIMSSON, Teledyne Gavia ehf, Reyjavik, Iceland
Robert MELVIN, Teledyne Benthos, North Falmouth, MA, USA

Topic B: subsea positioning

Introduction

The man-portable low-logistics survey AUV is now capable of rapid deployment and accurate navigation around a sub-sea inspection site, carrying a range of oceanographic and geophysical survey instruments. Over the past five years small survey AUVs have become increasingly 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.

A range of oceanographic and geophysical survey instruments can be mounted on the small AUV. Key equipment used in commercial survey work are depth mapping sonars, imaging side-scan sonars and optical cameras. In many areas the small AUV now offers a cost-effective alternative to a boat-mount, ROV-mount or towed sonar. The small vehicle size and low logistic requirements also confers specific advantages where low disruption, high asset safety, or access to hazardous areas are required. Small AUVs owned by commercial organisations are carrying out survey and inspection tasks on a weekly basis, delivering engineering-quality survey data with high productivity and low logistics costs, and it can be expected that the small AUV will become an increasingly important asset in many subsea survey and inspections roles (see for example McMurtrie 2010). Improvements in vehicle and payload reliability has helped drive system acceptance: experience in commercial deployments over the last 5 years shows that the small AUV is now capable of extended field operations with multiple deployments over multiple days with a variety of beach and boat launched missions to shallow, mid and deep waters.

A key factor in the commercial uptake of the small AUV has been improvements in the quality of the vehicle positioning. A survey platform must be accurately positioned in three dimensions for the sensor data to be useful for engineering purposes. In the small AUV this is achieved using an inertial navigation system aided by a doppler velocity log (INS/DVL) and high accuracy depth sensor. Advances in the integration of navigation-class INS/DVL systems in the 1990s and early 2000s led to a reduction in footprint and power requirements, enabling their use in small diameter AUVs.

The INS/DVL/depth sensor combination can provide positioning suitable for engineering survey and inspection tasks over tens of minutes. Long term errors in the sensors result in a position drift that grows with time, reducing positioning accuracy during extended missions. The size of the positioning error depends on a number of factors, including water depth, water currents, and survey layout. After the AUV submerges a typical error figure would be about 0.05% of distance travelled (e.g. McEwen et al 2005). At AUV operational speeds this error will exceed typical engineering positioning requirements in less than an hour. The positioning accuracy is therefore sufficient for short submerged missions but this is significantly less than the AUV battery life under operational load. Operational 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 can enable the use of small AUVs in many engineering survey roles (Hiller et al, 2011).

The small AUV can be deployed in areas where other survey methods are very costly or difficult. As an example of this, small AUVs are now capable of acquiring higher resolution bathymetry, side scan and sub-bottom data from up to 1000m water depths. 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. 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 increase the accuracy of these surveys and expand the AUV envelope of operations other methods of subsea position aiding are required. Typical options are a boat mounted USBL system or an LBL array. 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), which gives several advantages over traditional USBL techniques.

iUSBL Concepts and Advantages

In standard USBL a directional transceiver is mounted on the vessel and is used to determine the range an angle to a transponder on the AUV. A surface vessel is a high noise, dynamic environment, which reduces the achievable accuracy of the USBL 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 synchronisation of the time of the position update from the USBL system with the AUV's navigation sensor messages.

In the iUSBL technique the directional transceiver is mounted on the AUV and this determines the range and angle to a transponder mounted on the surface vessel. The position of the surface transponder is sent to the AUV as part of the response message, and the position of the AUV can be calculated in the AUV control computer. The iUSBL solution is able to achieve better range and angle solutions over longer ranges because the AUV-mounted directional transceiver is in a low noise, low dynamic environment. 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 synchronisation, 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.

Equipment

This paper presents results from an iUSBL solution implemented using the Teledyne Directional Acoustic Transponder (DAT-900, Teledyne-Benthos, North Falmouth, MA) system on the Gavia Surveyor AUV (Teledyne Gavia ehf., Reykjavik, Iceland).

The Gavia Surveyor AUV is a widely used low-logistics 20cm diameter commercial survey AUV. It is fully modular and can be rapidly assembled in the field in various mission-specific configurations. The Gavia Base Vehicle consists 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 used in commercial survey work, has additional positioning and payload modules (see figure 1 for an example of a Gavia configured for bathymetric survey). When configured for commercial survey work the Gavia includes: a differential-ready GPS receiver; a SeaNav T24 INS (Kearfott Corporation, Little Falls, NJ); a Teledyne WorkHorse 1200 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. The Gavia control module can be equipped with the DAT acoustic modem configured as a iUSBL system. 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.

Figure 1: The Gavia Surveyor AUV showing typical modular payloads. From Right: nosecone, battery, DVL/INS (Kearfott T24), control with GPS and acoustic modem, GeoSwath, propulsion.

The DAT iUSBL system is an extension to the Teledyne Benthos Telesonar modem. The DAT operates as a modem combined with a high precision range and bearing estimation system in one integrated package. The system uses a broadband component of the modem message to form estimates of the azimuthal and vertical arrival angles of a message sent by a remote modem. The use of broadband signal technology gives improved noise immunity, increased dynamic range and greater accuracy. Appropriate processing of wide band signals provides far better combined range and arrival angle estimation, especially at low SNR, than tonal signals. The DAT-900 is able to operate on Low frequency (LF) 9☐14 kHz, Mid frequency (MF) 16☐21 kHz or Band C (C) 22 – 27 kHz. For the Gavia the Band C frequency range was chosen to reduce any interference with the sub-bottom profiler module.

Figure 2: Gavia Control Module fitted with DAT iUSBL system

Deployment of small AUV systems in commercial application requires a high level of reliability combined with ease of use. This requirement has driven developments in integration of the DAT system and the Gavia vehicle, along with improvements in the interface with the Gavia control software for the iUSBL set-up, mission planning and control.

The DAT transceiver can either be mounted on the Gavia control module just ahead of the GPS antenna tower (figure 2) or in a separate module capable of installation on existing vehicles. It broadcasts an acoustic request which triggers the transponder, which is usually pole mounted on the boat with a differential GPS. The responder replies with a message that includes all pertinent data required to calculate a subsea location. The DAT calculates the round trip travel time in order to measure range to the surface node and the hydrophone array determines the vertical and azimuthal angles to the transponder. This is combined with the AUV orientation data (from the INS) and the transponder position (in the transponder message) to obtain the position of the AUV. If the sound velocity between the pole-mounted transponder and the AUV is not constant then the range and angle data will need to be corrected for the path of the sound through the water. During the dive to survey depth the AUV can collect the sound speed profile, and this can be used to correct to the estimated range and angles. Using the bearing, sound velocity profile, range, and location of the surface DAT node, and distance AUV has travelled during the USBL request, an accurate position can be calculated and used to aid the INS.

The estimation of the AUV position determined by the iUSBL technique will therefore have an error which depends on the acoustic environment and signal to noise level, and this needs to be taken into account when combining the iUSBL fixes with the other positioning data. In the INS the various sensor inputs (INS, DVL, GPS, depth and iUSBL) are combined in an extended Kalman filter. The objective is to provide the best estimate of the 3-D trajectory of the vehicle by combining all sensor information available, using appropriate weighting: the INS provides linear and angular accelerations; the DVL provides velocity; the GPS provides surface position; and the iUSBL system provides subsea position. In applying the iUSBL fix to the navigation care needs to be taken to use the correct weighting for the data, and to apply appropriate error models in the Kalman filters. The weighting of the fix will be variable based on the range and signal to noise levels. To help constrain the error the INS will perform filtering of the USBL fixes, and the system will not jump to a USBL fix unless commanded to do so.

Trails Results and Discussion

Integration of the DAT with the Gavia AUV took place in the first half of 2012. During the summer of 2012 a series of trials were run near Reykjavik, Iceland, to test the performance of the DAT iUSBL solution. The trials tested the positioning performance in multiple shallow extended and deep missions in various typical survey environments, and compared these with expected performance and performance without the iUSBL navigation aiding. Selected targets on the seabed were used to provide confirmation of the integrated system positioning accuracy and repeatability. At the time of writing of this paper these results were not available for release, and will be presented at the conference where an updated version of this paper will be made available.

Conclusion

The use of iUSBL in small AUV deployments increases the accuracy of the navigation solution by providing direct position aiding to the INS in real time. This addresses two current problems in small-AUV navigation: during an extended mission the DVL-aided INS position will drift beyond operational requirements in a much sorter time than the vehicle endurance; and in deeper waters the lack of DVL bottom-lock during the descent results in significant unaided INS drift. This is particularly useful in small AUVs that are capable of deeper water missions, such as the 1000m rated Gavia Surveyor AUV. The iUSBL solution has the potential to greatly increase the envelope of operations for the small AUV in commercial survey work, with a low impact in the operations logistics, deployed equipment, and system cost. Results from the trials of the DAT-900 modem on the Gavia Surveyor AUV illustrate the navigation improvements achievable with this technology.

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Author Biographies

Dr. Thomas Hiller obtained his PhD in experimental physics in the semiconductor sector, becoming involved with marine sonars in 1998 at Submetrix Ltd. He has managed interferometric sonar product lines at three different sonar manufacturers, including six years as Advanced Products Manager at GeoAcoustics Ltd., manufacturer of the GeoSwath sonars. He deployed the first interferometric sonar mounted on a man-portable AUV in Reykjavik Harbour in 2006. In 2011 Tom set up Thurne Hydrographic Limited to provide engineering consultancy, marketing representation, survey support, and data processing services to the worldwide hydrographic industry.

Arnar Steingrimsson heads up the sales and marketing department for Teledyne Gavia in Kopavogur, Iceland, and has since 2003 been involved in marketing, selling, and business development projects related to the Gavia AUV. Arnar has led the introduction and adaption of the Gavia AUV technology to international military, commercial and scientific users, with a recent emphasis on the commercial survey / hydrograhic use of the Gavia. Previous to joining Hafmynd / Teledyne Gavia, Arnar served in the US Navy on surface ships and amphibious construction battalions in various positions and has degrees in finance and international business from the University of North Carolina at Wilmington.

Robert Melvin is the Vice President of Engineering at Teledyne Benthos which includes Teledyne Gavia and Teledyne Webb Research. He has over 25 years of experience in both engineering and program management and is responsible for overseeing all of engineering including the GAVIA autonomous underwater vehicle and the Slocum glider. He has successfully managed numerous development programs for the U.S. Navy and commercial customers. Previous to Teledyne Benthos, he was engineering manager at Hydroid, Inc. While at Hydroid, Mr. Melvin spent over three years designing, developing, and operating autonomous underwater vehicles. During this period, he was the program manager working with the U.S. Navy EOD (Explosive Ordinance Disposal) team developing the Swordfish version of the REMUS-100. Previously he has held positions at Lockheed Sanders and the National Security Agency. He holds three U.S. Patents in the area of signal processing.