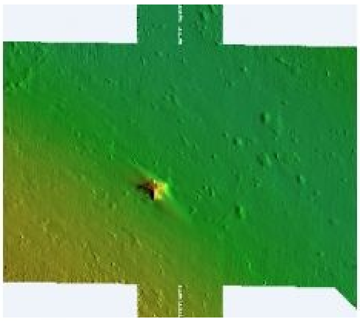
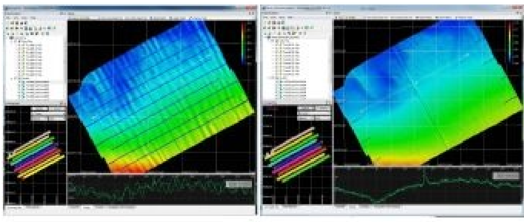
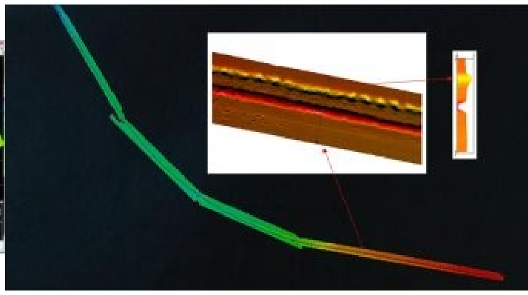
Building a Bathymetric Uncertainty Model for AUVs







Fleets of small AUVs are used to survey pipeline routes, rig scour and debris clearance, and for harbour development. While AUV bathymetry can be as good as or better than boat-mounted data, some of the concepts behind the error budgets are very different. This must be understood by the hydrographic surveyor so that they can deploy the AUV appropriately and qualify the data properly.

Recent advances in Autonomous Underwater Vehicle technology have led to low-logistics vehicles able to collect survey-quality data useful for engineering objectives. This class of AUV is easy to transport to site, quickly deployed and operated by a very small team. Fully modular AUVs provide a level of capability and flexibility that was impossible to achieve with earlier partly modular or monolithic AUV systems, and commercial organisations now operate multiple fleets on several continents.

The AUV can be considered as a truck for carrying sensors to the survey site. The bathymetric sonar on the AUV measures ranges and angles to soundings on the seabed, and the position of a sounding can be located relative to the AUV using an attitude sensor. These error concepts are very similar to a boat-mount spread. To georeference the data you also need the AUV position and depth. Here the boat-mount survey concepts are not so useful. This article presents some of the concepts that are unique to the AUV survey.

The AUV positioning system consists of a GPS on the surface and an Inertial Navigation System coupled to a Doppler Velocity Log (INS/DVL) for subsea, along with a high-precision depth sensor. Information from these sensors is combined in a Kalman filter to give position and depth. The individual sensors in the AUV will have errors in their measurements which can be related to a position and depth uncertainty. The issues in doing this are best illustrated using examples: this paper takes examples from the Gavia AUV.

The Gavia AUV

The Gavia AUV was developed by Hafmynd Ltd. (now Teledyne Gavia ehf, Reykjavik, Iceland) in the late 1990s. It was the first commercially available fully modular vehicle system and the first compact AUV capable of deepwater (1000m) operations. The 20cm diameter Gavia base vehicle can be enhanced by adding various sensor, navigation, and battery modules.

The Gavia AUV can be rapidly assembled in the field in various configurations. A common configuration for commercial survey work includes: a T-24 SeaNav Inertial Navigation System (INS) (Kearfott Corporation, Little Falls, NJ) or a Rovins154 (iXBlue, Marly le Roi, France); 1200kHz WHN Doppler Velocity Log (DVL) (Teledyne RDI, Poway, CA); Keller 33-Xe depth sensor (Keller-Druck, Winterthur, Switzerland); GeoSwath 500kHz wide swath bathymetric sonar (Kongsberg GeoAcoustics, Great Yarmouth, UK); AsteRx Global Positioning System (GPS) (Septentrio nv., Leuven, Belgium). This combination makes up the majority of the small AUV systems currently deployed in the industry for swath bathymetric surveys.

Uncertainty and Time

The error budget for a boat-mount survey is the same for the first and last ping. The AUV survey is different, with some errors that grow with time. One of the core INS sensors is an accelerometer, which is integrated twice to give position, giving an uncertainty that grows as time-squared. The INS will be aided by a Doppler Velocity Log (DVL), which reports the velocity of the AUV over the bottom. This velocity still needs to be integrated to give a position, and any bias will result in drift. Because the drift error is body-relative, any turns and reciprocal lines reduce the error, so a lawnmower pattern will give much reduced errors compared to running the AUV in a straight line. This also means that pipeline route surveys should be run in sets of short lines, rather than a few very long lines.

Position uncertainty will also arise from the AUV heading error. The AUV heading accuracy is determined by the gyrocompassing capability of the INS. This heading error is slowly-varying and body-relative. The magnitude of the error depends on INS specifications and also the latitude of the AUV. In a lawnmower survey pattern the final error will again be less than a long, straight line.

This growth of errors with time determines how long the AUV can operate once submerged. External position aiding extends this, either via GPS pop-ups, USBL or LBL fixes, or referencing from a bottom feature.

Getting Down and Deep

In deeper water the DVL will be out of range from the surface, giving a 'free inertial' INS error during the dive. Since the errors are body-relative, a 'descending box' dive pattern will help. In addition, the sensor output is not directly translated into position: it goes through a Kalman filter. The error in a short dive can be significantly reduced by good GPS aiding on the surface, improving the Kalman's estimates. In practice, the free-inertial drift can also be reduced using the 'water column navigation' DVL mode, and USBL or LBL aiding.

Error Timescales

Usually measurement errors are divided into two regimes: random noise and offsets. This is an oversimplification; the AUV surveyor should understand how errors can change over time, and how this relates to sensor specifications.

One key error source that has a time varying component is the depth, obtained via the pressure sensor. The pressure sensor error will be a percentage of full scale. For deep-rated AUVs this could be interpreted as a large contribution to the depth error budget, especially for shallow-water surveys. But this specification refers to the absolute value of pressure, which depends mainly on sensor calibration. This is stable and drifts only slowly over years. Also, the absolute pressure is not of interest - it is the differential pressure between the surface and the AUV that is needed. During an AUV operation the pressure sensor is tared (zeroed) on the surface and the difference from this zero is used to calculate the AUV depth. This difference is a lot more accurate than each absolute pressure reading, giving a depth accuracy of the order of the instrument resolution.

AUVs in Swell

Depth is measured using pressure, but the surveyor should understand that pressure is only a proxy for depth. Also, depth is relative; the depth compared to a fixed (tide) datum is required. The pressure can be translated into depth below the surface using the water density, assuming a flat surface. This is not always a good assumption: swell can have a significant effect on pressure to many meters below the surface. Sensor error models in the Kalmans are not a valid way to account for this.

The measurement physics helps here. The INS accelerometers are sensitive to the swell-induced motion, so the combination of accelerometer and pressure sensor can give centimetric depth errors even in the worse swell, given appropriate sensor models. Updating the way the sensor data is handled in the INS is an ongoing research field, and further improvements can be expected. Longer term effects which change the water level such as tide and atmospheric pressure changes should be measured by a local tide gauge and merged with the AUV depth data during postprocessing, as in a boat-mount survey.

Combining Errors: the Kalman Filter

The traditional boat-mount approach considers errors as random and independent, so they can be combined using 'sum of the squares'. In the AUV, the position and depth are the output of a Kalman Filter. A Kalman filter is a complex (but well understood) mathematical construct; an important concept is that the Kalman generates internal error estimates and applies these to its outputs, and these estimates depend on the measurement history and sensor models. Recently some effort has been put into updating AUV INS systems to reflect modern sensor advances.

Real-time Kalman filters can only use historic sensor data. The same data stream can be recorded, allowing post-processing using both past and future data to refine the Kalman filter's outputs. This also allows intervention where error models break down, for example removing USBL jumps when the topside passes through a boat wake. Post-processing software is now available for several brands of INS.

But how should sensor uncertainties be propagated through a Kalman filter? The Kalman filters themselves provide an estimate of uncertainty which can be used most of the time, but this cannot be relied on in all circumstances, for example when the sensor model assumptions break down. A knowledgeable & experienced survey professional should still qualify AUV-delivered data, as for boat-mount data.

Conclusions

The man-portable fully modular AUV is now a well-used survey tool, capable of rapid deployment and accurate navigation around a subsea site, collecting a range of high-resolution datasets. These AUVs are frequently used to perform survey tasks traditionally conducted from a vessel, towed system or ROV, and can deliver surveys with very high productivity and low logistics costs. AUV system error models are not the same as those used in boat-mount surveys, and the survey professional in charge of the AUV job should understand the differences. This understanding leads to better AUV mission planning and more appropriate reported error budgets.

Tom Hiller's current role is Senior Applications and Sales Engineer at Teledyne Gavia. He has worked with small AUV systems since 2006, joining Teledyne in 2012 to help develop the market and applications in the offshore energy sector for the Gavia AUV. This article gives a qualitative description of error concepts for AUV bathymetric surveys. A white paper with a quantitative analysis for the Gavia AUV

will be available from Teledyne Gavia later in 2014.

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