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Guiding principles

As their mission set expands, precision navigation technology is key to the successful deployment of UUVs. **By Rory Jackson**

UUVs now cover a broad range of missions, from mine countermeasures and surveying in shallow waters, to deep-water oceanography, marine biology, pipeline monitoring and other operations at depths hazardous to humans. Accurate and persistent navigation readings are vital to carrying out these roles safely and expediently.

Unmanned vehicle navigation generally relies on global navigation satellite systems (GNSS) for continuous and accurate positioning. However, UUVs cannot take advantage of SATCOM due to the opacity of seawater affecting electromagnetic signals, which quickly attenuate over sub-sea distances. GPS and similar systems are only useful for AUVs and ROVs if they persistently surface.

However, a number of systems are available to help UUVs localise themselves within an underwater map, and navigate from one point to another while avoiding obstacles and compensating for ocean currents. These technologies continue to develop and advance in line with the evolving requirements of UUV operators, such as SWaP optimisation and cross-platform aiding.

Dead reckoning

Inertial navigation systems (INS) have historically consisted of a computer connected to gimballed accelerometers, gyroscopes and sometimes magnetometers in an inertial measurement unit (IMU), to determine a UUV's position, velocity and orientation.

Modern INS products for UUVs differ from this in two ways. First, due to the complexity and expense of maintaining gimballed IMUs, commercial UUVs increasingly take advantage of 'strap-down' IMU blocks – often using microelectromechanical (MEMS) parts to optimise for SWaP and cost – while still achieving comparable accuracy in attitude data.

Second, attitude and heading reference systems (AHRS) are increasingly replacing IMUs. By using integrated processing units rather than a separate computer, they often achieve improved accuracy and reliability of navigation data.

These changes are manifest in VectorNav's new tactical series INS. The VN-110 IMU/AHRS measures 56x56x23mm ▶

The new Sea Wasp from Saab Seaeye uses the Teledyne RDI Explorer DVL to determine speed over the seabed. (Image: Saab) and weighs 160g. It benefits from 4GB of onboard memory for data logging and below 1° per hour in-run gyro bias stability, while consuming no more than 2.5W of power.

Launched alongside the VN-210 and 310 GPS/INS in May, it is well suited to underwater applications, with each VN-110 individually calibrated over the full operating temperature range of the sensor (-40 to +80°C) to allow for sensor bias, misalignment and scale factor errors – common INS concerns for long sub-sea missions. Both the VN-110 and its predecessor – the VN-100 – incorporate MEMS three-axis measurement devices, with data rates of up to 1kHz and a real-time attitude solution continuous over 360° motion.

'The VN-110, however, provides improved estimates for pitch and roll, due to the incorporation of an IMU that performs close to an order of magnitude better than the VN-100,' commented Jakub Maslikowski, director of sales and marketing at VectorNav.

'In addition to the improved IMU, the VN-110 includes the capability to integrate measurements from external sensors, such as external magnetometers, external [fibre-optic gyroscopes] FOGs and so on. It is also software compatible with the VN-100; users can replace their VN-100 with minimal integration effort,' he concluded.

Small world

VectorNav's tactical INS series also shows the trend towards SWaP-optimised systems. Though generally true for all avenues of technological progress, modern sub-sea navigation exhibits a pervasive commitment to this evolution.

Nortek's new Doppler Velocity Log (DVL) represents a key part of this, as company DVL sales manager Eric Siegel emphasised. 'We got to work to design from the ground up a new DVL that would be focused specifically for SWaP-constrained applications. We believe that SWaP-optimised products are the future of the industry. You can imagine applications such as advanced navigation control for autonomous small ROVs and AUVs, and underwater drones used to explore mines, caves and wrecks.'

The 1MHz cylindrical DVL measures roughly 135x148mm, weighing 900g in water and consuming 1.3W on average. The module can also store 16 or 64GB of internal memory and operate at -4°C, making it suitable for small ROVs and AUVs weathering colder climates.

Tracking exact positions can call for more accurate depth measurements than a DVL can provide. Valeport's ultraP pressure sensor detects depth to 0.01% accuracy and operates at different depth/pressure ranges depending on the user's requirements – from 10bar up to 600bar. The device is fitted into a 90mm-long, 300g titanium pressure housing, and depth variants are easily exchangeable by way of an RS485 interface and connector options that allow customers to pre-fit bulkhead arrangements.

Kevin Edwards, sales and marketing manager of Valeport, said that the ultraP, based on the company's popular miniIPS (intelligent pressure sensor), had been 'stripped back' for size reduction, fixed-voltage input and data output in RS485.

He continued: 'The pressure sensor is a temperature-compensated piezo-resistive sensor, which in combination with Valeport's control circuitry delivers performance previously only available from a resonant quartz sensor, but more cost-effectively. Its smaller and more robust construction ensures complex and vulnerable arrangements of diaphragms and oil-filled capillaries and reservoirs are no longer necessary.'

While products like the VN-110 and ultraP are designed to excel at a specific role, others aim to accomplish several. The ISA500 from ImpactSubsea consists of a combined altimeter and AHRS to provide close readings of not only altitude, but heading, pitch and roll as well. The altimeter emits a 500kHz acoustic pulse into the water which, upon contact with the seabed, is partially reflected. The reflected pulse is detected by the ISA500 and the time taken for it to return is recorded to determine the altitude above the seabed, accurate to 1mm and with a maximum range of 120m.

The AHRS also provides heading to ±1° and pitch and roll to 0.2° accuracy over ranges of ±90° and ±180° respectively. The multi-echo output capability, in which acoustic pulses can be emitted both upwards and downwards, means that the ISA500 is suited to measuring wave height and ice thickness in polar regions, alongside more obvious roles in underwater positioning and hydrographic survey.

Acoustic positioning

INS technology does not make for effective localisation of a UUV within a map. Acoustic communications are far better suited to the marine environment than GNSS and continue to advance. AUVs and ROVs can be tracked once the location of the acoustic transponders and transceivers has been found, either relative to each other or with GNSS co-ordinates.

Products continue to be innovated for ship-based ultra-short baseline (USBL) acoustic systems. Earlier this year, UK-based Applied Acoustics launched the Nexus 2 USBL system, consisting of the 15kg factory-calibrated, multi-element EasyTrak Transceiver head depth-rated to 30m from the fore or aft of a ship, and the EasyTrak Nexus 2 Console with embedded graphical navigation interface for assisting in digital communications with the transceiver.

The Sigma 2 digital acoustic coding, a proprietary set of bi-directional spread spectrum acoustic protocols from AAE Technologies Group, working with a complementary transducer design, means that positional accuracies – the Nexus 2's raison d'etre – have been improved by up to 0.2% slant range. Additionally, the system can track up to 16 vehicles simultaneously over a range of 2,500m (with a 995m option available), operating at frequencies between 18 and 34kHz.

Along with improved accuracy, a crucial objective of the secondgeneration upgrade was to bring up performance by increasing tracking distance and ensuring the repeatability of the calculated target position.

Technical manager Neil MacDonald elaborated further. 'The tracking transducer was completely re-designed. The 2,686 electronics have been re-engineered to increase the dynamic range and sampling capabilities. In addition, Sigma 2 has improved sensitivity and noise immunity. As a consequence, the resulting margin of error with a Nexus 2, compared to previous systems, is reduced by a minimum factor of five.'

The positioning system may be used with AAE's older 1000 Series beacons and the 1200A and 1300A Micro beacons, as well as newer and more accurate 1100 Series products. These were launched alongside the Nexus 2, and are capable of operating for up to 55 hours at one pulse per second, with rechargeable NiMH batteries and are compatible with the USBL systems of other major sub-sea navigation companies such as iXBlue, Kongsberg and Sonardyne.

UK-based Sonardyne's USBL portfolio includes the successful Ranger 2 system, which extends beyond 6,000m and can track up to 99 targets if upgraded to the Ranger 2 Pro version with options for inertial aiding and LUSBL – a combination of USBL and long baseline (LBL), which saves time in calibrating the LBL arrays by using a 'top down' calibration technique as transponders are deployed.

These can be combined with USBL vehicle transceivers such as the newer Wideband Sub-Mini 6 Plus, which offers full two-way wideband support – interrogation and reply signals – as well as support for signals from Sonardyne's legacy systems such as Wideband V2, WBV1 and HPR 400.

Additionally, Sonardyne's Fusion 6G LBL system remains widely used for missions over greater areas. Users first install Compatt 6 transponder arrays around the target area and measure the distances between them. The sixth-generation Fusion system allows for each Compatt to range to every other simultaneously, before telemetering the information back to the operators. As the company posits, an eight-Compatt array calibration that would have taken over 90 minutes to complete can instead be performed in less than 15 minutes.

The Bluefin-12 AUV now carries the Solstice side-scan sonar from Sonardyne, which delivers images in high resolution. (Photo: Bluefin Robotics)

The Dunker 6 LBL transceiver is then deployed from the surface vessel for positioning and data retrieval. Both AUVs and ROVs can be equipped to function in this LBL field, as Sonardyne's head of marketing David Brown explained: 'RovNav 6 is a remote LBL transceiver for ROVs, triggered by the vehicle's umbilical. We also have an instrument called Av-Trak 6 which is an LBL transceiver for AUVs. It also has a USBL transponder/responder mode, and can be used to send small packets of data and mission updates.'

All three modules offer ranging precision of 15mm or greater, and the UUV transceivers are depth rated to at least 3,000m and 5,000m, with a 7,000m rating available on request.

Deep blue

In practice, UUVs will combine inertial, acoustic and geophysical navigation to maximise the versatility and precision of operations, and to counter the weaknesses of each, such as INS bias errors or acoustic positioning bandwidth limitations. The Bluefin-12 AUV from Bluefin Robotics was designed with a suite of onboard navigation systems from Sonardyne, the latest addition being the integration of the Solstice side-scan sonar.

With improved coverage rates over previous generations (±100m), Solstice's onboard processing delivers geocoded side-scan imagery for automatic target recognition and post-mission analysis. A 'back-projection' beam-forming technique focuses 65 beams from either side on every point over a 1x1 pixel grid over the entire swath. To minimise distortion at longer ranges, micro-mosaicing algorithms stitch 'tiles' together, displaying objects in high resolution and contrast, with minimum geometric asymmetry.

In addition to the Solstice, the Bluefin-12 uses numerous other Sonardyne products. The Wideband Mini Transponder installed in the rear is coupled with the Ranger 2 for USBL tracking, and the Av-Trak 6 can provide for LBL systems. The Sprint-aided INS, with over 100Hz output rate and integrated AHRS, can be combined with USBL or LBL positioning for even higher fidelity, and complemented with Janus INS post-processing software to refine collected data, and potentially eliminate the effect of real-time problems such as system configuration errors or sensor data loss.

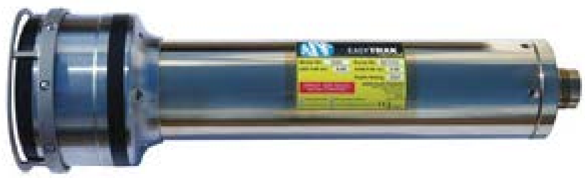
For additional safety, the forward-looking navigation and obstacle avoidance sonar NOAS installed in the front of the Bluefin-12 detects and classifies potential obstructions to safe travel using both 2D and 3D navigation. The former mode provides crucial long-range navigation data to guarantee a safe course, and the 3D sonar scans the seabed and the water column in front of the AUV for closer detection and classification of obstacles. In critical moments, manual control is possible through the uComm acoustic modem and BlueComm optical communications technology, which enables 20Mb per second of real-time video data to be transmitted wirelessly to users.

The pervasiveness of Sonardyne technology is also visible with possibly the biggest ROV debut of 2016. As Saab Seaeye's defence sales manager Chris Lade commented to *UV*: 'An acoustic positioning system needs to be quick and easy to set up and this is hard to achieve with USBL or LBL systems... We have had good results testing with Sonardyne equipment.'

The Sea Wasp was assembled by Saab Seaeye, which leveraged technology from its existing line of commercial ROVs and added capabilities previously developed for its military systems. The company then worked with the US underwater hazardous device response community to adopt it for EOD purposes and procedures.

Intended as a cost-effective and hydrodynamically stable tool for mine countermeasures without risking human lives, the Waterborne Anti-IED Security Platform (WASP) relies on precise navigation systems to acquire and communicate accurate and real-time data to its control console located onboard the support vessel, or from a control vehicle ashore, by means of a fibre-optic tether from which it also takes its power.

The ROV's sensor and navigation suite is primarily designed to locate targets that may have been placed on a ship's hull, a harbour wall or the seabed. The Sea Wasp then uses a range of tools and techniques to identify the nature of the threat and the optimum method for disposal.



The 15kg EasyTrak Nexus 2 Transceiver head is depth-rated to 30m. (Photo: Applied Acoustics)

Saab's Sea Wasp uses the Teledyne RDI Explorer DVL to ascertain speed over the seabed and altitude up to 66m (or 81m if using a phased array transducer). For inertial navigation, 'The IMU is a fibre-optic gyro with "a few degrees drift" per hour, good enough to find true north with our algorithms,' Lade said, adding: 'The goal for selecting these navigation systems was to keep an eye on the true-north heading, and to maintain very light drift and stable station keeping.'

The new ROV also carries a multi-beam forward-looking sonar and two colour cameras, one of which is situated on the arm. Though not integrated with navigation primarily in mind, Lade confirmed: 'We are, going forward, looking at image processing and sonar processing to complement the DVL.'

The swarm

Newer still is the concept of using swarms of small AUVs for wide-area monitoring. Though constrained by the complications involved with guiding multiple vehicles, swarms could one day become the method of choice for surveying multiple locations simultaneously and providing a dense and temporally consistent data cloud. Applications such as tracking and mapping outflow plumes of water treatment and desalination plants, and live monitoring of particle plumes during dredging operations, would be made significantly easier.

Swiss company Hydromea has designed and produced the 7kg Vertex micro-AUV to fulfil this role, along with the technology for multiple Vertexes to cooperate and communicate as a swarm.

Besides size and cost constraints, the key challenge faced by Hydromea lies in most underwater navigation and communication equipment assuming that only one or a handful of vehicles is within telemetry range at a time. This inefficient use of available acoustic bandwidth made scaling this approach up to larger swarms troublesome, especially when forced to rely on existing communication and ranging technology earlier on.

Its labours have resulted in a novel workaround. 'By exchanging navigation information, each vehicle can improve its position estimate by taking the other AUVs' estimates into account,' explained Hydromea's co-founder Alexander Bahr. 'A GPS fix obtained by a single surfacing vehicle can drastically improve the accuracy of many nearby AUVs. Typical AUV navigation sensors like FOGs and DVLs are presently too large and expensive for our AUV, so we utilise a MEMS-based AHRS in combination with a custom-built communication and ranging system, and the software operating all these systems is designed from the ground up to make use of the multiple AUVs and the tight integration of all systems.

'Obtaining a photomosaic of the sea floor or finding unexploded ordnance with a magnetometer are two additional applications where a single AUV can only cover a small area during a given time. Both of these applications can be drastically sped up using swarm technology.'

The implications of achieving successful swarm navigation must not be underestimated. Aside from clear oceanological uses, swarms of AUVs could one day be used to monitor vast swathes of oceans persistently and at low cost for narcotics and human trafficking. Fisheries, oil rigs and refugee convoys could all be surveyed and protected more effectively, should swarm navigation become a standard for UUV developers.

Beyond the sea, the implications could be greater still. The third offset strategy for the US revolves around new doctrines of military deterrence against China and Russia based on compensating for the 'mass' absent from many modern Western militaries, potentially through swarms of autonomous systems (with UUVs being a key area for development). Smaller nations may also invest in swarms of aerial and underwater drones as a cost-effective means of deterring the overwhelming military capabilities of superpower forces. ■