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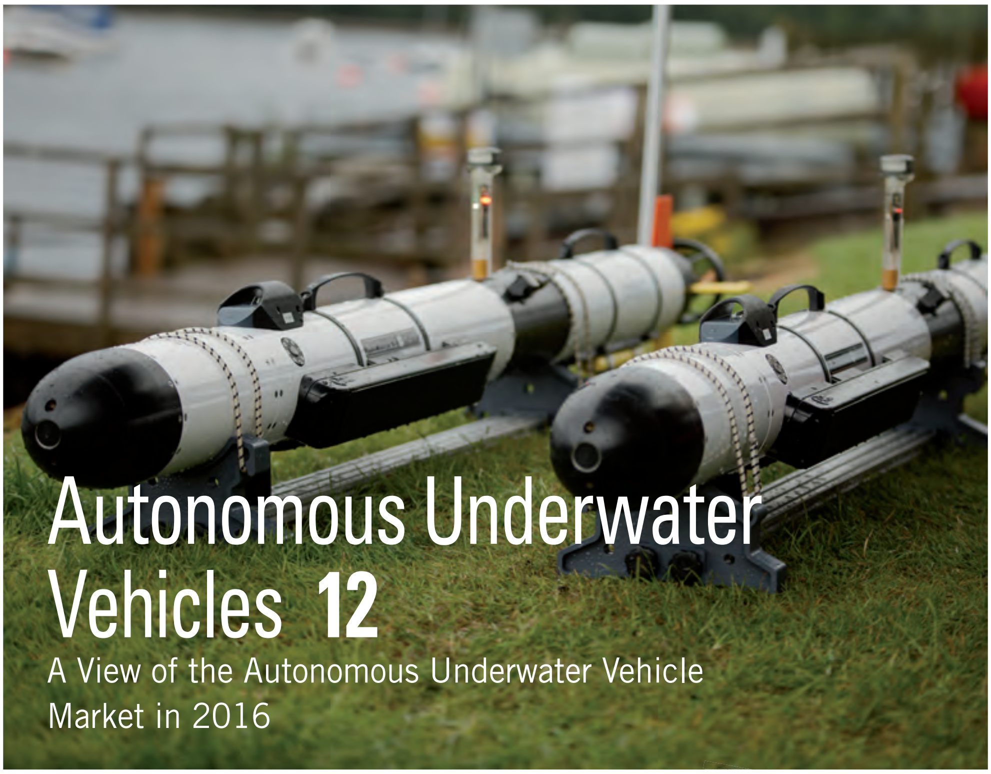
UNMANNED SYSTEMS SPECIAL 2016 | VOLUME 20

UNMANNED SYSTEMS SPECIAL

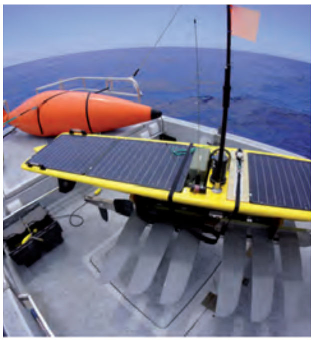
## Bering Strait ASV Enforcement

AUVS IN HYDROGRAPHY
VIEW OF THE AUV MARKET IN 2016

## Oceans of Earthquakes












**Unmanned Systems Special 2016 Volume 20**
*Liquid Robotics Wave Glider and Boeing aircraft seen from below. The image was created visualising the cooperation between the companies for Anti-Submarine Warfare (ASW). Image courtesy: Liquid Robotics.*



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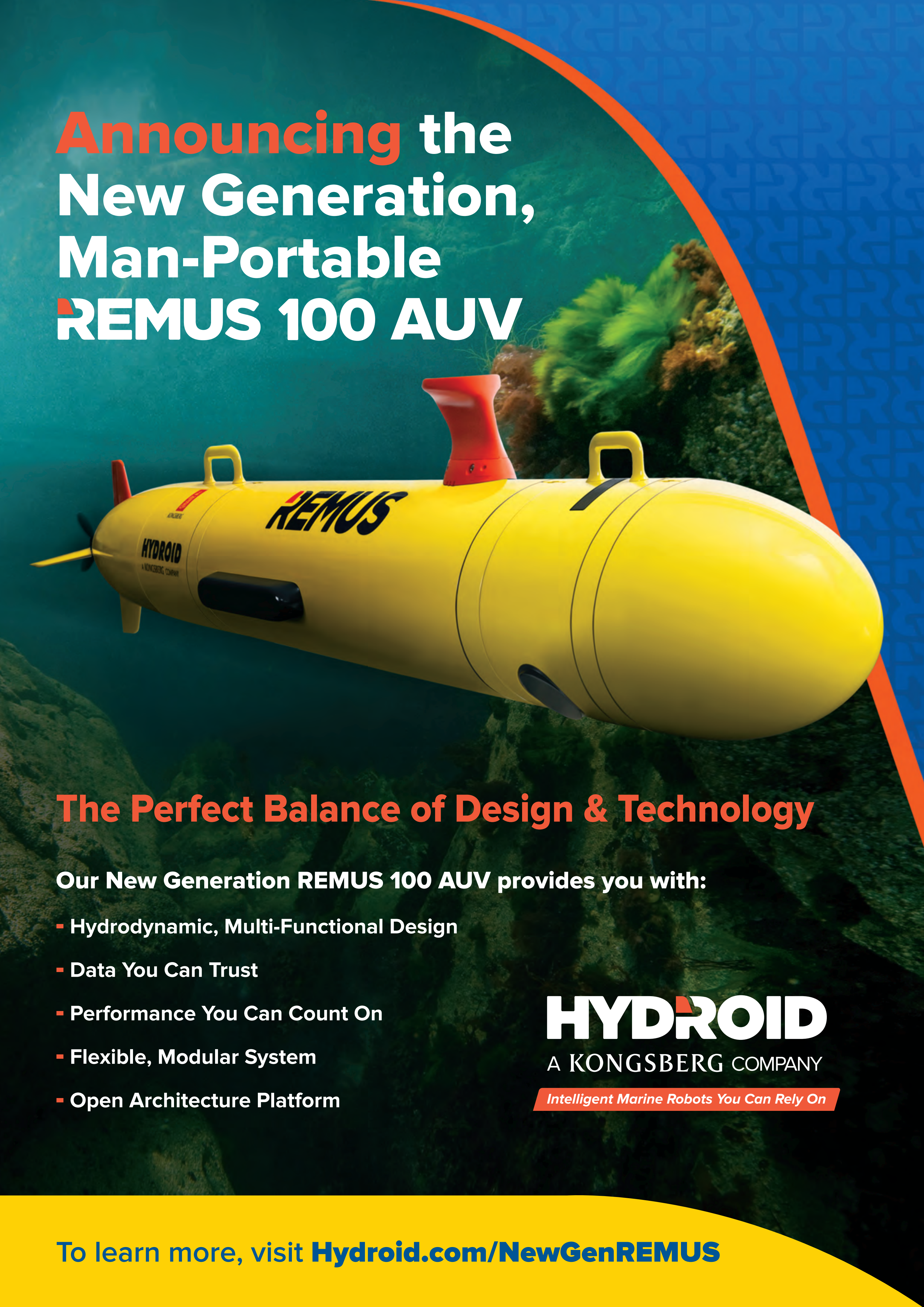
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# Contradictory

Welcome to this third edition of the Unmanned Systems special of *Hydro International*. It's the most successful so far. Many manufacturers are showcasing their products in the issue and to be honest, it was actually quite easy to collect an array of articles for this special to keep you up to date with all the developments in this fast growing sector of our industry. It all sounds quite contradictory. Wasn't the offshore industry in a slump? And aren't large companies laying people off by the hundreds, if not thousands? Yes, that might all be true. But maybe the community around the building and deployment of Unmanned Systems at sea is showing opportunities that could serve as an example. I would like to point out our overview article Autonomous Underwater Vehicles on page 12 by Ioseba Tena, a regular author for *Hydro International*, who shares an overview of the market in 2016: where are we and where are we going? Ioseba Tena makes an interesting remark, namely that he holds the low oil price responsible for the growth in this part of the market. The low oil price is probably the most talked about issue at board meetings, conferences and tradeshows and other opportunities including two or more hydrographers. The dip in the oil price has seen a reduction of work in the offshore sector, and oil companies and suppliers in the chain are looking for more cost efficient ways to operate leading to an increase in the use of AUVs, just because of their level of technical and operational maturity at a very competitive price. Tena identifies a second trend: smaller vehicles with bigger impact. It is exactly this that makes deployment easier and again, cheaper. Big systems are there as well. They might very well serve the needs of companies needing to survey large areas and sometimes even replace vessel and crew – and of course in that sense – although big, may save costs in the end. On the edge of traditional hydrography much research is being conducted on habitat mapping, marine renewables and fisheries, to name but a few. AUV technology is very much a part of the scope of the researchers in these fields. Indeed, it's really not very bad for the AUV sector in this year of suffering for traditional hydrography. Hopefully the manufacture and deployment of all these systems, old and new, small and big, close and far away, can serve as a contradictory development to the general mood in our sector. I hope you enjoy reading this special, that it inspires you and that it helps your business!

**Durk Haarsma** durk.haarsma@geomares.nl


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## Underwater Robot to Sample Below Antarctic Ice Shelves

An underwater robot that will help scientists answer important questions about the Antarctic is due to arrive at the University of Tasmania in Tasmania in early 2017, thanks to a contract awarded to International Submarine Engineering (ISE). Capable of diving to depths of 5,000 metres and travelling over 100 kilometres under metres of thick ice, the 'Explorer' class autonomous underwater vehicle (AUV) will be programmed to collect data on research missions.

▸ *bit.ly/2a0yNeP*

*ISE Explorer for University of Tasmania. Image courtesy: ISE.*

## Using ROVs for Mining

In the oceans offshore Japan, the seabed still holds a wealth of gold and other valuable mineral reserves created by hydrothermal activity. Seeing the potential for extracting these minerals, Tokyo University has engaged Kaiyo Engineering, a specialist marine science company, to undertake seabed research using two Saab Seaeye robotic systems, the Leopard and the Falcon. They will be used to explore the feasibility of mining the gold, cobalt and the copper-rich manganese crust.

▸ *bit.ly/2a0AaKy*

## AUVs for Search and Recovery

Teledyne Gavia, Iceland, has recently delivered two Gavia AUVs to the Turkish Air Force through a contract with the Turkish government support and procurement company Savunma Teknolojileri Muhendislik Ve Ticaret A.Ş (STM). The 1,000m rated Gavia AUVs will be utilised for Search and Recovery applications and will provide the Turkish Air Force with highly effective deepwater, rapid response capability from a man portable AUV system.

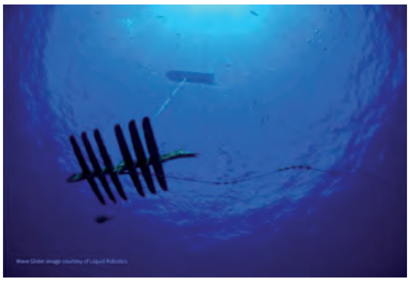
▸ *bit.ly/2a0A2uH*

*Gavia local partner, Ozan Durmus of EKD Company, and a pair of Turkish Air Force Gavia Vehicles.*

## Wave Glider Swims 2,808 Nautical Miles in South Pacific

A Liquid Robotics Wave Glider swam 2,808 nautical miles (5,200km) to the Big Island of Hawaii after successfully completing a 4-month patrol mission of the Pitcairn Island Marine Sanctuary for the UK Foreign & Commonwealth Office (FCO). This achievement represents a fundamental enabling capability for unmanned systems as it proves the feasibility and flexibility of autonomous mission deployment. The Wave Glider began its mission on 27 November 2015 in the South Pacific, where it helped the UK FCO protect the Pitcairn Island Marine Sanctuary against illegal fishing activities.

▸ *bit.ly/2a0zZPp*



*WaveGlider Returning Home from Pitcairn Island Marine Sanctuary. Image courtesy: Liquid Robotics.*

## Integrating Autonomous Underwater Vehicle Capability into Hydrographic Operations

# AUVs in Hydrography

The US Navy and the Naval Oceanographic Office (NAVOCEANO) are committed to realising the vision that Autonomous Underwater Vehicles (AUVs) are available, affordable, and can play a critical role for many applications. Working in partnership with NAVOCEANO and the Office of Naval Research, the Remote Environmental Monitoring UnitS (REMUS) was developed at Woods Hole Oceanographic Institution and has improved positional accuracy due to newly developed technology. NAVOCEANO recently procured a REMUS 600 with a commercial shallow-water multibeam system onboard that meets the stringent accuracy requirements for hydrographic applications. NAVOCEANO hydrographic survey missions can now be augmented by LBS-AUV operations. However, the hydrographer must understand how AUV-relevant parameters affect the data collection scheme.

### Vehicle Positioning

Major advances in technological and payload sensor quality have greatly increased the positional accuracy of the AUV. From a transducer mounted on a surface vessel (e.g., High Precision Acoustic Positioning System (HiPaP)), the Ultra-Short Baseline (USBL) system can be used to position bottom transponders and initiate AUV positioning. Once initiated, precise acoustic navigation is accomplished with state of the art Underwater Transponder Positioning, or UTP. An advantage to UTP is that one or more transponders may be deployed, contrasted to Long Baseline (LBL), which requires a minimum of two transponders, preferably more. UTP transponders can be placed within the survey area instead of peripherally as in LBL. Tight integration between the UTP range measurements and the vehicle inertial navigation system (INS) significantly improves the real-time position accuracy.

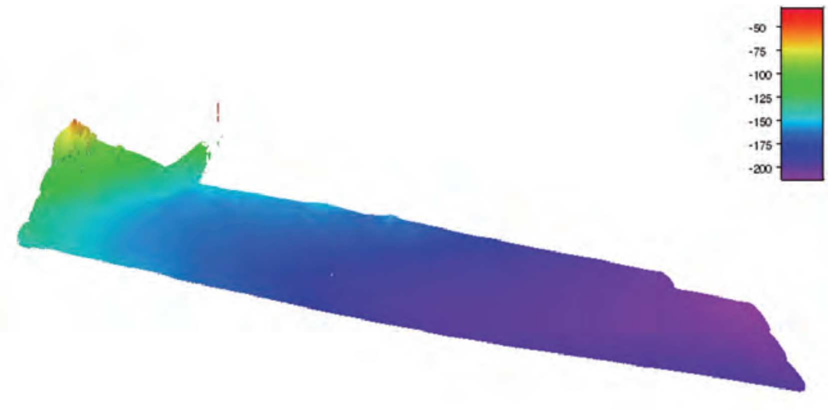
**Orientation of survey lines and vehicle speed can be strategically used to overcome the influence of currents and help lessen the vehicle drift**

### DVL-Aiding

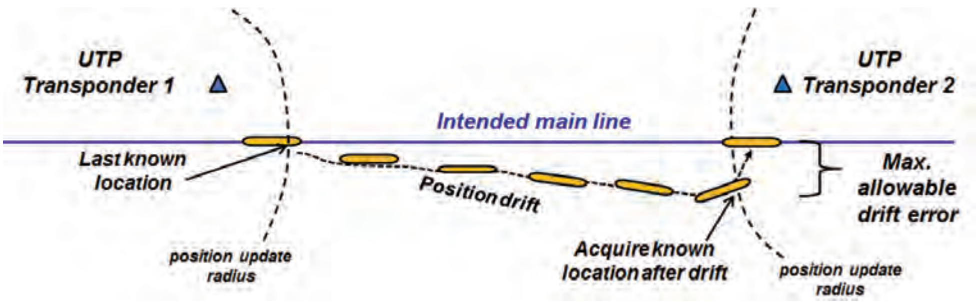
Without constant known position fixes from global positioning systems (GPS) or a reference station, an INS must be used to meet positional accuracy requirements. An independent and reliable measurement of the actual vehicle velocity is required to aid the INS in detecting and mitigating its inertial measuring unit (IMU) velocity error. A Doppler Velocity Log (DVL) provides this input and makes DVL-aiding a critical component to the LBS-AUV equipment suite as DVL-aided INS is a key factor to positional accuracy.

### Manoeuvring and Cross-Track Drift

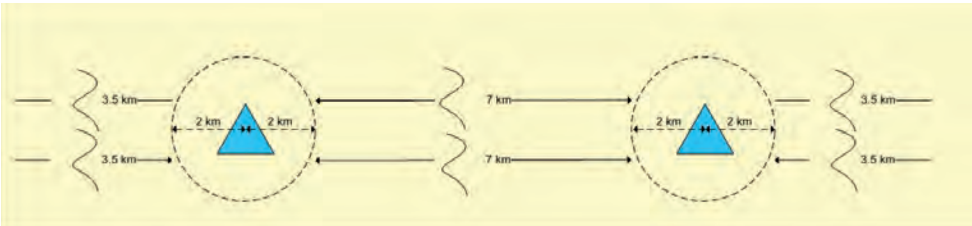
Empirical tests show that manoeuvring also has a significant impact on the IMU velocity error. The lawn mower pattern survey-line layout has an order of magnitude less position error, both along and across track, than a long straight line. Consequently, turns can be programmed into the line layout when the accumulated drift becomes greater than the allowed cross-track error (amount of lateral drift from the main line). Verification trials of the real-time navigation processor show that the drift rate is on the order of 0.1% (or better) of the distance travelled. When planning, the hydrographer must consider the position drift rate as it is a key




▲ *Figure 1: REMUS 600 EM3002 multibeam data collected over a broad depth range on a single sortie with no data gaps between swaths.*




▲ *Figure 2: Transponders are placed to update vehicle position as needed.*




▲ *Figure 3: Placements of UTP transponders (blue triangles) relative to the line layout.*

parameter in determining survey-line length and must be determined for each AUV survey system.

### Real-time and Post-time Position Solutions

Two critical tools used to ensure accurate positioning are the onboard navigation processor and the navigation post-processing suite.

The real-time navigation processor provides complete time synchronisation and integration of onboard navigation and environmental sensors and can be remotely initialised, monitored, and supplied with surface position updates via acoustic modem from the USBL. In addition, the navigation processor uses tight coupling between the INS and UTP as well as navigation and environmental sensor inputs to calculate the current best present position.

The navigation post-processing application implemented in MATLAB® uses positioning and velocity measurements before and after a given time to make the most accurate post-processed solution through the optimal smoothing algorithm implemented in the Kalman filter. Post-processing the navigation is necessary to refine the real-time positions to achieve the required positional accuracy.

### Vertical Sounding Corrections

Tidal fluctuations are a well-known contributor to error in shallow-water bathymetry surveys. Observed tide measurements from land-based tide gauges are not always available to an AUV mission. Alternatively, GPS tide measurements extracted using ellipsoid-referenced survey (ERS) techniques may help satisfy the requirement for applying water-level corrections to sounding data from surface vessels. Unfortunately, the AUV's lack of continuous ellipsoid height observation complicates the issue. To remedy this, virtual tide corrections (VTCs) from a GPS buoy, a wave glider, or a nearby surface vessel can be computed and extrapolated to the AUV soundings.

NAVOCEANO is testing various methods for sounding corrections by calculating a VTC from ellipsoid height observations.

### Mission Planning

The overall mission is a set of multiple sorties. Each sortie includes the vehicle movement and conduct from launch to recovery. For proper survey planning, it is critical to understand the role of myriad mission and sortie parameters, which includes the following:

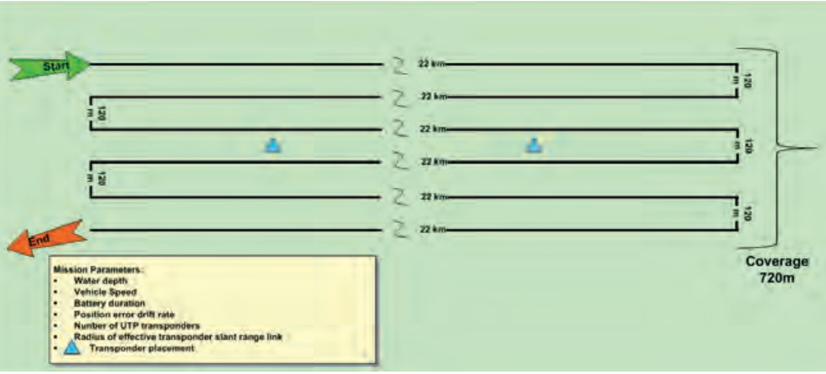
- Altitude from the bottom and resultant swath width
- Bottom lock
- Currents
- Endurance of the battery
- Frequency of vehicle position updates
- Frequency of transponder re-positioning
- Location, spacing, and number of UTP transponders
- Maximum allowable position drift
- Number of lines and turns
- Number of sorties to complete the mission
- Oceanographic conditions
- Orientation of lines
- Position drift rate
- Speed of advance

**Their applications range from navigation hazard inspections, to under-ice surveys, to areas where surfacing or support from a surface vessel is not feasible**

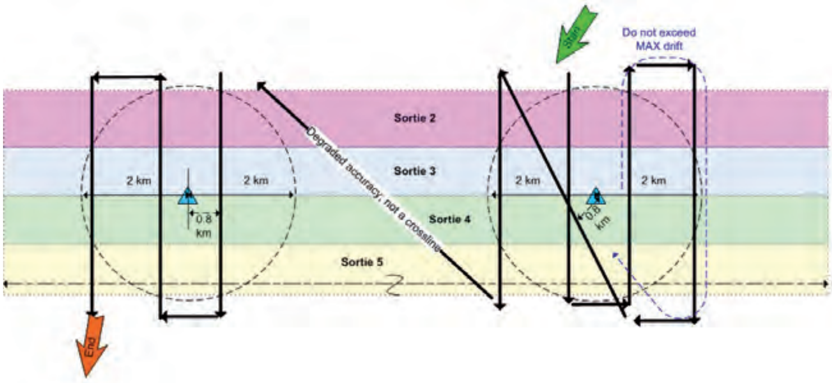
Other planning parameters will depend on the vehicle's configuration and positioning system.

The AUV is very efficient at data collection because it can keep a constant altitude, thereby eliminating swath-narrowing data gaps. The optimum altitude is as high as possible for a wider swath but is limited by the distance that both the DVL and multibeam sonar can maintain bottom lock. Figure 1 illustrates a REMUS 600 multibeam swath collected over depths ranging from less than 50m to over 200m. The constant altitude results in no data gaps. For this reason, the orientation of lines during an AUV survey has more flexibility than the line direction for a surface vessel, which is oriented parallel to the contours.

If the real-time position drifts too far from the planned track, excessive corrections may be needed. Post-time position analysis will help improve estimation of the required position update frequency. This makes the cross-track position drift rate a key parameter in mission planning. The surveying agency will determine the maximum allowable position drift, which greatly affects the transponder spacing and quantity. As shown in Figure 2, transponders




▲ *Figure 4: Layout of main lines for a single sortie.*




▲ *figure 5: Single sortie of cross-lines spans multiple main line sorties.*

are located so that real-time position updates are provided before the vehicle can stray beyond the maximum allowable cross track drift. Additionally, the vehicle drift can be impacted by the direction and strength of currents. Orientation of survey lines and vehicle speed can be strategically used to overcome the influence of currents and help lessen the vehicle drift.

The UTP transponder manufacturer indicates a fix can be obtained within a 2km radius of the transponder in most environmental conditions. In reality, oceanographic conditions will impact the acoustic communication distance between vehicle and transponder; this will vary in each survey area. Figure 3 illustrates survey-line layout for a sortie when the number of transponders is two and the 2km communications radius is achieved. The survey-line length is determined by the Hydrographic Office - determined allowable cross-track drift and survey positioning requirements.

A major limiting factor on the amount of data collected in a single sortie is the battery endurance. Data collection is restricted to several hours less than the battery life to allow for vehicle deployment, recovery, and CTD data collection. Figure 4 illustrates the layout of a main-line sortie that can be accomplished before the vehicle must be recharged. In this example, the number of lines is calculated and spaced 120m apart. The layout in Figure 4 is relative to the swath width that can be obtained at the altitude for DVL and multibeam bottom lock while allowing for a 10% overlap in the multibeam sonar outer beams.

Successive sorties can be run until the lateral distance from transponders reaches maximum reliable acoustic communication, at which point the transponders must be moved for another set of sorties. Multiple sorties may be stacked to reduce the amount of transponder repositioning as demonstrated in Figure 5.
The number of sorties planned to complete a mission area will be determined by considering all the parameters discussed above.

### Quality Control

A cross-line sortie is collected before main lines so that data are available for comparisons as the mission progresses. Systematic errors are more likely to be discernible during cross-line data comparisons. A single sweep of cross lines oriented 45 to 90 degrees from main lines can span multiple AUV deployments as depicted in Figure 5.


**Ms. Sebastian** has worked extensively in the field of Hydrography for NAVOCEANO in the past 30 plus years conducting shipboard hydrographic surveys. She is an IHO Category 'A' graduate from the University of Southern Mississippi and has facilitated the International Discussion Group on Hydrographic Data Quality Assurance and the Multibeam Uncertainty Workshop at the US and Canadian Hydrographic Conferences for 15 years.
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**Mr. Ladner** is the director of the Hydrographic Department of the Naval Oceanographic Office. He began his career performing oceanographic systems engineering. Notable achievements include the design and implementation of the NAVOCEANO Data Warehouse, and the development of the Joint METOC Data Administration programme, and initial development of the Littoral Battlespace AUV systems.
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### Conclusions

The US Navy has invested in and is committed to unmanned capabilities, and NAVOCEANO is its flagship for implementing this technology. The applications for unmanned operations are numerous and range from navigation hazard inspections, to under-ice surveys, to areas where surfacing or support from a surface vessel is not feasible. The science and capability of LBS-AUV operations is an exciting new area of expansion for hydrographic applications at NAVOCEANO and provide hydrographers with opportunities to apply previous knowledge of mission planning and data collection to new applications and techniques. ◂

*The views expressed in this paper are those of the authors and do not necessarily reflect the official policy or position of the Department of Navy, Department of Defense, nor the US Government.*

## A View of the Autonomous Underwater Vehicle Market in 2016

# Autonomous Underwater Vehicles

This last year has seen an increase in Autonomous Underwater Vehicle (AUV) sales and prospects for new sales. The lower than usual oil price may be responsible for much of that growth. Faced with operating in an increasingly harsh market where cost efficiencies can be the difference between success or failure for a business, Oil and Gas companies have had to look for ways to operate profitably. This often means a fairly radical restructure of their business and operations. Survey class AUVs offer a level of technical and operational maturity at a price point that encourages their use by oil companies. Military sales remain strong; the number of navies operating AUVs now is internationally widespread and operational systems now number in their hundreds.

Technically, it has also been an interesting period. Inventors and manufacturers are developing many new concepts from small 'swarms' of AUVs to extra large diameter systems operating in isolation for extended periods of time. Today, there is a solution for every need, or a solution is, at the very least, being developed.

This report aims to shine a light on the various solutions and their uses. It will provide an overview of the most common uses and also outline some of the innovative solutions fuelling the imagination of the industry.

This report limits itself to traditional AUVs: self-powered unmanned underwater vehicles operating without a physical link to the surface and their operators. These systems are typically powered by batteries and carry payload sensors to measure their surroundings. The report does not consider Gliders, which are also self-powered, but carry much smaller payload sensors and batteries.

The following sections explore some of the latest trends in AUV technology and highlight some of their uses.

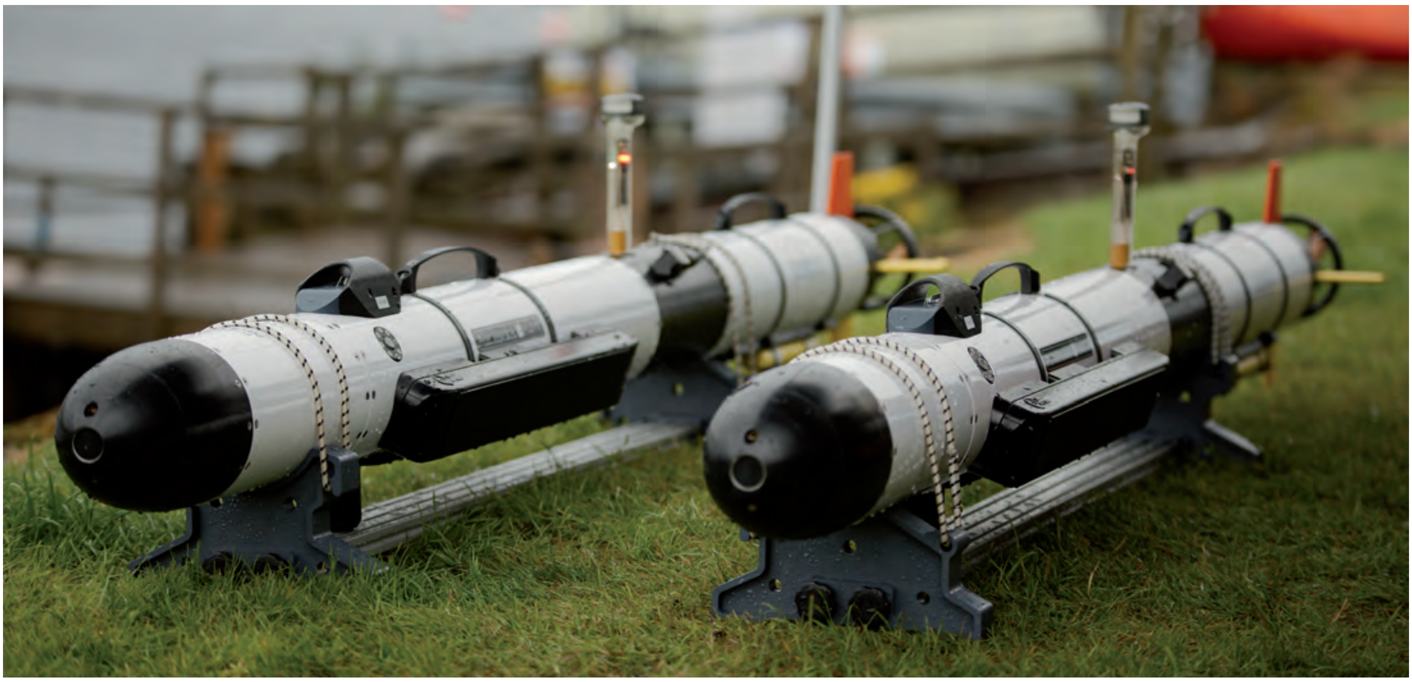


Figure 1: Multiple AUVs collaborating help improve results.

## Small Vehicles, Bigger Impact

A recent trend has been to develop small, low capability AUV systems with limited endurance. These AUVs can be carried in your hand and often weigh less than 15kg. The vision is to launch swarms of these systems and have them work together to meet a common goal. Developments in swarm technology are creating a new future for AUVs; a future where large groups of them can be deployed to achieve a certain goal or outcome and, based on feedback from their sensors, the AUVs are able to adapt their routes to meet these aims. Though each small AUV would find it hard to carry out a mission using its sensors alone, when working together, fusing information from the swarm, they all improve their performance.

There are advantages in using these small AUVs, even taking into account the cost of buying an entire fleet as they are less costly than their larger counterparts. Crucially, a swarm can withstand the loss of a member of the group, they can cover a wide area, and the size of the swarm can be chosen to fit the mission. Swarms can be deployed to track fish and marine mammals, for salvage operations, and for mapping the seafloor. There has also been consideration in the public domain to replace traditional 'seismic streamers'; each node in the swarm performs operations on the seafloor to produce data over a wide area. It is not clear when these systems will become operational, but a number of start-ups and established AUV companies are pushing this concept.

## Is Bigger Better?

However, if small is not right for you then go big! Larger than life AUV systems are now a reality. These systems can be deployed and recovered from the shore and their missions are expected to last months instead of days. Equipped with as many state of the art sensor technologies as are required for the job, extra large diameter AUVs will change the range of tasks for which an AUV may be used. The primary requirement for these systems has been generated by the US Navy's Large Displacement Unmanned Underwater Vehicle (LDUUV) programme. However, commercial applications may also be of interest. Large area survey, oceanographic sampling and marine biology are but a few examples where a large AUV may prove itself more economical than a vessel and crew. To date most of the work done has been at the proof of concept level, but the appetite for large AUVs is likely to prevail.

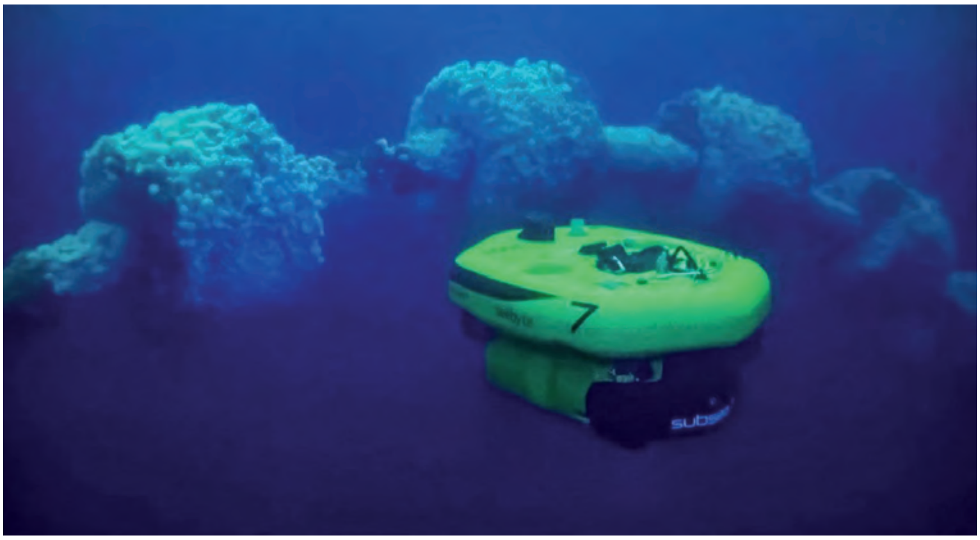


*Figure 2: Subsea 7's AIV conducts the first truly autonomous inspection of a live riser by an AUV.*

## Naval Priorities

A common AUV shape is cylindrical and AUV sizes are typically defined by their diameter. The most common sizes are 9 inches, 12 inches and 18 inches or over. These AUVs have now established themselves as a force multiplier, adding value to the traditional assets. Often deployed from a surface vessel, they put distance between the operators and potentially dangerous environments such as mine clearance applications. Their effectiveness for Mine Countermeasures (MCM) in the littoral and Very Shallow Water (VSW) environment is no longer called into question. All leading navies have procured or plan to procure these systems. Importantly, their ability to double up as tools for hydrography, special operations and salvage work makes them useful for small, highly flexible navies. They enable rapid mobilisation across multiple geographies.

The AUVs have been so successful that many of the current procurement efforts are planned to replace, or compliment, traditional MCM vessels with off-board assets. Navies see AUVs acting as a workhorse to detect man-made objects on the seafloor. Programmes like the Littoral Combat Ship MCM module using UUVs to find buried mines, the UK and France's MMCM programme and Australia's SEA 1778 are in the process of demonstrating and/or procuring capability. These concepts are considering the use of AUVs, unmanned surface vessels, disposal robots and towed arrays. They are addressing military doctrine in order to integrate off-board assets to their current concepts of operations.

The US Navy continues to lead the way and has set up a new unmanned warfare systems directorate (OPNAV N99) to look at how humans and machines can cooperate in missions across all domains: subsea, surface and air. The intent is clear: in the future there will be more AUVs and, in time, their uses are likely to extend to other missions beyond simple surveys.

## Oil & Gas, AUVs in the Era of Low Oil Prices

The low price of oil has had a destructive effect on the industry. Established oil companies have had to restructure and cut costs for significant parts of their business and this has snowballed through the whole supply chain. AUV manufacturers are part of that supply chain. However, last year saw a significant increase in the sale of AUVs into this sector. Are AUVs immune to the challenges faced by the rest of the industry? To some extent they are not. Traditionally, AUVs have been operated by oil and gas contractors to carry out surveys at extreme depths. For this purpose they have become the tool of choice. However, the interest in these surveys has dwindled as operating wells at such depths is an expensive business and is unsustainable under the current oil regime.

However, AUVs can be operated from smaller, less costly vessels than traditional ROV systems. As they increase the range of tasks that they tackle they become more appealing investments to prospective owners. They are able to offer a new business model to do work at a time when new business models are required. This has resulted in a renewed interest and push to develop hover capable AUVs to inspect the infields. Some examples of autonomous inspections in actual fields have recently been reported and many new initiatives have been announced in the press.

### Other Market Opportunities

Oceanographic institutes have found AUVs to be excellent platforms that allow them to gather high-quality data for scientific purposes. It is likely that there will be a sustained growth in this domain. Vessel upgrades typically incorporate AUVs as part of the mix.

There has also been a renewed interest in AUV technology from the marine renewables industry, fisheries, hydroelectric facilities and ports and harbours. To date these remain small opportunities. However, industries like these may benefit in later years if AUVs continue to gain popularity and low cost, easily deployable systems reach the mass market. This network effect may be key for AUVs to reach market opportunities beyond traditional ones.

Universities and research institutes are also important players in the AUV market. They are fuelling innovation and pushing the boundaries of the possible. Significant research is now underway, helping to develop concepts for adaptive autonomy and providing a framework for AUVs to deal with the unexpected. They are also investing in the next generation of AUV engineers and competitions like AUVSI's Robosub are a testament to how far and wide the AUV community spans, with teams from all corners of the world taking part.

### Where to Next?

The next challenges include over-the-horizon operations; AUVs that operate autonomously at distances outside the reach of the operator. To do this the AUV must be equipped with sufficient onboard autonomy to deal with and adapt to changes in the environment or to changes in its own state. This is where Unmanned Surface Vessels and Unmanned Air Vehicles can help. They can act as communication relays to the shore and the operators enabling real-time monitoring over vast distances. This effectively helps reduce one of subsea's greatest challenges - poor underwater communications!

Another challenge is to reverse the current trend that requires a trained crew of operators for each AUV. Operating a single AUV becomes a costly training exercise and if we would like to operate more AUVs we soon come to the realisation that there will never be enough operators. This is a tricky problem to solve. Software plays an important part and I have been fortunate to work alongside a group of people who are leading the way in tackling this issue. However, a lot of work still needs to be done. How do you deploy and recover hundreds of AUVs? How do you recharge their power sources? How do you tell them what to do? If AUV swarms are to become a reality, these challenges must be solved.

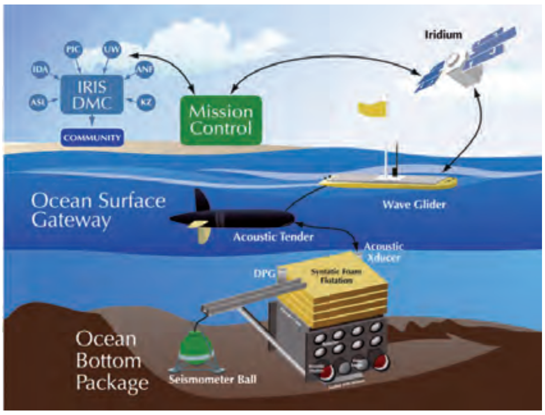
I am looking forward to finding answers to these questions in the years to come and expect that in doing so the AUV market will experience considerable growth. ◀

As SeeByte's Sales Manager, **Ioseba (Joe) Tena** is responsible for the development of SeeByte's commercial strategies and managing the marketing sales process within the company. He has been involved in developing smart solutions for the underwater vehicle industry for more than 10 years and continues to lend his engineering expertise to the team.

## Real-time Detection of Seismic Events

# Oceans of **Earthquakes**

Globally, the proliferation of sensors and resultant explosion of data is growing at exponential rates. Every digital device and sensor is expected to be available day/night to provide instantaneous results. This is possible if sensors are land or space based. This is not the case for ocean data. Ocean observations, especially far offshore in the remote deep ocean, are sparse due to the high cost, risk and difficulty in the collecting data especially from seafloor sensors. This challenge is one that all industries face in the quest to directly measure and better understand the biological, geophysical and environmental conditions occurring in our ocean.




▲ *Figure 1: High Seas Telemetered Seismographic Observatory concept of operations - Scripps Institution of Oceanography.*

**Real-time, High Seas Telemetered Seismographic Observatory**

Scientists at Scripps Institution of Oceanography (Scripps) have taken on this challenge by creating an innovative, unmanned observatory that provides real-time seismic telemetry from the seafloor through the water column to space and shore. Partially sponsored by a US National Science Foundation and in collaboration with Liquid Robotics™, it's called the High Seas Telemetered Seismographic Observatory. This system was created to demonstrate the feasibility of placing permanent seafloor seismic observatories, paired with surface communications gateways, to directly measure seismic activity in locations far from continental sites or nearby islands.

To overcome the obstacle of communicating seafloor sensor data to the ocean's surface through 4,000m of water, Dr. Jon Berger along with his collaborators, Dr. John Orcutt, Gabi Laske and Jeff Babcock, architected a two-part system comprised of the Ocean Bottom Package (OBP) sitting on the ocean floor and the Ocean Surface Gateway (OSG) located on the ocean's surface. The Ocean Bottom Package measures, records and telemeters sensor data through the water column to a free-floating gateway system holding station above. The Ocean Surface Gateway then buffers and retransmits the data via satellite to shore in near real-time. If communications to the satellite are paused, the sensor data is stored on the OSG until communications are restored.

**A two-part system with a float on the surface connected to a wing rack 4 to 8m below**

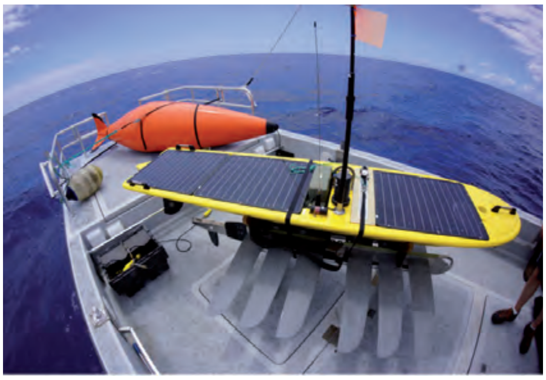
**Unmanned, Long Duration Ocean Monitoring, Towing and Communications**

The breakthrough technology that made this system possible is an Unmanned Surface Vehicle (USV) called a Wave Glider™, developed by Liquid Robotics. It is comprised of a two-part system with a float on the surface of the ocean connected to a wing rack or Sub, 4 to 8m below. It directly harvests and converts wave energy into forward propulsion while using solar energy to power the computing, communications, navigation and sensor payloads. Powered 100% by renewable energies it can operate autonomously at sea for up to a year collecting and communicating data while producing no emissions.

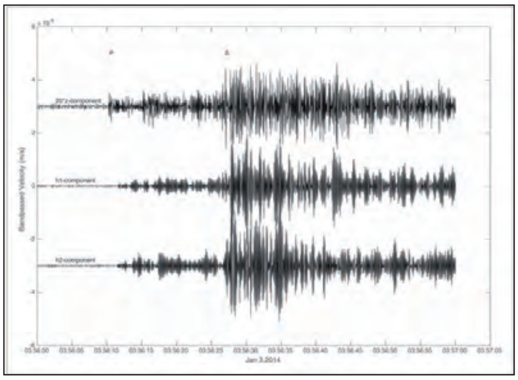
The Wave Glider hosts a wide variety of sensor payloads both onboard the vehicle and towed from behind. For the Scripps' mission, the Wave Glider towed an acoustic modem and directional low-frequency transducer, both of which trailed behind in a neutrally buoyant Towed Acoustic Modem (TAM). For properly designed towed payloads, the Wave Glider was able to navigate with the towbody with little observed loss of speed. In addition to towing the TAM, Scripps tested the feasibility of using the Wave Glider for autonomous deployment of the OBP. The concept uses the Wave Glider to tow an appropriately designed OBP to the desired location, release it, and then hold station to provide real-time telemetry. This eliminates the need for costly ship operations and greatly reduces the life-cycle cost of an ocean bottom station.

**Mission: Detecting Seismic Earthquakes, even those Previously Undetectable**

In September of 2014, Dr. Berger and his team launched the Wave Glider, 30km from Point Loma, CA, to travel west of San Diego



▲ *Figure 2: Liquid Robotics' Wave Glider with prototype OBP towbody.*



▲ *Figure 3: Recordings of an unknown local event recorded at ADS3, 3 January 2014.*

approximately 300km. In 4,350m of water, the Wave Glider held station, collected and transmitted telemetry data in near real-time from the bottom seismic sensors to the Iridium satellite. The tests of the surface gateway demonstrated an acoustic efficiency of approximately 396 bits/J. For example, it was able to send 4 channels of compressed, 1 sample per second data from the ocean bottom to the gateway with an average power draw of approximately 0.15W and a latency of less than 3 minutes. As long as the horizontal distance to the seafloor instrument was within an ocean depth, the data return rate was nearly 100%.

## It is possible to overcome the technology challenges to real-time, seafloor to space communications of sensor data

During the 68 days at sea, the system detected and recorded seismic earthquakes along with one small earthquake that did not appear in any earthquake catalog nor was it recorded by the nearest land station on San Clemente Island. The magnitude of this event was approximately 2.0. It is very likely that such events remain undetected with the current on-land seismic monitoring network capability in Southern California. Data such as this from previously unobserved oceanic areas are invaluable for both national and international agencies in monitoring and characterising earthquakes, tsunamis and nuclear explosions.

### Conclusion

Demonstrating the first, near real-time observations of an earthquake from an autonomous offshore observatory, scientists at Scripps Institution of Oceanography have proven it is possible to overcome the technology challenges to real-time, seafloor to space communications of sensor data. Their tireless efforts to produce an integrated, deep-sea seismic observatory advances early earthquake and tsunami detection and prediction that will contribute to improved disaster preparedness and ultimately a reduction in loss of life and property.


### Acknowledgements

The authors wish to thank the scientists at Scripps Institution of Oceanography, Dr. Jon Berger, Dr. Jonathan Orcutt, Gabi Laske and Jeff Babcock, for their leadership and collaboration in developing the High Seas Telemetered Seismographic Observatory. Liquid Robotics is proud to be a technology partner and to play a small role in the advancement of unmanned deep ocean seismic research.


**More information**

**An** ocean bottom seismic observatory with near real-time telemetry, Authors, J. Berger, J. Orcutt, G. Laske, J. Babcock, Scripps Institution of Oceanography, University of California, San Diego, California, USA, First published: 5 February 2016 in AGU Publications, Earth and Space Science.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## Patrolling Marine Protection Areas

# Autonomous Vessel as Enforcer

There are currently 13764 Marine Protected Areas (MPAs) jointly covering over 2% of the oceans. One such MPA is Malaysia's newly formed Tun Mustapha Park comprising 1 million hectares of marine park and shark sanctuary in northern Borneo. Governance, management, effective real-time situational awareness and enforcement are essential for the preservation of the resources in these water spaces and especially the hundreds of fish species that they support.


*Figure 1: Jura operating off Plymouth with surveillance equipment fitted.*

Arguably the key challenge is the scourge of Illegal, Unregulated and Unreported fishing (IUU), which has a significant impact on the global economy (estimated to be worth up to GBP30Bn a year) and also causes much wider ecological damage and social impact. In many parts of the world the marine and maritime sectors are often the poor relations in government funding terms. The areas they must patrol are vast and limited resources are stretched. In many instances this means the perpetrators of IUU can fish almost unhindered and unchallenged.

The challenge is to find ways to monitor and patrol such vast expanses in as time-efficient, cost-effective and collaborative a manner as possible. Conventional policing of MPAs and EEZs involves manned vessels and has become the responsibility of coastal patrol authorities, border force agencies and navies. Manned vessels are naturally limited by their ability to patrol over extended periods and covering large areas requires a great number of vessels, which are expensive to operate persistently.

### The Jura USV

A potentially longer-term and cost effective solution is the development and deployment of unmanned surface vehicles (USVs). One such vessel is the Jura, a 5 metre USV designed and operated by Chichester-based MOST (AV) Ltd. It is equipped with a passive acoustic monitor, an HD stills camera and a gyro-stabilised HD video camera enabling a remote operator to monitor an area of sea space in near real-time over the Inmarsat satellite link. The boat can be remotely piloted or configured to autonomously patrol an area of sea either holding position or following a specific pattern or route.

Jura is propelled by wave energy, and has achieved speeds of up to 4 knots with a deck of photovoltaic cells that, even in higher, colder latitudes, generate 300W power allowing it to remain at sea for up to 3 months. This power charges a storage cell for the integrated passive and active sensor suite. It can also be diverted to an auxiliary propulsion unit for a surge of speed over short distances.

While primarily deployed as a situational awareness platform, Jura's 100kg payload capacity permits the installation of additional active and passive sensors for secondary marine data gathering tasks. In Jura these sensors are a CTD, hydrophones, a fluorometer (for measuring water quality), a weather station. and a subsurface stills camera that captures images through a window in the hull.

Ongoing research and development activities are investigating options for deploying a range of hydrographic sensors including SBES and MBES for coastal and ocean bathymetric survey on what will be a persistent 24/7 bathymetric data gathering platform.


▲ *Figure 2: Jura Surveillance equipment with the VREO prototype gyro stabilised camera system and Inmarsat FB150 terminal on deck.*

### Plymouth Trials

To test its effectiveness in countering IUU, Jura undertook several missions off the coast of Plymouth, UK, in April and May 2016, to demonstrate its connectivity and the quality of the images that could be captured. Results were encouraging with, for example, the capture of images of Eddystone Lighthouse at a distance of 11miles.

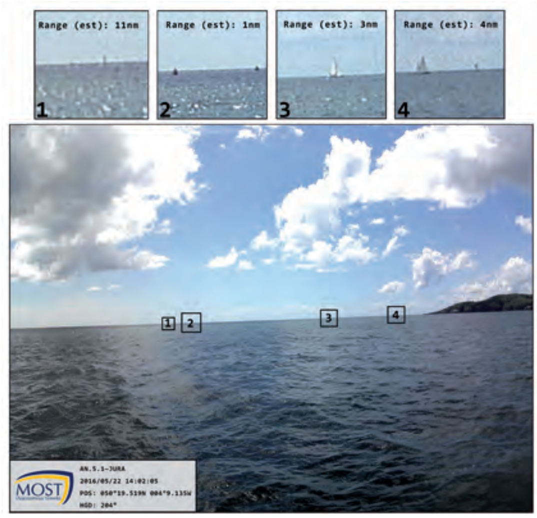
Jura successfully navigated autonomously and under remote control; holding position and travelling around a course of pre-determined waypoints whilst all the time sending back images and collecting data from her sensor suite.

The recent Plymouth trials also highlighted how a USV like Jura could be used as part of a wider situational awareness capability. Working with the Harwell based Satellite Applications Catapult, Automatic Identification System (AIS) vessel tracking system exactEarth and Blue Economy consultancy NLA Ltd, the demonstrations showed how data from AIS trends could be used to identify potential fishing vessels by their tracks and speed.

## Data could be used to identify potential fishing vessels by their tracks and speed

Bathymetry could be used to identify areas which naturally attract high fish numbers. Synthetic Aperture Radar was also tested for its ability to capture images of smaller non-metallic vessels. A combination of all of this information could be used to cue Jura to patrol areas at higher risk of IUU.

Legal advisers were involved in the demonstration to assess whether video and photographic images were of sufficient quality to be deemed as useful evidence. Results were favourable not least because captured images could be time, date and location stamped making it easier to use as evidence in conjunction with other sources that identify specific vessels and their activities.




▲ *Figure 3: Surveillance Targets as taken by Jura during the Plymouth trials with post-processed position, date/time and heading stamp (later to be part of formal software).*

### Future Use of ASVs

Whilst patrolling valuable ocean spaces such as MPAs clearly presents a challenge these demonstrations and trials suggest that autonomous technological innovations, combined with earth observation data to create a situational awareness system, may be a valid response.

As with any emerging innovation with the potential to scale, the broader need to re-assess and re-evaluate existing delivery support mechanisms – in this case, for example, command and control infrastructure, human resource allocation, legal requirements and data storage capabilities – will also be vital.

A fleet of autonomous surface vehicles patrolling large sections of an MPA could mean that some sea going human resource transfers ashore, engaging with and acting on data as it arrives. With USVs and Unmanned Aerial Vehicles potentially operating in a networked surveillance approach, the strategic command and control requirements become yet more challenging, but also more immediately responsive. In such a scenario, how can decision makers ensure they have the capability to see and act on incoming visuals at all times?

Finally, the combination of enforcement with the collection of bathymetry and other marine environmental data offer the promise of additional cost savings, as science and enforcement activities can be conducted simultaneously. Such joint missions may also factor in the monitoring of offshore installations in the oil, gas and energy sector, the monitoring of goods and people smuggling, and many more. Shared procurement across related agencies offers promising solutions for tightly constrained budgets.

## Captured images could be time, date and location stamped

Looking over the horizon to the next wave of innovation, it is clear that visual recognition algorithms may have an important role to play so that these next-stage activities can also be automated, with taskers and decision-makers receiving alerts as and when targets or anomalies are identified digitally.


**Acknowledgements**
Special thanks are due to MOST (AV), Satellite Applications Catapult and exactEarth. All images courtesy of MOST (AV). ◂


**More information**
**MOST** JURA Autonaut: www.autonautusv.com
**Satellites** Applications Catapult: sa.catapult.org.uk
**exactEarth**: www.exactearth.com
**Marine** Protected Area Atlas: www.mpatlas.org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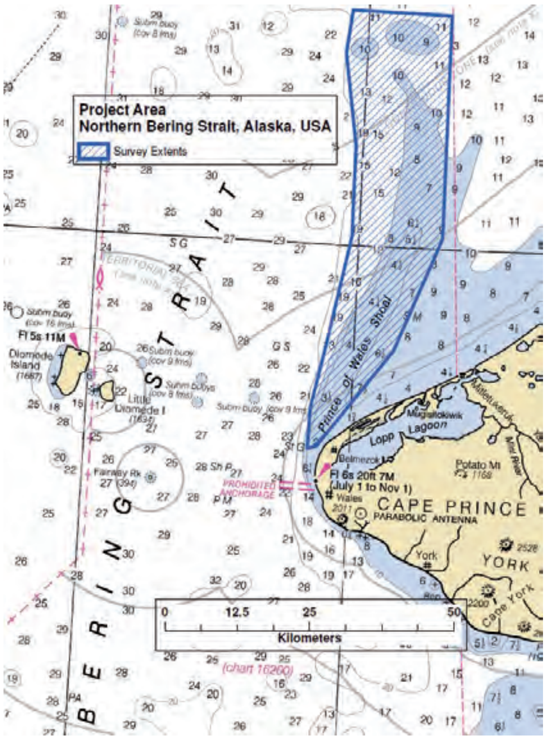
▲ *Figure 4: Jura as photographed from an Unmanned Aerial Vehicle.*


▲ *Figure 5: Autonaut* Gordon *operating off Plymouth with a Royal Navy Type 23 Frigate in background.*

## Autonomous Surface Vessel as a Bering Strait Hydrographic Force Multiplier

# **Bering Strait** ASV Deployment

TerraSond, a hydrographic services company based in Palmer, Alaska (USA), utilised an unmanned Autonomous Surface Vessel (ASV) to assist with the acquisition of survey data in July of 2015 in the northern Bering Strait region of Alaska. The 12' ASV, a military target drone converted into a hydrographic vessel, worked in conjunction with a larger survey vessel and acquired the first data from an unmanned vessel to be used to update a US nautical chart.




▲ *Figure 1: Area overview. The survey area is located in the Bering Strait region of Alaska's Arctic.*

### Background

TerraSond has long been interested in the possibility of using ASV technology on hydrographic survey projects. Obvious potential exists to survey areas normally unworkable from a manned vessel due to factors such as extremely shallow water, as well as to increase production by serving as a 'force multiplier', whereby an unmanned survey vessel would work side-by-side with a conventional survey vessel.

The potential benefits of using ASV technology is even more apparent in regions like Alaska. Most of the Alaska coastline is far from ports and easy resupply. Therefore, operations in

## The ASV reduced the required total days on-site by about two days

Alaska waters often require expensive vessel mobilisations and long transits using relatively large vessels of sufficient endurance to reach and work remote survey areas. Once the effort and expense of reaching the site is realised, the potential benefits of deploying one, or more, smaller unmanned vessels from the larger vessel to increase production is clear, especially when work needs to be completed during Alaska's limited field season.

When the US National Oceanic and Atmospheric Administration (NOAA) tasked TerraSond to survey a remote area in the Bering Strait for the purpose of nautical chart updating, the right combination of factors came together to make use of an ASV on a major charting project possible.

### Project Suitability for ASV Operations

The NOAA task order called for a hydrographic survey centred on Cape Prince of Wales Shoal, a poorly charted but navigationally significant area experiencing increases in Arctic vessel traffic. Covering about 1,030 square kilometres of seafloor, the area, and consequently the project effort, was of sufficient scale to overcome the fixed costs associated with mobilising an ASV.

The project area was ASV-friendly due to relatively light vessel traffic with ample room for manoeuvering, which mitigated concerns of unintended vessel-vessel interactions. However, the region's notoriously inclement weather and unprotected exposure of the survey area would make small boat operations difficult.

Project requirements called for fixed line spacing, which simplified line planning and the logistics of operating a manned and unmanned survey vessel simultaneously. Single beam was an acceptable echo sounder method, which streamlined the equipment suite necessary to deploy on the ASV.

Additionally, the chartered survey vessel, the 32-metre R/V *Qualifier 105* (Q105) had sufficient deck, craning, and fuelling capacity to support a small ASV, as well as the ability to conduct multibeam operations concurrently with ASV single beam operations.

### ASV Selection

Options from various manufacturers were investigated based on suitability, availability, and cost. Most options were ruled out as cost prohibitive, unsuitable for the weather conditions of the area, too large to deploy from the *Q105*, or unavailable on the project timeline. TerraSond ultimately contracted ASV, LLC (ASV) of Broussard, Louisiana to provide a suitable model.

ASV redesigned and customised a C-Target 3 (CT3) military target drone for hydrographic use. The C-Target models were designed for naval gunnery training, weapons testing, and ship command and control assignments. Advantages of the CT3 included its small size (3.5m in length and about 325kg in weight),

Figure 2: The ASV runs survey lines near the RV Q105. The two vessels collected data simultaneously.

which meant it could be transported economically from Louisiana to Alaska, and easily managed by the deck crane on the *Q105*.

The CT3 had some disadvantages including its hull design (designed as a high-speed target drone and not a low-speed survey vessel) and single-point lift system. The gas outboard would also limit endurance to less than 24 hours, despite installation of increased fuel capacity.

### ASV Modifications

Extensive reconfiguration was necessary to adapt the CT3 to hydrographic purposes. These included increased fuel capacity, increased power output to support survey equipment, software modifications, installation of a Survey PC (in addition to an existing Control PC), and additional IP radios, and mounting/integration of survey equipment.

Survey equipment was chosen based on its power-efficiency, compactness, and prior track record. Major components included an Odom Echotrac CV100 single beam echo sounder, a Hemisphere Vector V113 positioning system, and a Trimble 5700 GPS receiver. HYPACK 2014 was installed on the Survey PC and configured to communicate with the survey instruments and log all survey data.

### Communications and Control

An IP radio that communicated with the ASV Survey PC was integrated into the same ship network as the *Q105* acquisition system. This allowed an existing Acquisition PC on the *Q105* to be used to remotely monitor (via remote desktop methods) the ASV Survey PC without special modifications, making it so that acquisition personnel could monitor and control both the *Q105* multibeam system and ASV single beam systems simultaneously. This had the dual benefit of allowing real-time monitoring of ASV data quality without the need to dedicate additional acquisition personnel to the task.

ASV's proprietary 'ASView' software served as the ASV software interface. ASView was operated on a second PC and IP radio link independent of that used for the survey system monitoring. ASView was used to send commands to the vessel, including what line to track, and monitor onboard systems as well as the vessel position. This included fuel levels in three separate tanks with the ability to remotely move fuel between them, fuel consumption rate, engine status, electrical status, temperatures, actuators and relays. A streaming camera view also helped with obstacle avoidance and docking with the larger vessel.

## The ASV use served as a proof of the force multiplier concept

### Operations

With its small size and the disadvantages of deploying at-sea using a crane and single-point lift, the ASV was deployed only during favourable weather conditions (generally considered to be seas of 0.6m or less, limited primarily by the ability to safely lift and deploy the ASV by way of the *Q105* crane). Given the exposed, inclement nature of this region and poor weather experienced during the survey, favourable conditions were infrequent.

When deployed, the ASV was operated in an 'unmanned but monitored mode'. In this mode it was continuously supervised from the *Q105* and would autonomously run planned survey lines adjacent to the *Q105*, staying in visual and communication range. Standard operational distance was about 200m from the *Q105*, which was equal to the project line spacing.


▲ *Figure 3: The ASV returning to the RV* Q105 *to be recovered back on deck.*

**Results**

The ASV collected about 330 line kilometres of single beam data acquisition, or 5% of the project total, which reduced the required total days on-site by about two days.

Production was less than anticipated, largely because of poor weather conditions that often made deployment of the ASV impractical. Decisions on whether or not to deploy the ASV were highly dependent on the ability to safely deploy from and recover the vessel.

In addition to main scheme survey lines, the ASV surveyed one particularly shallow portion of the area which was unsafe to survey with the *Q105* due to its 2m draft. Overall, the ASV use on this project served as a proof of the force multiplier concept, whereby minimal additional personnel (in this case two ASV technicians) were required on-site to field an additional survey vessel. Additionally, soundings collected from the ASV were the first collected by an unmanned vessel to be used to update a US nautical chart.

**Future Plans**

TerraSond plans to utilise a C-Worker Hydro 5 model, also provided by ASV, LLC, during 2016 for a major survey for NOAA in the Bering Sea. The C-Worker Hydro 5 is a purpose-built hydrographic model and will be outfit with multibeam and towed side-scan sonar systems, and will incorporate experience gained in using the ASV-CT3 in 2015. A custom launch and recovery davit system (LARS) will be used to improve the operational weather window.

**Acknowledgements**

Thanks are due to NOAA for funding this work, ASV, LLC for providing, outfitting, and managing the ASV-CT3, and Support Vessels of Alaska (SVA) for field deployment support on the *Q105*. ◀

▲ *Figure 4: Craning operations to place the ASV back on deck aboard the RV* Q105.

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## Performance and Challenges in shallow water

# Can I **Communicate** With My AUV?

The prospects for an increased future use of autonomous underwater vehicles (AUVs) in the Maritime & Offshore sector are high, mainly due to the search for cost effectiveness. AUVs reduce the need for large crews, divers and vessels in the operational area. AUVs are already operational for bathymetric and environmental mapping, pipeline tracking and mine hunting, and there is a trend towards their use for inspection and environmental monitoring.

When using non-tethered solutions, underwater communication becomes crucial for data transfer and positioning. The latter holds even more given that the long-term goal is the deployment of multiple autonomous vehicles, possibly working in a network to carry out joint operations. As of today, the best technology to set up long-range underwater communication links is acoustic communication, of which the performance is highly dependent on the environmental conditions. In the North Sea, for example, the combination of shallow water and strong winds complicates performance prediction for an underwater acoustic network. Sea trials with underwater acoustic modems have taught us that communication ranges can be much less compared to the nominal performance as advertised by the vendors, depending on environmental conditions.

In this article, we make an inventory of what can affect the performance of underwater acoustic communications, with a focus on shallow-water environments typical for the North Sea. Knowing what influences underwater communications enables better planning of autonomous subsea operations.

### The Performance of Underwater Acoustic Communications

Underwater acoustic communication using acoustic modems consists of transforming a digital message into sound that can be transmitted in water, and vice versa. Based on our experience, we can group the factors influencing the success of communications into three categories: sound propagation conditions, specific modem properties and background noise in the communication band (Figure 1).

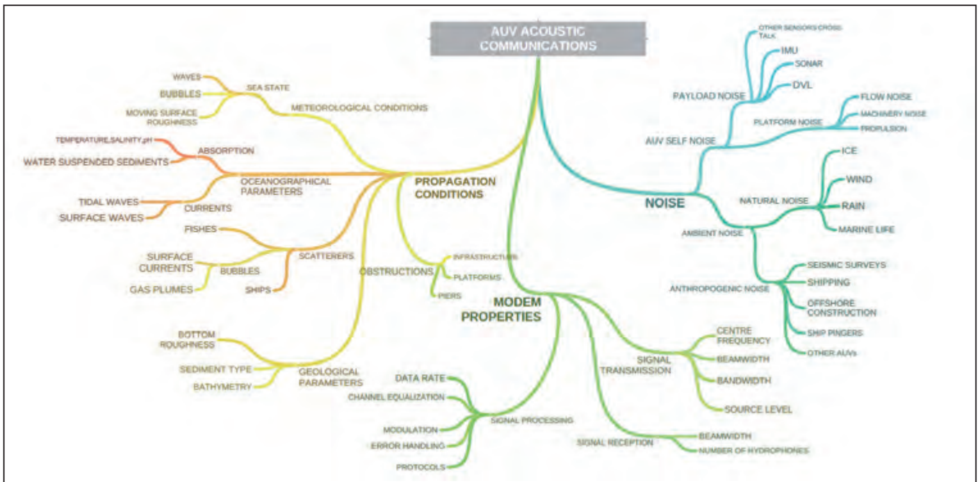



*Figure 1: Overview of factors influencing underwater communication performance.*

### Propagation Conditions

The following physical mechanisms can deform the signal and challenge the reception and interpretation of the contained message:

- **Frequency-dependent attenuation:** for frequencies relevant to underwater communications (1-100kHz), attenuation by water strongly depends on frequency. This results in a strong dependence between the communication range and the useful acoustic bandwidth.
- **Geometrical spreading and multipath propagation:** As acoustic energy spreads over larger areas the level diminishes with range. Furthermore, reflection from the bottom and sea-surface boundaries will cause distortion of the signal, the net effect being a spreading of the received signal over time.
- **Ocean surface variability:** The movements of the surface due to wind and currents strongly affect the surface communication paths, causing Doppler spreading of the signal in frequency. For a realistic channel, the distribution of signal power over time and frequency (Doppler shift) is shown in Figure 2.
- **Variable speed of sound:** Sound bends towards regions where the sound speed is lower. In deep waters, this is the main factor affecting communication between two platforms due to the creation of 'shadow zones' where no acoustic communication is possible. In the North Sea, the sound speed profile is relatively constant over depth due to the mixing of the water by currents and waves.

| Non-coherent modulation methods | | | |
|---|---|---|---|
| **Type** | **Rate [kbps]** | **Band [kHz]** | **Range [km]** |
| M-FSK | 1.2 | 5 | 3 |
| M-FSK | 2.4 | 5 | 5 |
| **Coherent modulation methods** | | | |
| **Type** | **Rate [kbps]** | **Band [kHz]** | **Range [km]** |
| M-PSK | 0.5 | 0.3-1 | 90 |
| M-PSK | 0.02 | 20 | 0.9 |
| M-PSK | 6.7 | 2-10 | 2 |
| 16-QAM | 40 | 10 | 0.3 |

▲ *Table 1: Overview of commonly used modulation methods with typical ranges and nominal bandwidths. Courtesy of Akyildiz et al.*

## Modem Properties

An underwater modem translates digital messages into waveforms that can be transmitted acoustically. Digital modulation is the technique that allows a digital signal to be transferred over an analog channel and consists of mapping the information bits into analog waveforms that represent the data that we want to transmit. After propagation through the medium, received analog signals are sampled and demodulated to recover the original digital message.

The main characteristics of an underwater modem are its communication bandwidth, its carrier frequency and the employed modulation method. The useful bandwidth is strongly dependent on the environment and the communication range. Often, for a modem designer, the goal is to optimise effective data rates while simultaneously focusing on robustness. To reach both these goals, the modulation must be spectrally efficient, and be able to cope with the time-varying underwater conditions. Within their designated bands, most underwater modems are not limited by ambient noise, but by delay and Doppler spreading, i.e. the signal can be heard but not understood due to its distortion by the channel. At present, most commercial modems use non-phase-coherent modulation. Improvement can be attained by using phase-coherent modulation schemes, which require estimation and tracking of the phase of the transmitter. An overview of common underwater modulation methods tested in shallow waters is given in Table 1. The main ones are based on Frequency Shift Keying (M-FSK), Phase Shift Keying (M-PSK) or Quadrature Amplitude Modulation (QAM).

## Noise in the Communication Band

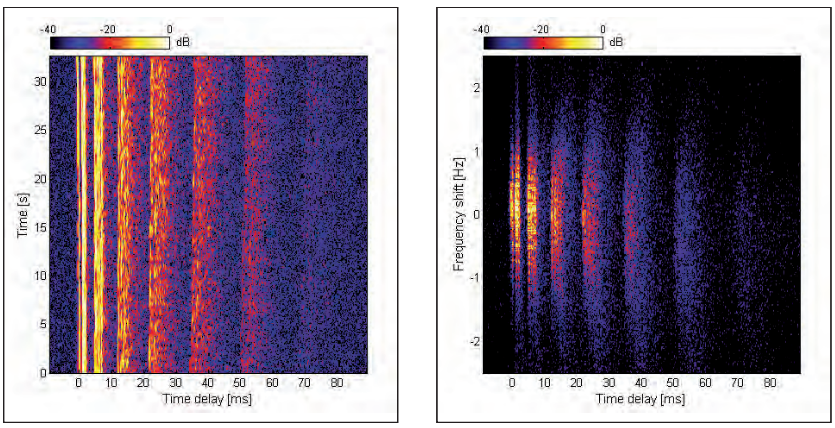
### AUV Noise

Noise from an AUV can interfere with the onboard modem and with the reception of acoustic messages from a receiving hydrophone. Noise sources at the AUV include hull vibrations and mechanical noise, propeller noise, electronic noise, flow-induced noise and payload cross talk. We measured the net radiated noise by an AUV during a sea trial in the EDA-NECSAVE project. Figure 3 shows the uncalibrated sound pressure spectral density level (0 - 35kHz) measured by a receiving hydrophone while the AUV was approaching at a speed of 2m/s from a distance of 500 to 50m. Acoustic messages are transmitted and received in the 18-34kHz band (Figure 3: the sharp vertical lines are acoustic messages between the AUV and the control station). The AUV noise contributes mostly to the lower part of the frequency spectrum (<15kHz) at these distances but on approach the high frequency contribution increases, because of the diminished attenuation. At close distance AUV self-noise can therefore be a significant source of disturbance for communications. It is easy to understand how this could be even more important for an onboard acoustic sensor.

**Noise from an AUV can interfere with the onboard modem and with the reception of acoustic messages**

### Ambient noise

Ambient noise is most prevalent in the low frequency band. However, anthropogenic noise originating from nearby sources can have a disruptive effect for communications, as can be seen in the recording shown in Figure 5 where a ship is passing nearby an AUV communicating to a control station. At time 15:00, the ship is at its closest point of approach and the noise covers the whole communication band causing potential drop-out of messages. Although this effect is only significant for close passages, the intensity




▲ *Figure 2: Impulse response evolution measured in in time (left) and the delay-Doppler spreading function (right) from the TNO RACUN trial. Image courtesy: H. Dol.*

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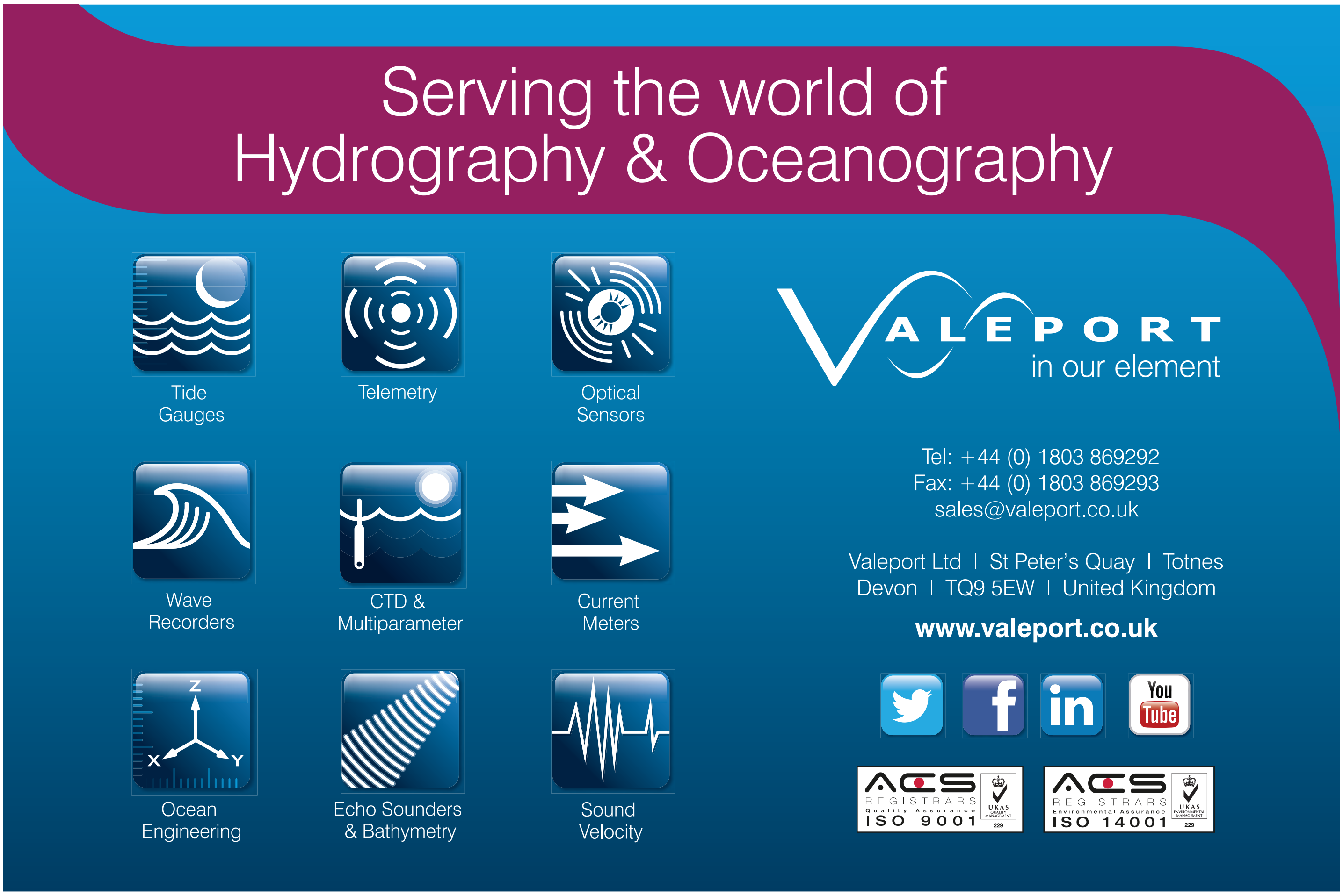

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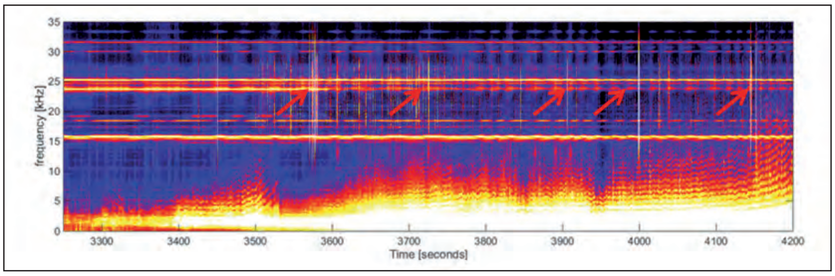
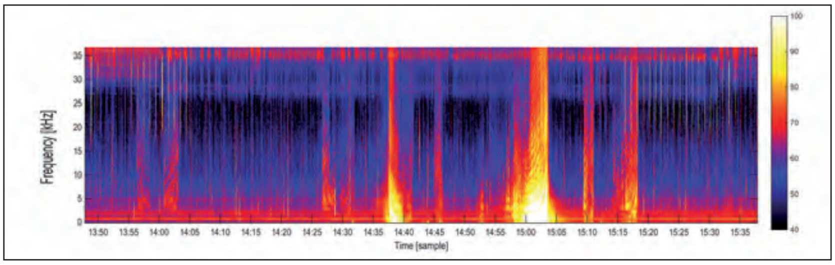



▲ *Figure 3: Uncalibrated spectral density level for a small size AUV approaching the receiving hydrophone at a speed of 2m/s up to 50m distance starting at 500m.*



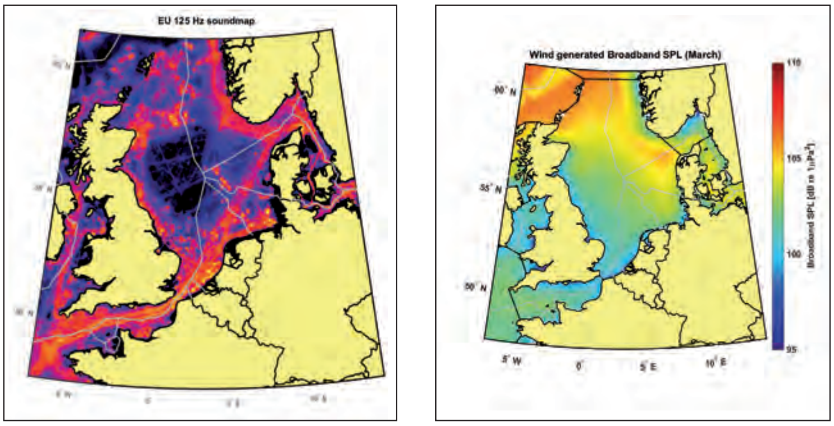

▲ *Figure 4: Calibrated recording of underwater sound from a test in a harbour with a small size AUV and multiple ships passing. The colour scale is sound pressure spectral density level in dB re 1μPa²/Hz.*

of shipping in the North Sea makes it an important effect to be taken into account when performing operations. As an example, a sound map due to shipping in the North Sea is shown in Figure 5 (left).
Models such as the Wentz curve do not capture the strong variability in space and time and of the noise sources. Figure 5 (right) shows a sound map for wind in the North Sea in March that has strong location and season dependence due to the variability of oceanographic parameters.

## Conclusions

Many factors can affect underwater communication to and from AUVs. By having good knowledge of these factors in situ, it is possible to plan AUV operations more efficiently by adapting the bandwidth, communication protocol, network topology, and level of autonomy of the vehicle used. In particular, future networked operations in the North Sea should be complemented by planning tools that take all the parameters presented in Table 1 into account to realistically predict and improve the performance of AUV communications (giving an 'underwater communication range of the day'). ◀

## Physical mechanisms can deform the signal and challenge the reception and interpretation




▲ *Figure 5: (left) The modelled yearly-averaged spatial distribution of ship-generated sound pressure level in the 125Hz one-third octave band. (right) Broad-band SPL for wind-generated sound for the average wind speed in March. Both maps are generated with the Aquarius sound mapping software developed by TNO.*


**More information**

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## The Effect of Hydrography on Unmanned Systems

# A **Software** Perspective

The field of hydrography is poised to make some substantial contributions to the unmanned systems community. The mantra of 'making a map is easy, but doing hydrography is hard' positions hydrographic practitioners favourably into the world of unmanned systems. Moreover, these technologies, once limited to defence and academia, are currently undergoing an expansion into the commercial realm. Not only has this increased the facility of using unmanned systems, it has also spawned innovative uses of these technologies and has blurred the lines between the traditional surveying community to the benefit of all.

As the healthy debate continues with respect to robots replacing humans, we offer an alternative possibility, that is: any technological achievement born from unmanned technology is poised to yield a positive benefit to the manned world. However, to fully realise this vision, we must also be willing to redefine the meaning of what is considered unmanned and pivot our own perceptions. One such proposition can be exemplified by the NOAA Ship *Thomas Jefferson* whose approximately 64 metre reach would be traditionally characterised as a manned vessel. While a majority of the time is spent in this manner, the ship (and survey launches) leverage hydrographic software to communicate and engage the onboard autopilot to steer the platforms utilising a bevy of standardised protocols such as XTE (Cross Track Error) messages.

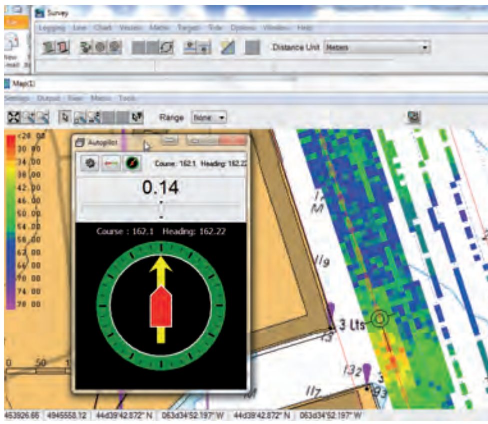
The concept of coupling hydrographic software to an autopilot is not new, but defining this particular mode of operation as 'unmanned' is.

## Any vessel equipped with an autopilot has the capability to become unmanned

To reiterate this idea: any vessel equipped with an autopilot has the capability to become unmanned. The benefits to the manned community can likely be quantified in terms of increased operational safety, less work related injuries and better data quality. Leveraging this technology has the added benefit of increased situational awareness to the coxswain who can now focus their attention on the safe operation of the vessel. Additionally, the hydrographer benefits with improved data quality affording the ability to intelligently interrogate the raw samples into information.

Interestingly, enhancements to the traditional autopilot routines are a direct result of the application toward unmanned surface vessels (USV) and have increased the


▲ *Figure 1: Operating the NOAA Ship* Thomas Jefferson *as an unmanned vessel. Image courtesy: Vitad Pradith - HYPACK*




▲ *Figure 2: Coupling a vessel's autopilot with hydrographic software using standard NMEA messages (National Marine Electronics Association). Image courtesy: Vitad Pradith – HYPACK*

Figure 3: A SeaRobotics USV operating in HYPACK mode. Image courtesy: Geoff Douglass SeaRobotics Inc.


**Vitad 'V' Pradith** manages the portfolio of unmanned systems for HYPACK and provides technology and developmental support to the mapping community. He is particularly interested in enabling technologies that provide real value to the hydrographer by increasing their safety and effectiveness.

v@hypack.com


robustness of unmanned operations.
The innovations and adaptations of the technology to the unmanned industry have opened up new use cases and have spawned a new set of tools to aid the hydrographer such as streamlined mission planning.

### Breaking Down Barriers

Unmanned technologies have also disrupted some of the in situ surveying practices and have bridged the gap between the traditional topographic and hydrographic surveying communities. Together, they are poised to tackle the problems such as assessing the condition of public infrastructure. Again, hydrographers are well positioned to provide their own expertise with respect to the maritime domain and technical savvy.

### Facilitating the Unmanned Paradigm

With the increasing utilisation of unmanned systems into operations, this technology is being adopted to solve all sorts of problems and use cases. From a software design perspective, several tools are needed to facilitate success including command & control, situational awareness, data integrity & quality, all the while maintaining a human in the loop. Commercial entities should also be open to engaging the Open Source community who may present a novel solution to a problem. Everyone benefits from the value added innovation driven by those who seek to advance the unmanned revolution. The hydrographic industry has also transcended its own boundaries into other applications because as any seasoned hydrographer knows, adapting to the changing environment is a perpetual constant.

**Any technological achievement born from unmanned technology is poised to yield a positive benefit to the manned world**

Figure 5: Land Surveyors using a USV with a Robotic Total Station and HYPACK Geodimeter device. Image courtesy: Vitad Pradith - HYPACK.

## Society of Maritime Industries (SMI)

# The **Business** of Maritime **Autonomous Systems**

Attend any conference or exhibition in almost any sector and you will be hard pushed not to find a paper or product offering which addresses the theme of autonomy, particularly in the marine environment. In response, SMI decided it was time to focus on the business of maritime autonomous systems (MAS).

The Society of Maritime Industries (SMI) is the voice of the UK's maritime engineering and business sector promoting and supporting companies that design, build, refit and modernise ships, and supply equipment and services for all types of commercial and naval ships, ports and terminals infrastructure, offshore oil & gas, maritime security & safety, marine science and technology, maritime autonomous systems and marine renewable energy.

**Raise awareness and solve technical, practical, legal and social challenges**

We all know the ocean is a big place, none more so when trying to find out what is underneath its surface or what changes are being wreaked on its chemistry by man's continued occupation of the planet. Therefore it is hardly surprising that those tasked with surveying this vast area are seeking more cost effective ways of undertaking this critical work and increasingly autonomy is being offered as the solution.

### Setting Up Standards

Three years ago the UK government and industry, represented by the UK Marine Industries Alliance, of which SMI is a strategic partner, embarked on a rolling collaborative programme 'to raise awareness and solve technical, practical, legal and social challenges' in the deployment of maritime autonomous systems. Initial activity has centred around collaborative R&D, supported by government grants and development of the regulatory regime required to gain acceptance of MAS, which also addressed standards and training requirements for systems with 'man-in-the-loop'.

The UK Marine Industries Alliance brings together all aspects of this diverse sector with the goal of working together to secure the maximum opportunity for the industry to flourish. The Marine Industries Leadership Council set it up on behalf of the industries and all UK companies, trade associations and public sector agencies operating in the marine sector are offered free membership of the UK Marine Industries Alliance and use of its brand identity. The Leadership Council includes trade associations, regional groupings, government departments, devolved administrations and other public bodies. The work on regulation and standards has

Figure 1: John Murray, chief executive, Society of Marine Industries.


Figure 2: The Marine Autonomous Robotics Systems (MARS) Innovation Centre at the National Oceanography Centre (NOC) in Southampton, UK. Image courtesy of the National Oceanography Centre.


▲ *Figure 3: RSS* Discovery *and her autonomous fleet. Image courtesy of National Oceanography Centre.*

▲ *Figure 4: A glider in the Antarctic. Image courtesy of National Oceanography Centre.*

been progressing apace and earlier this year a Code of Conduct for surface autonomous vessels was published and efforts are now focused on a Code of Practice supported by regulators, standard setters, lawyers and the insurance industry. International support for these moves is essential and a programme of engagement has begun with initially favourable results.

**MAS Business Focus**

It was against this background that SMI saw the need to provide a focus on the business opportunities which were becoming more prevalent from the adoption of MAS as the technology became more main-stream. An inaugural meeting of members in February confirmed this view when a capacity gathering asked the executive management to progress with the formation of a MAS Council to guide the development of policy and activities to aid the business development of members with an interest in MAS. Formally launched at Oceanology International London in March 2016, one of the MAS Council's first tasks has been to survey members and obtain a base line picture of MAS activity in the UK and help guide future activities.

As expected, the initiative has generated favourable interest in organisations wishing to join SMI from a wide spectrum of maritime backgrounds. This is not surprising because MAS is not only changing the world of oceanography and hydrography but has application in maritime defence and security, underwater asset management, deep-sea mining, offshore oil/gas, marine renewable energy, environmental monitoring and maritime transport. Our members with an interest in MAS include manufacturers, academia, researchers, survey companies and system suppliers, and all benefit from the connections and activities provided through membership. Estimates of the potential business value varies but all agree it can be measured in billions of dollars. SMI is now able to focus on this area of business utilising the extensive experience of its Council members in developing activities which will include facilitating outward and inward trade missions to create business opportunities through greater international cooperation; arranging information briefings on key developments in the market; organising networking opportunities with those who have a common interest in maritime autonomous systems; a regular programme of meetings on various aspects of MAS developments and operations with senior high calibre speakers, some of these meetings are restricted to members only; and assistance with sourcing relevant contacts within the industry.

All of this activity is in keeping with our mission statement of 'promoting and supporting the interests of all UK companies that do business in the maritime industries' and more information can be found on the SMI website - www.maritimeindustries.org. ◀

▲ *Figure 5: C-Worker 6 Autonomous Surface Vehicle. Image courtesy of ASV.*

### Track Record Built During Shallow Water Survey

# Autonomous Vessel Delivers in Challenging Environment

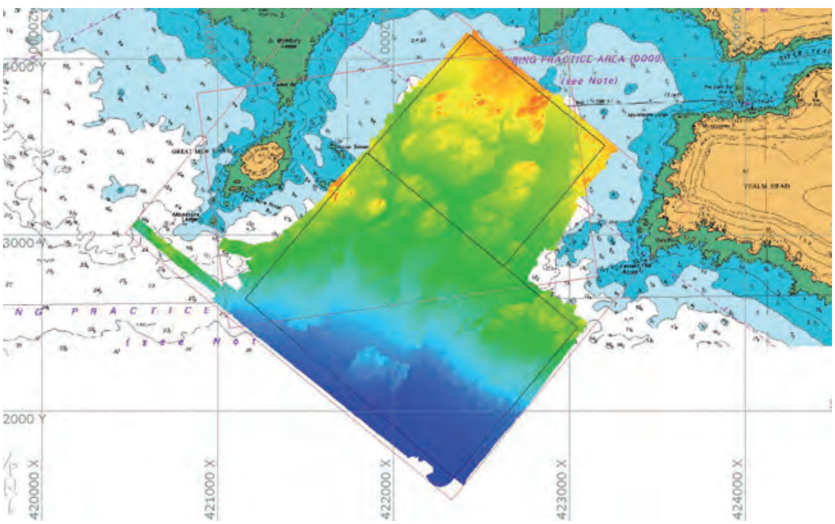
The hydrographic survey industry is changing and moving away from manned operations in an effort to reduce costs and increase safety. During the Shallow Water Survey 2015 conference this new approach and the associated challenges were assessed by Swath Services during the collection of 'The Common Dataset' associated with the conference. The aim of participating with an Unmanned Survey Vessel (USV) was to determine if it was actually possible to undertake such a high specification challenge with a USV. The common dataset provides a benchmark against which the performance of the USV can be measured.

**Shallow Water Survey 2015**

For 2015, The Common Dataset encompassed two survey areas within the natural harbour of Plymouth Sound in England. Participants were required to follow a set of specific operational rules for their dataset to be included. The specific multibeam data collection tasks were split into three categories: Target Detection, Survey Area 1 and Survey Area 2. Each area has its own specific environment and settings. The target detection task was designed to ensure that data was collected over known features and in such a way as to allow direct comparison. In order to achieve this, set line plans were produced and participants were required to adhere to a set speed of 6 knots over the ground, in addition to a swathe angle of 70° either side of Nadir.

**The entire survey was completed in four days including the first day of calibrations**

For the two survey areas 1 and 2 with a depth of 0 – 35m there were no restrictions on survey speed or sonar settings, but participants were asked to deliver a dataset that met S-44 Order 1a. Survey Area 1 with an approximate size of 2km² included tidal currents, a narrow passage through the Bridge and shallow water (< 5m). Survey Area 2 (Figure 1) was divided up into Block A of 2km² and Block B of 1km².




▲ *Figure 1: Survey results of Area 2.*

**Survey System**

To meet the high survey specification requirement an R2SONIC 2022 with Integrated Inertial Navigation System (I2NS), Valeport MiniSVS, Trimble RTK (3G corrections) and Hypack Hysweep data acquisition software were installed on the dedicated payload frame of a C-Worker 6 vehicle from ASV Ltd (Figure 2). A further Valeport SWiFT was used on the support vessel.

The C-Worker 6 Autonomous Surface Vessel (ASV – Figure 3) has been designed for offshore survey applications: long endurance (up to 30 days), and multiple sensor installation with a quick payload change capability. During this project real-time operational control and data quality checking was achieved through a high powered dedicated WiFi link to the vessel using remote desktop capability.

▲ *Figure 2: Payload frame with all sensors installed.*

▲ *Figure 3: C-Worker 6 in action during Shallow Water 2015.*

**Mobilisation**

The Shallow Survey events allow five working days to be given to each participant to install and operate their equipment from a designated local vessel of convenience. The installation, offset measurements and equipment testing was conducted onshore (Southampton) during one morning preceding the week of survey operations. The complete vessel and installed equipment was then transited to the survey site via road and lifted into the water (Figure 4).

One of the clear benefits at this stage was the ease of equipment installation. There was a dedicated and rigid payload frame that could house the multibeam transducer, INS sensor and poles for the GNSS antennas. This allowed for offset measurements to be taken by hand and then cross-checked against technical drawings without the need for costly dimensional control surveys to be carried out. The other benefit is the repeatability of the mounting arrangement and the reduced need to re-calibrate sensor components.

**Survey**

The entire survey was completed in four days including the first day of calibrations. During the survey a survey team was located on a support vessel that was always in sight of C-Worker 6. This was not so much a technical requirement but rather an operational one. Although the rules and regulations for USVs to operate in busy commercial and/or naval ports are yet to be defined, current practice is to seek permission from the harbour master prior to any activities taking place. Although permission was given by Plymouth's Queens Harbour Master (QHM) and a full risk assessment undertaken, the C-Worker 6 was only allowed to operate in these survey areas subject to having an attending support vessel present. In addition to this, VHF communications were used so that the survey team could advise QHM of daily activities and their locations.

All survey operations were controlled from the support vessel by remote desktop with the exception of taking sound velocity profiles. As no Sound Velocity Profiler (SVP) winch was present on C-Worker 6 at the time of survey operations, these were taken from the support vessel in close proximity to C-Worker using the Valeport SWiFT SVP. This SVP records a GNSS position prior to deployment at each location and then stores it in the header of the recorded data file. The data file was transferred to the survey laptop onboard the C-Worker 6 via the same 3G connection used for the RTK corrections. Within minutes of taking each profile the HYSWEEP software was applying real-time SVP corrections to the multibeam data.

**Results**

In total C-Worker 6 completed Survey Area 1 (with exception of one target) in a record time of 10hrs 5mins. Survey Areas 2 A and B were also completed in just 10hrs 40mins. This does not include transit time to/from each site, calibration activities or any other down time. Only one other participant recorded completing all areas in the allotted boat time. The ability of the vessel to navigate accurate straight lines by using its autonomy programming considerably reduced field survey time thus increasing overall survey efficiency and productivity. In areas where the depths changed dramatically or the vessel was close inshore direct remote control was chosen by the operators. Direct remote control, which allows the operator to very quickly change course or bring the vessel to a halt, was used in conjunction with onboard cameras and georeferenced background charts to avoid obstacles in the water. This was especially evident when avoiding many of the lobster pot buoys, sailing dinghies and diver charters.

The performance of all survey equipment was no different than on a manned vessel and met IHO Order 1A. Quality checking and adjustments were made as if a surveyor was present on the vessel. The only difference was the slight time delay in the remote desktop update rate, which meant that any adjustments to online filters were delayed. Fortunately, the

## The performance of all survey equipment was no different than on a manned vessel and met IHO Order 1A


▲ *Figure 4: Installed payload frame.*

R2SONIC automatic filters tracked the seabed effectively reducing the need for manual adjustment. Despite this, these delays had no effect on operational capabilities, such as the ping rate of the sonar. Data was logged on the vessel which allowed for greater ranges of up to 10km to be possible between the support vessel and USV.

The target areas (Figure 5) proved challenging due to the fast tidal currents in these areas. The maximum speed of C-Worker 6 only just reached the required 6 knots over the ground. Strong currents also meant that additional time was required to make vessel turns and to ensure offline distances remained within specification, however, this was no different to being on a manned vessel.

**Greater ranges of up to 10km between the support vessel and USV were possible**

One of the lessons learnt occurred onsite when the original survey line plan could not be imported into the navigation system on C-Worker 6. This resulted in additional time being required to replicate the line plan manually on route to each location. Another significant consideration was that although the SVP solution onboard the support vessel was very effective in Survey Area 1 there was limited 3G reception in Survey Area 2, which not only meant that the SVP data could not be transmitted to the unmanned vessel but that unreliable RTK corrections were experienced as well. Consequently, the SVP profiles had to be added at the post processing stage and the Applanix POSPac software used for post-processing all positional data.

## Conclusion

In general, the vessel performed beyond expectations and proved to be very reliable and a suitable platform for undertaking hydrographic survey operations. It surveyed all three areas completely (with exception of one target location due to a moored yacht). It was one of only two that achieved all three objectives. However, until regulations change, the use of the support vessel alongside a USV could make this solution more expensive than using a manned vessel of convenience. In time, as these types of vessel become more prevalent, such inshore surveys may then be commercially viable.

## Acknowledgements

Thanks are due to ASV Ltd for their support during the survey. ◂

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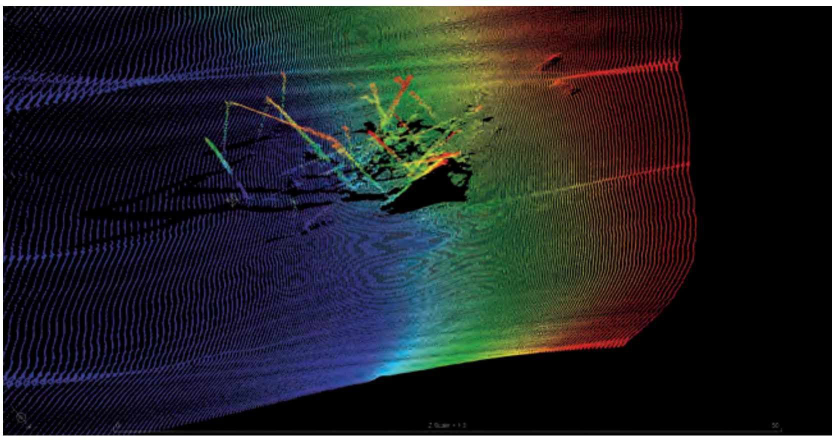

▲ *Figure 5: 400kHz survey results from one of the target areas.*

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