A VIEW OF THE AUTONOMOUS UNDERWATER VEHICLE MARKET

The Advancing Technology of AUVs

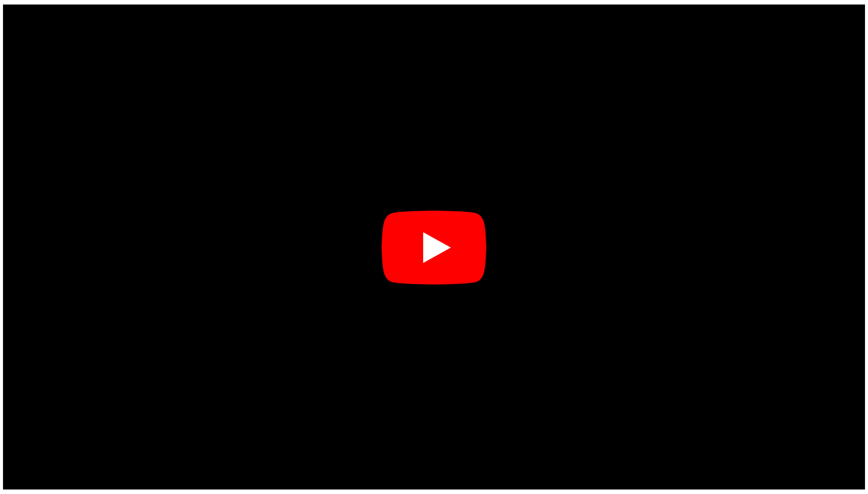
Since the last autonomous underwater vehicle (AUV) review in 2016, the market has continued to grow. The biggest market for AUV systems remains the military. The world's most advanced Navies own and operate low-logistic AUV systems for mine countermeasures (MCM) in very shallow waters. These systems can operate in confined areas where MCM vessels cannot. The same systems can also be used in search and recovery operations, hydrography and salvage. This market used to be dominated by a handful of AUV providers. However, the number of manufacturers is increasing.

Defence primes are also investing in these technologies through internal development programmes or acquisitions. In the commercial sector, the number of companies offering AUV services has grown too and new concepts of operations have been developed to adapt their use. As an example, Ocean Infinity operates multiple AUV systems from a single vessel, enabling faster data acquisition. The success of this application was demonstrated by the search for and discovery of the *ARA San Juan* submarine.

Technical Building Blocks

The growth in AUV use is in part driven by continuing improvements in AUV technology and capability. In the last two years, new AUV models have been launched and these can gather more data, over longer periods and more accurately. Many of these AUV systems are more compact than their predecessors despite their increased capacity.

Better endurance, improved communications, more accurate navigation, enhanced imaging, artificial intelligence and big data are all contributors. Recent advances in energy density, spearheaded by the mobile phone industry, have helped improve AUV endurance. In parallel, communications, navigation and payload instruments are becoming more effective. The latest advances in signal design are being used to make acoustic communications travel further and carry more data, using less power. Other techniques like free space optical modems are also enabling large amounts of data to be transferred through-water to AUV systems, using the visible light spectrum at distances of up to 150m. More than ten thousand times more data can be transferred this way than is possible with acoustics. In parallel, navigation performance is improving thanks to new inertial navigation systems that can dead-reckon with as much as twice the certainty of what was possible even two years ago. This is possible by combining latest generation gyros and acoustic aiding from Doppler velocity logs as part of a single instrument.



Better Understanding of the Environment

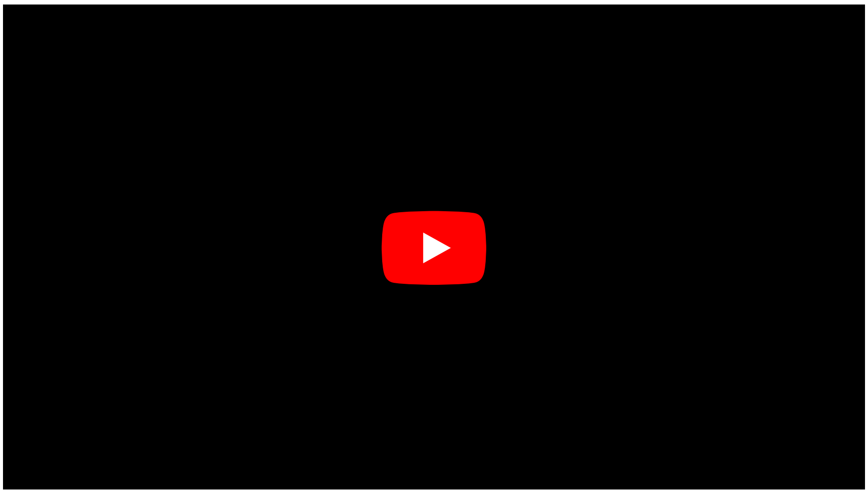
There are now many more options for AUV payloads. When thinking about a mission, operators can choose from lasers, sonars and even stereoscopic high-definition video. Electronically scanned sonar systems are now manufactured in all sizes - even as small as a GoPro camera – for every application. Some produce stunning imagery at 5m range using high frequencies. Others, working at lower frequencies, can spot obstacles at ranges of over 1000m. For inspection missions, video and laser are combining to provide stunning pictures of the subsea environment as it has never been seen before; at centimetric resolution and in full colour. When it comes to survey, operators are not just limited to side-scan sonar imagery and multibeam bathymetry. There is now a new generation of multi aperture sonar systems capable of extending range and producing three-dimensional bathymetry. Synthetic aperture sonar has also proved popular for large AUV systems. This is an industry generating more data than ever before. Fortunately, it is at a time when storage solutions have become more prevalent, and machine learning and big data techniques are becoming wide-spread.

So, how are AUV systems being used? The following section explores some of their current uses.

Military Roadmaps

Cylinder shaped AUV systems with a diameter of approximately 9in-12in have become a common sight in MCM operations. These systems are typically equipped with side-scan sonar systems and high-grade survey systems. They are launched from small vessels or rigid hull inflatable boats and survey rectangular areas of the seabed in search of objects of interest. The data quality and speed of survey make them the ideal tool for this purpose. The number of working systems operated by navies keeps increasing and the number of navies adopting them is also increasing. They are also playing an important role in helping navies understand and learning to use autonomy. At the end of 2016, the UK hosted the Unmanned Warrior exercise in the UK. It was a showpiece for autonomous technology, with international participation from industry and foreign delegations. Following that exercise, governments realised that autonomous systems are indeed very capable and stand to revolutionise the way their navies operate.

Leading the pack, the Belgian and Dutch navies are currently accepting bids for their next generation MCM vessels, which will be equipped with AUV systems and other autonomous assets as standard. This will be a world-first; traditionally, mine hunting vessels are equipped with towed or variable depth sonars. The UK's mine countermeasures and hydrographic capability programme and the US littoral combat ship MCM module follow a similar model. AUV systems may become the de-facto mine hunting tool.



Autonomous Submarines

The US Navy announced recently that it had awarded contracts to Boeing and Lockheed Martin to develop extra-large diameter AUV systems. These systems will replace submarines in many of their missions, deploying from shore and travelling thousands of nautical miles to conduct intelligence gathering, surveys or inspections. It is not just the military that is contemplating long-endurance AUV systems. The National Oceanography Centre (NOC) in Southampton, UK, has developed a range of systems named Autosub long range (ALR) which can travel for months and can conduct scientific missions across large distances. The most famous ALR, nick-named Boaty McBoatface, will be operated from the UK's flagship oceanographic vessel the RSS *Sir David Attenborough* when it launches. The ALR has already demonstrated the ability to operate 'over-the-horizon' by linking to an unmanned surface vessel and using it to establish a link to shore. It has also demonstrated the ability to detect leaks and seeps and its use for carbon capture inspections.

Extra-large diameter AUV systems can be deployed and recovered from shore, so launch and recovery is simpler and they can operate in a much wider set of sea states. They do, however, need a large battery pack and very accurate navigation. The promise of this technology is that it can deliver science at a fraction of the cost of a vessel and crew. Others may well follow NOC's designs.

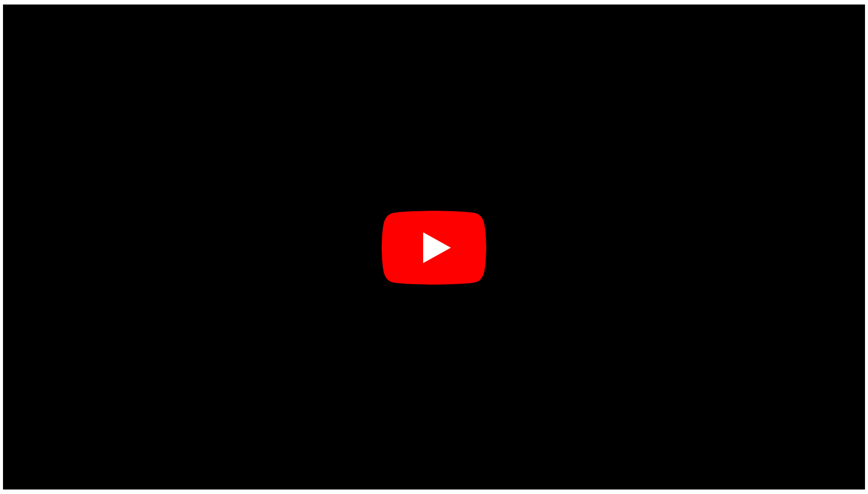
Low-logistic AUVs have become the survey tool of choice for expeditionary forces. Pictured here is the Bluefin-9 two-man portable AUV from General Dynamics Mission Systems.

Another future use for these systems in the military domain may be anti-submarine warfare (ASW) operations. The persistence of extra-large diameter AUV systems is also attractive for this purpose. They can monitor choke points or work together in the open ocean. Since ageing fleets of ASW vessels are nearing replacement and these AUV systems are seen as a cost-effective force multiplier, they may, in time, become the ASW force.

Oil and Gas Today

This sector has been using AUV systems commercially for many years for deepwater surveys. The last two years saw some new players enter the market and a renewed interest in autonomy from operators in autonomy. The downturn in the oil price meant that operators had to seek more efficient ways to operate and AUV systems were and remain part of the solution. In this sector, the commercial use of AUV technology is still dominated by the deepwater survey market. There are also some systems available for surveys in shallower waters and a lot of work has been done with these in West Africa. Companies like Ocean Infinity are questioning the status quo and it will be interesting to see what happens. Other companies, like MMT, have banked on remotely operated vehicles (ROVs) capable of fast survey speeds. Interestingly, these fast ROVs look remarkably like an AUV but remain tethered to a surface vessel.

Will there be a time when the tether is severed? Perhaps not for survey tasks. However, as far as subsea inspections are concerned people are asking when, not if, the tether will be severed. In this area, there is a race for dominance. Saab Seaeye introduced the Sabretooth product, a hybrid ROV/AUV for prolonged duration inspection missions, many years ago. Since 2011, i-Tech Services has been working on its autonomous inspection vehicle (AIV) offering for oil and gas inspections. Now, these companies are being joined by Oceaneering, with its Freedom concept, Saipem, with Hydrone and its FlatFish license, the Eelume snake-like AUV, and Houston Mechatronics' Aquanaut. IKM also offers a resident electronic ROV concept. While each system has its differences, they all mix remote operation with autonomous decision-making. Furthermore, they are all being built in response to operator demand. Companies like Equinor have made no secret of their vision for underwater intervention drones, a term they have trademarked. Recently, other companies including Aker BP have included AUV operations in their vision statements. This promises to be an exciting space to watch.



AUV Swarms

Another development is the proliferation of low cost, small AUV units, which collaborate and work together for one common goal. This is typically referred to as a swarm of AUV systems. There have been some well publicised trials by several companies, and other work has been published but not discussed in the open media. More work is being conducted by companies which prefer to remain outside of the public domain while their technology is being developed, deployed and manufactured. The biggest commercial driver for this technology is thought to be for marine seismic applications. However, the military and oceanographic bodies are also keen to develop tools that enable them to cover larger swaths of the oceans. This is very much work in progress and it is hard to predict when the technology will become commercial. Crucial technical hurdles still need to be met: How does the swarm communicate? What payload sensors can it carry and afford while remaining commercially viable? How do we launch, operate and recover each and every AUV?

C-Worker Unmanned Surface Vehicle and National Oceanography ALR working together in recent trials demonstrating acoustic and optical communications.

The Shell Ocean Discovery XPRIZE

While this article was being written, the final of the Shell Ocean Discovery XPRIZE was taking place in Greece. Many teams entered this competition with the ambition of being the first to provide a solution capable of launching from shore or air in order to explore the competition area, to survey it and to photograph a specific object. The competition area is up to 4000m deep. There is US $7 million in prize money to be won. Eight teams made it to the final, each with their own unique concept, from AUV systems supported by unmanned surface vessels for launch and recovery, to air-deployed ones.

The aim of this competition is to help increase our knowledge of the oceans. Today, only 5% of the ocean floor has been explored yet the oceans provide 50% of our oxygen. In fact, we know more about the surface of Mars than we know about our own seabed.

Academia and Native AUV Systems

Academia continues to use and develop AUV systems. Institutions such as the NOC, Woods Hole Oceanographic Institution, Scripps Institution of Oceanography and Monterey Bay Aquarium Research Institute have lead these efforts. Now, many other programmes are being developed across the world. From South America to South East Asia, researchers are developing home-grown AUV systems to help advance their own understanding of the technology and to help adapt it to their own needs. This is evidenced by the diversity of teams that took part in this year’s AUVSI Robosub, a high school and undergraduate AUV design competition. The top three teams were from China, Singapore and Canada, respectively - in a competition that took place in the US.

What Should We Expect to Happen Next?

Operating autonomously subsea is challenging: lack of communications, intense physical pressure, no ambient light and unchartered waters add up to make it one of the most difficult technical challenges for humanity to solve. Solutions have been found and over the last two decades the market has grown in ways which we never anticipated at the start of this journey. As new blue technology industries such as aquaculture, mining and renewables evolve, I expect AUV systems to play a part in their evolution. The successes of the last two years should help with the continued expansion of the AUV market. New successes to come will in turn fuel future market growth. Will the market be dominated by extra-large AUV systems, AUV swarms or extra-large AUV swarms? Most likely a combination of them all.

Saab Seaeye Sabretooth using BlueComm free space optical modem for wireless communications.