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The Evolution of Autonomous Vehicles at the National Oceanography Centre, UK

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***Abstract*— The UK government considers robotics as a key future industry sector and has been an enthusiastic supporter of NOC's use of marine robotic systems, releasing funds to enable to NOC to build the 'MARS Innovation Centre' to build on this leading capability, which opened in Autumn 2015 to act as the UK's focus for marine autonomous robotic systems.

Autonomous systems are steadily becoming more capable, more reliable, and are gaining longer endurance. Costs are falling as new vehicles enter the market, and the supporting sectors such as the insurance industry gain more experience of working with the operators. For unmanned surface vehicles in particular it is likely that costs will fall enough for new users such as marine environmental protection charities or fishing organizations to deploy their own systems. Military use will certainly increase as well.

Gradually the dream of replacing a research ship with a robot will be achieved for a wide range of missions, greatly increasing humanity's knowledge about the global ocean, enabling us to better-manage resources, provide early warning of geohazards or algal blooms, and adapt to changing climate conditions. NOC's experience will feed into international capacity building and knowledge exchange activities through the UK's actions in support of UN Sustainable Development Goals and Technology Transfer under the UN Convention on the Law of the Sea. The industry will continue to grow, and soon the idea of autonomy in the ocean will be as normal as the ubiquity of satellite communications, remote sensing and navigation.

***Keywords*—** AUV, sea observations, NOC, Autosub.

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I. Introduction

USING a ship to gather routine oceanographic observations gives high quality data but has very low spatial and temporal resolution and is very expensive, for a global class research vessel approx.100m length at least $US25000 per day at modest fuel prices and with a small crew, excluding the high capital costs of building the ship in the first place, which is now tens of millions of dollars.

Surely there's a cheaper but still effective way to gather sustained observations such as temperature, salinity, chemistry, nutrients or underwater sound to meet societal, defense and industry needs? Satellites or long-endurance patrol aircraft are superb at sea surface measurements but are of limited use at providing sub-surface data, and although long-range active sonar has some value for detecting a limited range of oceanographic measurements there are often strong environmental objections to using ocean basin-scale acoustic techniques, due to impacts of low-frequency noise on marine wildlife.

Back in the 1980s Professor John Woods, then head of marine and atmospheric sciences at the UK's Natural Environment Research Council (NERC www.nerc.ac.uk), argued persuasively that the ability of researchers to gather sustained observations at sea could be through the use of autonomous underwater vehicles (AUVs). The engineers at NERC's Institute of Oceanographic Sciences Deacon Laboratory (IOSDL) at Wormley in Surrey, England, came up with proposals for two designs - "DOLPHIN" (Deep Ocean Long Path Hydrographic Instrument) and "DOGGIE" (Deep Ocean Geological & Geophysical Instrument Explorer). DOLPHIN was a streamlined long endurance system intended to make profiles through the water column; transmitting data regularly back to shore, and with the range to conduct long missions such as Greenland-UK. DOGGIE needed lots of power to survey the ocean floor so was more dependent upon a 'mother ship' to recover data and recharge batteries.

With the battery limitations of the late 80's it was considered that the DOLPHIN vehicle was not yet achievable, and as the Cold War gave way to more peaceful relations with the former Soviet Union the potential anti-submarine warfare value of a long range surveillance vehicle optimised for the harsh waters of the Greenland-Iceland-UK region dropped in importance, so priority was given to pursuing a version of DOGGIE that became known as "Autosub" – a 7m long, 1m diameter vehicle initially powered by 12v lead-acid automotive batteries. The Mk1 prototype was completed soon after IOSDL relocated to the Southampton Oceanography Centre in 1995, and embarked on a series of trials in 1996 to prove it could offer genuine scientific capability. As trials progressed new pressure vessels were designed using innovative carbon fibre tubes to house the electronics and the lead-acid batteries were replaced by packs of several thousand alkaline manganese primary 'D'-cells, enabling the upgraded Mk1a vehicle to achieve 800 to 1000km range, but an expensive recharge as the cells were single-use.

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In 1997 NERC awarded a contract to the Autosub team to deploy the Mk1a vehicle on a series of science missions, intended to prove AUV technology in a variety of scenarios (http://www.bodc.ac.uk/projects/uk/autosub/). These included shallow-water surveys of North Sea sand waves; deep water tests of a submersible flow cytometer system; fisheries surveys with an EK500 sonar in collaboration with the research vessel ‘Scotia’ to determine if autonomous systems could be used for such survey work in the future; a survey and reconnaissance mission in the Straits of Sicily; and the most challenging of all – the first surveys under ice off Antarctica.

Autosub passed the tests with flying colours, delivering gigabytes of data whilst allowing the mother ship to go off and do other work, acting as a ‘force multiplier’ enhancing the value that a single ship was able to provide whilst commissioned to do work in a given area.

On the success of the first series of missions NERC commissioned a second tranche after 2000, ‘Autosub Under Ice’ (http://www.bodc.ac.uk/projects/uk/aui/), that focussed mainly on polar operations off Antarctica and Greenland. Autosub was upgraded to Autosub 2 standard with improved systems, but given the high probability of loss in such uncharted waters the decision was taken to build another vehicle, Autosub 3, which was delivered in 2005 and added a fibre-optic gyrocompass. This turned out to be a wise investment as Autosub 2 was eventually stranded under ice, some 17km from open ocean in February 2005 under the Fimbulisen – but not before returning data from hundreds of kilometres of passage under the ice sheet. Autosub 3 was first deployed under ice in January 2009.

By now Autosub had proved itself an effective and reliable system, and helped encourage the confidence for major commercial AUVs to emerge from industry, for example Subsea 7 built a licenced version of Autosub 1a, Simrad produced the Hugin series, and from the USA several small AUVs such as ‘Remus’ went into production. Maridan’s ‘Martin’ AUV was bought by de Beers to conduct diamond mining surveys off West Africa and several navies began to test autonomous mine hunting systems, with varying levels of success. Autosub remained the long-endurance champion, but the large size and weight of the vehicle made it difficult to fit on ships of opportunity and required a specialist deployment and recovery system. A deep-diving version with rechargeable lithium batteries was built in 2007, Autosub 6000 (for 6000m diving capability) and this vehicle remains in the front line of deep exploration of the ocean floor, discovering deep ocean vents in the Cayman Trench and, with added camera systems, surveying biodiversity over the UK continental shelf as part of the baseline assessments for the EU’s marine strategy framework directive.

To meet the need for a versatile, long endurance but less bulky vehicle the Southampton team next came up with Autosub LR – for ‘Long Range’. The institute was renamed the National Oceanography Centre (www.noc.ac.uk) in 2007 and had a remit to provide leadership and innovation for the marine science community, and the Autosub LR was an ideal platform to show the progress that was being made. With new legislation emerging that required affordable sustained observations the Autosub series was beginning to meet the ‘DOLPHIN’ mission criteria envisaged back in the 1980s. The first Autosub LR sea trials began in January 2011 as part of the ‘FASTNet’ programme (http://noc.ac.uk/news/autosub-long-range-ready-cast), and the vehicle has since logged hundreds of hours at sea. When fully developed, Autosub LR will be able to conduct 6 month, 6000km missions. It achieves this by a careful combination of low energy use, slow speed, efficient systems and good hydrodynamic design.

With the NOC team gaining many years of hands-on experience in AUV deployment the next challenge was to assess the scientific value of autonomous surface vehicles. Three systems are now in use at NOC, all commercial off the self – the USA-made Liquid Robotics SV3 Waveglider (http://www.liquidr.com/technology/waveglider/sv3.html), and two UK-manufactured vehicles, the compact MOST AV AutoNaut (http://www.autonautusv.com) and larger ASV C-Enduro (http://asvglobal.com/product/c-enduro/). NOC have used them alongside commercial off the shelf gliders and the existing AUV fleet as part of a project to see how ‘swarms’ of vehicles can operate together. Known as MASSMO, (http://projects.noc.ac.uk/exploring-ocean-fronts/tags/massmo) the first joint mission off the Scilly Isles was very successful and is leading to a series of follow-up exercises including partners from other institutes and the Royal Navy, some adding their own vehicles into the mix.

The UK government considers robotics as a key future industry sector and has been an enthusiastic supporter of NOC’s use of marine robotic systems, releasing funds to enable to NOC to build the ‘MARS Innovation Centre’ to build on this leading capability, which opened in Autumn 2015 to act as the UK’s focus for marine autonomous robotic systems. A visitor to the facility will see a fleet of three Autosub LR vehicles, Autosub 3, and Autosub 6000 alongside gliders, floats and the new surface vehicles – plus the expert staff and facilities who enable safe and effective operation of these leading edge systems. Operating on the surface presents a new set of challenges as safely of life at sea and anti-collision regulations set strict rules over the safe operations of un-crewed vessels, indeed there are many gaps in the existing international legislation as it never evolved to assume that autonomous systems would be in use. The Intergovernmental Oceanographic Commission, International Maritime Organisation and other such as the Institute for Marine Engineering, Science and Technology are working together to put this right – but it will be some years before legislation catches up with technology.

What might the future hold? Autonomous systems are steadily becoming more capable, more reliable, and are gaining longer endurance. Costs are falling as new vehicles enter the market, and the supporting sectors such as the insurance industry gain more experience of working with the operators.

For unmanned surface vehicles in particular it is likely that costs will fall enough for new users such as marine environmental protection charities or fishing organisations to deploy their own systems. Military use will certainly increase – the stealth, long endurance and improving capabilities of AUVs make them attractive platforms for surveillance and tracking, perhaps one day to challenge the relative invulnerability of submerged missile-carrying submarines – which could find themselves tracked by swarms of small robots throughout their deployment, not even definitely owned by governments – an anti-nuclear pressure group could create huge political impact by exposing the position of a nuclear submarine to the public.

Gradually the dream of replacing a research ship with a robot will be achieved for a wide range of missions, greatly increasing humanity's knowledge about the global ocean, enabling us to better-manage resources, provide early warning of geohazards or algal blooms, and adapt to changing climate conditions. NOC's experience will feed into international capacity building and knowledge exchange activities through the UK's actions in support of UN Sustainable Development Goals and Technology Transfer under the UN Convention on the Law of the Sea. The industry will continue to grow, and soon the idea of autonomy in the ocean will be as normal as the ubiquity of satellite communications, remote sensing and navigation.