MARINE AUTONOMOUS AND ROBOTIC SYSTEMS

Autosubs

Autonomous Underwater Vehicles (AUVs) are robot submarines, which are used to explore the world's oceans without a pilot or any tether.

Before launch from the research ship, the AUV's computers are programmed with instructions of where to go, what to measure and what depths to go to. With no link to the mother ship, all communications with the AUV are limited to using acoustics (sound) while the AUV is underwater (this typically has a range of a few kilometres), or satellite communications (such as Iridium) when the AUV is floating on the sea surface.
The NOC has been developing the Autosub range of AUVs for many years with the first missions taking place in 1997. You can read about the history of the development of Autosub.

Power and propulsion

Energy supply for the propulsion system and sensors is a challenge for AUVs. Without the supply of oxygen from the atmosphere, internal combustion engines are not practical. Rather, the AUV must rely on batteries. As the amount of energy available from 1kg of the best batteries is about ten times less than that available from the same quantity of diesel fuel, currently AUVs are limited in range and speed compared to surface vessels. As the required propulsive power increases very rapidly with operating speed (approximately proportional to the speed cubed), the solution is usually for the Autosub to travel slowly to enable sufficient range. The current Autosub AUVs run at approximately 1.7ms^{-1} (surface ships typically run at 5 to 10ms^{-1}).

Navigation

Accurate navigation is also a challenge for an AUV. At the sea surface, AUVs can be positioned using the satellite-based Global Positioning Systems (GPS), however, satellite signals are not able to penetrate even the top few millimetres of the ocean and hence other means are needed to navigate the AUVs once they have dived. The Autosub AUVs rely mostly on an approach known as dead reckoning; the AUVs bounce sound off the seabed, and by measuring the Doppler shift of the echoes, they are able to measure their speed relative to the seabed. For dead reckoning, the AUV must also accurately sense its heading. On the Autosub AUV a fibre-optic gyro-based sensor is used, giving heading accuracy of better than 0.1 degrees. Overall, accuracies of about one metre error for each kilometre travelled are achievable. Navigation accuracy is critical to many survey missions, and hence, the NOC are researching and developing techniques to further improve upon this performance.

The NOC Autosub fleet

The NOC operates four AUVs: Autosub6000 and three Autosub Long Range vehicles. The Oceanids programme is developing a further four Autosub AUVs, each with its own unique and specific strengths.

Autosub 6000

Autosub6000 has been developed to operate in extreme environments, to the depths of the oceans, 6000m deep, where the crushing pressures are 600 times greater than at the surface.

Autosub6000 AUV

Following its first sea trials in 2007, Autosub6000 has undergone significant development. In the summer of 2008 it undertook its first science missions, surveying deep-sea scour features on the deep western European Margin with multi-beam sonar.
In October of 2009, the AUV completed successful trials to an operating depth of 5600m, and tested a new obstacle avoidance system, based on scanning sonar, over the rugged terrain of the Casablanca Seamount. This was put to good use in early 2010, operating off the RRS *James Cook,* where the AUV was crucial to the effort to locate and pinpoint the positions of two hydrothermal vent sites in the mid Cayman Rise area of the Caribbean Sea. One of the innovative features of Autosub6000 is that - unlike the earlier Autosub3 - it does not use strong pressure vessels to protect the batteries from the external pressure. Rather it uses batteries that we have specifically developed, which can themselves withstand the pressures at 6000m depth. These are fitted into cut-outs within the buoyancy foam (syntactic foam) which makes up the centre section of the AUV.

Autosub Long Range

The Autosub Long Range AUV (or Autosub LR) is a new type of AUV with a depth rating of 6000m. Although a third the weight of the Autosub3 and the Autosub6000 AUVs, it is able to travel greater than ten times the distance and can be deployed for over a hundred times the duration.

Autosub Long Range AUV

The key to achieving this performance is efficient propulsion at slow speed (at 0.4 ms^{-1}), and by keeping tight control of the power used by the AUV sensors and control systems. One area in which recent advances in technology has helped make this possible has been in the development of microprocessors for devices such as mobile phones which have ample processing power, but which use very little energy.
With a 2000km range, and a depth rating of 6000m, this AUV is very useful to oceanographers in providing measurements of ocean and seabed properties over ocean scales, and without the need for a research ship. The AUV periodically surfaces and transmits the data back to the scientists via an Iridium satellite data link.

Gliders

Gliders are a type of robotic underwater vehicle used for measuring oceanographic parameters such as chlorophyll levels, temperature and salinity, which are then transmitted back to the shore. They are very effective tools for gathering data from the ocean and carry a great variety of instruments.

Find out more about the gliders, what they are capable of doing, and how they are being used.

About
A glider uses an internal pump to change its buoyancy, enabling it to move up and down in the water, where as conventional robotic vehicles or Autonomous Underwater Vehicles (AUVs, such as Autosub) are propeller-driven. The movement of internal weights back and forth enables the glider to angle itself to dive or climb in the water column. Like an aerial glider moving vertically through the air, underwater gliders use the lift generated by the wings moving through the water to convert vertical force into forward motion. Gliders are fitted with an inbuilt compass, which they use to steer a course. Gliders move very slowly, usually at less than a mile per hour, but can maintain this speed for months on end.
Gliders have been around for around 20 years in one form or another, designed and built by universities and research institutes. Today they are made and sold commercially, mainly by companies in the United States. The NOC glider fleet has gliders from two manufacturers: Slocum gliders from Teledyne Webb Research Corporation, and Seagliders from Kongsberg Underwater Technology Inc.

To move up and down, the glider does not change its mass, but by pumping a fluid (oil in this case) from an internal reservoir to an external flexible bladder, so it can increase its volume. The density of a glider depends on both its mass and its volume; by pumping oil in and out of the bladder the glider is able to make itself alternately denser and lighter than the surrounding water – the glider can sink to a pre-programmed depth then float back to the surface.

Technology
Glider missions can run for many months with directions being sent remotely via two-way satellite communications (Iridium) link. They use little energy and so are inexpensive to operate compared to using traditional methods. Gliders sensors have very low-power requirements, typically consuming an average power of less than one Watt.
With a typical length of 2m and weight of around 65kg, gliders do not always need to be deployed or recovered from the deck of a research ship, which makes glider missions cheaper to run and more versatile to schedule. Many glider missions are started and ended using two people and a fast RIB, piloting the glider close to the shore at the start or end of its mission. Where ship deployment or recovery is necessary, it usually only takes only a few hours of ship time.

In principle, buoyancy engines are neither more nor less efficient than a motor and propeller, but the fact that gliders travel very slowly means they consume little energy in propelling themselves. A Seaglider or a Slocum glider diving to 1,000 metres consumes about 65 Watts from its batteries, for about two minutes, when it pumps some oil to the external bladder and returns to the surface. This pumping of oil to the external bladder is the biggest power drain on the glider's battery, although this process is only carried out once every few hours. When the glider reaches the surface, a small valve is opened and the partial vacuum inside the main hull sucks the oil from the bladder back into the reservoir. Another motor moves one of the heavy batteries back and forth a small distance to angle the nose up or down, which enables the glider to see-saw between the ocean surface and its maximum depth, moving slowly forwards with each vertical movement. This type of glider cannot fly level unless an auxiliary propeller is fitted, which can be done with the Slocum, although both Slocums and Seagliders can stop and drift at depth for some types of measurement.

Gliders can use conventional alkaline batteries for short missions and some are now using rechargeable lithium batteries. For longer missions, gliders need the power density of a primary lithium battery pack. With a small sensor load, i.e., temperature and salinity against depth, a glider is able to last six to nine months at sea. Sensors that use luminescence to measure, e.g., relative chlorophyll density or oxygen, will use more power and restrict missions to three months. Biofouling in the form of barnacles and algae will slow the glider and take any optical sensor readings out of calibration. Cold water such as over the Antarctic continental shelf also reduces mission duration as all batteries have reduced capacity as the temperature approaches freezing.

In order to transmit data back to land, the glider establishes communications with the shore station over an Iridium satellite link each time it surfaces. This allows the pilot to monitor progress, check the state of critical systems such as battery level and make changes to the mission course. The glider sends back data from its sensors, which we can then plot, almost in real time. In order to follow the mission course, the glider takes a GPS fix on each surfacing and recalculates the course to its next waypoint.

Capability
Standard sensors usually fitted to gliders in the NOC fleet include conductivity, temperature, depth (CTD), a fluorescence sensor measuring chlorophyll, optical backscatter and colour of water and an oxygen optode. They can usually carry one other sensor, such as a fish-finding echo-sounder or a light level sensor (PAR sensor).
On certain expeditions, gliders have also been fitted with larger, more power-hungry sensors. Because they are not designed for this, the battery consumption is increased and mission length is decreased, often to only a few weeks. The slow and gentle way a glider flies enables it to measure a profile from 1000m, to within a couple of metres of the surface, without disturbing the structure of what it is measuring, as most other vehicles or methods would.

The great strength of a glider is the ability to build up a picture of the structure of the ocean in both space and time, what is called 4-D sampling, giving us fine detail over a wide area. They are good at mapping the position of oceanic fronts, plotting the change in the thermocline where the surface water meets the deep oceanic water and many other slowly changing features that are important in the calculations behind oceanic global warming models.

Expeditions
To keep up to date with current glider missions and to see the global position of each of the vehicles in our fleet please visit https://mars.noc.ac.uk/vehicles

Autonomous Surface Vehicles

Autonomous Surface Vehicles (ASVs) are robotic vehicles that sit on the sea surface recording oceanographic data across a range of variables. Different types of ASVs use various methods of propulsion, principally wave-powered or propeller driven.
ASVs are generally larger than autonomous underwater vehicles (AUVs) allowing for larger payloads and battery capacity. By remaining on the surface, they can employ solar or wind power to enhance or completely supply their continuing power needs. Wave powered vehicles have been made by hobbyists since the 1950s, but these commercial craft, used for

scientific research are recent developments.

Surface vehicles pose unique challenges to the pilot, especially when working inshore or in congested waters, however they offer a variety of solutions to the problems posed. For deep water or when operating among commercial shipping, the challenges of being seen and keeping a watch is largely met by Automatic Identification System (AIS). An AIS transponder continuously transmits the vessel's position and some metadata on the vessel type, while receiving the same from any AIS-equipped vessel. This is relayed to the shore and allows the pilot to take a measure of avoiding action when encountering another AIS-equipped vessel. Maritime law requires all vessels over 500 tonnes to carry AIS, but that is not a guarantee of its use. Although many smaller vessels also carry it, AIS cannot be relied upon, especially for yachts, fishing vessels and warships. An active radar reflector is a more direct way of being seen by larger vessels, and finally navigation lights and day-marks should be visible to vessels of all sizes. You can read about the history of the development of Autonomous Surface Vehicles.

The NOC ASV fleet
The NOC operates three ASVs: a Liquid Robotics SV3 Waveglider from the USA, an ASV-Global Ltd C-Enduro, and a MOST Ltd AutoNaut, the latter two are from the UK. Each has its own specific strengths and limitations.

Waveglider
The Waveglider consists of two parts: a float or surface unit and a glider or submarine unit, connected on the NOC vehicle by a 7m umbilical. Developed in Hawaii, the float unit is based on a surfboard. The sub is fitted with pivoting wings and - as the float rises and falls with the waves on the surface - the sub unit is moved up and down at depth, where the

pivoting wings provide drive and the vehicle moves forward. The float contains the control unit, battery and sensors and is covered with solar panels.
Deployment is straightforward - the float and sub are strapped to a floating frame, towed into position or lowered from the deck of a ship. The release line is pulled and the sub drops away, powering the vehicle instantly. The float has GPS and Iridium modules, and is steered by a rudder on the sub. There is also a thruster for limited manoeuvring when there is insufficient swell to power the vehicle. Recovery requires two lifts onto the deck of a ship or, more delicately, a harbour wall when the vehicle has been towed into port.

The Waveglider weighs approximately 250kg with the weight split fairly evenly between the surface and the sub-unit. The surface unit is 2.9m long with a beam of 0.66m. It has three main payload bays and several masts for instruments and communication. The sub-unit is 2.2m long with a wingspan of 1.4m for the fins. Sensors can also be fitted to the sub-unit, as can towed instruments. Currently one battery is fitted, with a second to be fitted in the future, charged by three photovoltaic arrays capable of up to 156W. As long as the consumption over 24 hours does not exceed the solar power supply, the sea endurance of the Waveglider is technically indefinite.

In its current configuration, the NOC Waveglider is fitted with a Seabird CTD on the sub, a Sonardyne acoustic modem, an RDI 300kHz workhorse ADCP and an Airmar WX150 weather station. Speed in a good swell can be 3-4 knots but 2kts is more usual. It has a SeaMe X-band radar transponder and an AIS receiver. Piloting and communication is via Iridium, mobile phone and WiFi. It also has a secondary independent GPS tracker.

AutoNaut

The AutoNaut, developed in the UK, is a wave-powered vehicle with two pairs of wings or foils set on struts at either end of the vehicle. The hull is narrower than the Waveglider with its shape resembling a canoe. It is also significantly smaller than the Waveglider, making deployment, recovery and towing a lot simpler. In order to recharge the battery while at sea, AutoNaut too has solar panels fitted to the surface and can be fitted with a 25W methanol fuel cell for longer deployments where sunshine is at a premium.

The AutoNaut is 3.5m long with a beam of 0.43m and weighs around 100kg. The ASV is currently fitted with an Airmar WX150 weather station with a hull penetrator for a fluorescence puck and two towing points to which one RBR CTD can be fitted. AutoNaut also has an AIS transponder, SeaMe radar transponder and back-up GPS tracker. The two photovoltaic arrays in series provide 125W and a lithium ion sulphur battery provides the main power. Communication is via Iridium or short-range radio. Operating more like a glider than the other two ASVs, the AutoNaut has an operating speed of 1–2 knots, but can reach a maximum of 3 knots. AutoNaut also has a small thruster, which can be used to aid in propulsion. The small size and small battery mean that for most missions, consumption has to be kept within what the PV array can provide. This in turn gives it very long duration, of up to six months.

C-Enduro

The C-Enduro is a catamaran driven by a pair of electric outboard legs and powered by a large array of solar panels, a wind turbine generator and a diesel generator in the starboard hull. Very much a power boat in design, it too was developed in Britain. It is launched and recovered from a road trailer and is towable. It has the largest payload capacity both physically and electrically, but probably the shortest sea endurance period of 60-90 days. Sensors can be mounted on the main vessel, on the drop keel or tow an array. It also has a 100m electric winch, although not with a conducting or fibre optic cable.

The C-Enduro is a 4.2m by 2.4m catamaran with a large arch or mast giving an air draught of 2.8m. The total weight is around 500kg. Currently NOC’s C-Enduro it is fitted with an Airmar WX150 on the mast, an RBR CTD and a fluorescence puck on the drop keel and several ports for GoPro cameras. Navigationally it has an AIS transponder and a SeaMe radar transponder. Communications are received and transmitted via WiFi or Iridium. For power, the 12 photovoltaic arrays provide up to 1.2kW, the Aerogen wind turbine up to 0.7kW, and the diesel generator provides 3.2kW when it is running. The propulsion uses up two 1.4kW motors, but is usually run at around 50% to give a nominal speed through the water of 2.5–3.5 knots, with a top speed of 7 knots.

Of the three ASVs, C-Enduro will suffer from biofouling to a greater extent than even a 200m underwater glider and consequently, will lose speed over a three-month deployment even if antifouling paint or another similar coating is applied.

Scientific capability
The instruments that can be carried by each of the ASVs in the NOC fleet are many and varied. Unlike gliders, each design can carry a payload of several instruments. The biggest limitation with ASVs is the lack of depth profiling, although the C-Enduro can carry out some deployments to 100m using its winch and the Waveglider has a 7m deep profile. The biggest strength of an ASV is their persistent surface presence. This can be used for things like photographic monitoring and weather information. They also have a future as data harvesters, where an underwater vehicle or moored device talks to the ASV acoustically, and the data is relayed over Iridium.

Examples of instruments that have been installed to ASVs for demonstration projects such as the MASSMO series are the Vemco fish tracker, Decimus passive acoustic monitor with a Seiche acoustic array, UK Met office self contained meteorological instrument suite, Kongsberg sidescan sonar, single beam echosounder, pyranometer, Chelonia PAM and SMRU SoundTrap (PAM). All of the vehicles have been installed with at least two GoPro cameras to record both images and video from the vehicles. In the near future, it is planned to fit the SeaOWL oil and chlorophyll detector to the AutoNaut.

Remotely Operated Vehicle

A remotely operated vehicle (ROV) is a tethered underwater robot that is unmanned, highly manoeuvrable and controlled by an operator(s) aboard a vessel. They are linked to the ship by the umbilical – a group of cables that carry electrical power, video and data signals back and forth between the operator and the vehicle.

ROVs vary in shape, size and capability, depending on their task. They are a complex array of electrical, electronic, hydraulic and mechanical systems, comprising monitoring and control equipment, launch and recovery systems, umbilical controls and winches.

The NOC currently operates one ROV, called Isis, the UK’s deepest diving ROV dedicated to science. Isis collects samples, drills sediment cores and shoots high definition video and stills at ocean depths of up to 6,500 metres (four miles). The vehicle is supported with containerised control room, workshop and spares storage, with a launch and recovery system.

Isis technical specification

Weighing 4000kg laden in air with dimensions 2m × 2m × 2.5m, the vehicle is equipped with cameras, lights, thrusters, manipulators and numerous scientific sensors. Isis is connected to the ship with an 18mm umbilical cable; this is steel armoured with three electrical and three fibre optic passes. A hydraulic power pack allows for hydraulic functions, e.g., manipulators, cable cutter, tool drawer.

The lower half of the vehicle is designed as a detachable tool sled so it is feasible to have a number of units preconfigured for specific tasks. Suitably sized and dynamically positioned (DP) ships of opportunity enable the system to be freighted and operated around the world.

Scientific capability

ROVs enable intricate surveys of the seabed enabling the collection of precision samples from the seafloor. Experiments at extreme water depths unreachable by human divers, due to the water pressure, are also possible with the ROV. Although manned submersibles exist that can transport humans to extreme depths, ROVs are a more compact, portable and practical alternative, without the human risk element. An ROV can be manoeuvred precisely with its thrusters (propellers). Through its eyes (cameras), the manipulators (hands) can recover small, delicate objects more precisely than any other sampling system. Scientists can see the undisturbed area from where samples are selectively taken, providing them with a better understanding of habitats and structures. Complex in situ experiments can be achieved maintaining the environmental conditions and minimising sample damage caused by recovery to the surface.

HyBIS

Hydraulic Benthic Interactive Sampler (HyBIS) is a modular, versatile, robotic underwater vehicle (RUV) capable of reaching depths of 6000 metres, developed and operated by the NOC. Controlled via fibre optic cable connected to the ship, HyBIS is equipped with sampling grab, cameras and equipment used to record conditions in the deep sea.

The main module consists of the steering unit represented by two propellers as well as the energy supply, the cameras, the light, the hydraulic systems and the telemetry. Depending on the sampling requirements, different modules can be mounted under the main module.

In contrast to a conventional remotely operated vehicle (ROV), HyBis is not neutrally buoyant. Both the descent and the ascent of the HyBIS, as well as the operating depth are controlled from the ship by the fibre optical cable. Therefore, HyBis can deploy and recover a net load up to 700kg (sampling equipment and sampling material), which is several times the payload of an ROV. As well as sampling the ocean it has also been used to help to recover two different seabed landers containing scientific equipment worth over £300k.

In its first four years HyBIS has dived over a hundred times, recorded more than 450 hours of HD video footage and taken 1,000s of HD photographs. It has undertaken complex sampling missions at over 40 different sites.