

The Scottish Marine Robotics Facility: Use of unmanned vehicles for environmental measurement, monitoring and decision making

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Abstract: Advances in marine technology are essential to allow us to study the marine environment on which life on our planet depends. The Scottish Association for Marine Science is the world's largest independent marine research organisation with a long history in marine technology development. In 2015, the institute announced the opening of its new marine robotics facility. The facility pools together a broad range of technology's spanning deep sea, coastal, surface and aerial platforms. The facility specialises in the integration of new and novel technologies into fundamental marine research to improve measurement, monitoring and decision making. Each case study presented in this paper highlights the importance of autonomous systems within marine research, the diversity of applications being developed within the robotics facility, and the significance of science communities working in conjunction with technology developers to test, evaluate and support autonomous system development.

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1. INTRODUCTION

The Scottish Marine Robotics Facility (Scot-MRF), based at the Scottish Association for Marine Science (SAMS), was formed in 2015. Scot-MRF is a science led facility, drawing on existing expertise in using cutting-edge technologies to answer pressing environmental science questions. Unique in the UK, the facility applies an exceptional range of robotic capabilities to support academic, regulatory or commercial projects. From aerial mapping, to surface fluxes and the properties of deep water. In this paper we present four case studies from Scot-MRF, highlighting the adoption of unmanned systems in environmental measurement, monitoring and decision making in marine science.

2. LONG-TERM OCEANOGRAPHIC MONITORING

Scot-MRF plays host to the North Atlantic Glider Base (NAGB). NAGB is part of a world leading programme to support and develop the scientific application of robotic technologies. Since its formation in 2009, NAGB has reinforced a number of renowned national and international oceanographic research programmes including; Fluxes Across Sloping Topography of the North East Atlantic (FASTNET), the Extended Ellet Line (EEL), and, more recently, the Overturning in the Subpolar North Atlantic Program (UK-OSNAP). Through these programmes, NAGB has developed novel observational techniques, combining autonomous robotic systems with more traditional ocean

monitoring tools i.e. fixed moorings and CTD transects) (Sherwin *et al.*, 2014).

Located on the west coast of Scotland, NAGB is perfectly positioned to provide access to the UK continental shelf edge, and the wider north Atlantic. NAGB operates a fleet of seven deep water (1000m) Seagliders. Funded through Natural Environment Research Council (NERC) national capability, NAGB is part of the Marine Autonomous Robotic Systems (MARS) group, acting as the centre for deep water glider operations across the UK.

2.1 Case Study: UK-OSNAP

UK-OSNAP is part of an international collaboration to establish a transoceanic observing system in the subpolar North Atlantic (the OSNAP array). International OSNAP is led by USA and includes 10 further partner groups in Canada, France, Germany, the Netherlands and China. The OSNAP array is designed to complement the RAPID array (<http://www.rapid.ac.uk/>) and NACLIM observations (<http://www.naclim.eu/>), thereby providing measurements to evaluate inter-gyre connectivity within the North Atlantic.

There is mounting evidence of the importance of the transports of heat and freshwater by the North Atlantic Subpolar Gyre for impacts on European and global climate via temperature, precipitation and wind strength. It is also highly significant for the region's marine ecosystems, the

formation of hurricanes, and rainfall in the Sahel, the Amazon and parts of the USA. The Subpolar Gyre is presently inadequately measured, and no ocean general circulation or climate model represents it accurately.

The UK-OSNAP team is developing a new observing system and innovative modelling techniques to characterise the ocean circulation and fluxes of the North Atlantic Subpolar Gyre. UK-OSNAP is a partnership between SAMS, NOC, and the Universities of Oxford and Liverpool. The first aim of the programme is to provide a continuous record for four years (2014–18) of full-depth, trans-basin mass, heat, and freshwater fluxes in the Subpolar Gyre.

Since July 2014, gliders have been deployed in the framework of the UK-OSNAP glider programme as part of the Eastern Boundary array (Fig. 1.). The goals of this glider survey is to quantify the flux of northward-flowing warm and saline water across the Rockall-Hatton Plateau (one section every month). To do this, NAGB manages the deployment, operation and recovery of Seagliders, thus maintaining a 365 day presence in the Atlantic Ocean. Each glider is capable of measuring temperature, salinity, dissolved oxygen, pressure, fluorescence and backscatter. As well as supporting scientific objectives, the data is fed to third parties (i.e. The UK Met Office) to support planning and decision making.

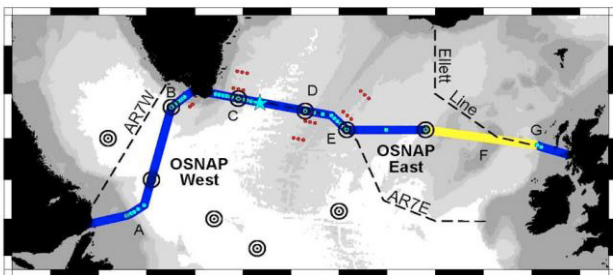


Fig. 1. Full extent of the OSNAP monitoring transect. Section F permanently occupied by Seagliders. (Source: UK-OSNAP)

3. HIGH-RESOLUTION SEABED SURVEYING

In 2015, Scot-MRF acquired a Teledyne Gavia surveyor Autonomous Underwater Vehicle (AUV) in partnership with MARS. The AUV supports SAMS ongoing marine mapping objectives, coordinated through the Marine Environmental Mapping Programme (MAREMAP), a NERC national capability initiative (<http://www.maremap.ac.uk/>). Scientists within SAMS use the AUV to compile high resolution maps for habitat assessment, glacial mapping, artificial reef monitoring, ship wreck classification, and many other applications. In addition, SAMS are at the forefront of examining how capabilities, unique to AUVs, can support ongoing UK marine monitoring obligations.

2.3 Case Study: MPA Mapping

Increasingly, autonomous and remote sensing technologies are being seen as an important tool by which MPAs are monitored in the future (Wynn *et al.*, 2012). As part the new NERC centre for doctoral training (NEXUSS), Scot-MRF and SAMS are working in partnership with Heriot Watt University to test and evaluate the use of AUV technologies to survey and monitor benthic habitats in Marine Protected Areas (MPAs).

Scientists within the project aim to test the suitability of AUVs to monitor MPAs on the west coast of Scotland and to develop viable strategies for their use. AUVs have a unique capability to fly closer to the seabed, using less power to provide greater detailed maps at relatively low cost. This capability allows end-users to identify features previously invisible during traditional boat based surveys (Fig. 2.). The project will also explore novel technologies and models to develop a ‘toolbox’ of AUV-based approaches that can be applied to a wide range of vulnerable benthic habitats. Novel algorithmic approaches combing new high resolution AUV acoustic bathymetric data with existing models will generate predictive habitat maps at unprecedented spatial resolutions for a range of MPA habitats.

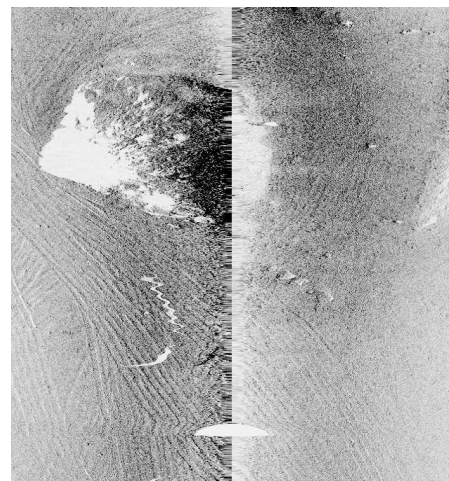


Fig. 2. AUV side-scan data showing extensive trawl damage around a rock outcrop in the Firth of Lorn.

The objective is to develop generic approaches which can be applied in other dynamic inshore coastal environments. The aim will be to develop approaches which are readily reproducible and defensible, supporting the renewables, subsea cabling and fish farm site selection and development.

4. REMOTE PILOTED AIRCRAFT SYSTEMS

Advancement in remote airborne technologies has permitted the capability to observe and monitor areas that would otherwise require complex and expensive solutions. Since 2012, Scot-MRF has been developing remote piloted aircraft systems (RPAS), providing platforms, sensors and qualified flight groups to develop measurement capabilities for research scientists throughout the UK. The facility is

supported through NERC national capability funding, operating an expensive range platforms ranging from fixed wing aircraft to multi-copters.

2.3 Case Study: Spectral Imaging

Scot-MRF specialises in the integration and combination of new and existing sensors to construct unique scientific platforms. These platforms are designed to support complex scientific objectives. Recently, engineers at Scot-MRF have developed a quad copter-mounted spectrometer. The platform is used to investigate the potential for remotely identifying the presence of phytoplankton and other suspended and dissolved matter within coastal waters local to the west coast of Oban.

Following on from laboratory based measurements and modelling of expected reflectance values for a selection of water properties and conditions, *in situ* measurements were collected using a specially designed, miniaturised spectrometer system integrated into a custom-built RPA. Ground-truthing the system included using a pair of calibrated, radiometers to collect data just above and just below the water surface from a ship, and water samples were collected for optical characterisation and constituent analysis.

During the process of equipment development, the quadcopter was also tested to examine its capability of flying a mission in conjunction with a Hydroid REMUS-600 AUV. The mission proved to be highly successful, with GoPro footage taken on board the RPA showing that both instruments were able to survey in a co-ordinated manner along a pre-decided transect path with regards to both time and space. Future work will involve using the AUV to provide a higher spatial resolution of in-water constituents for ground-truth purposes.

Scot-MRF continues to develop RPA spectral imaging techniques alongside co-ordinated multi-platform, subsurface/airborne, missions. The methodologies being developed will provide a test-bed for future studies to examine a variety of complex environmental problems such as harmful algal blooms, jellyfish or macro-algal blooms, oil spills, and sea ice measurements.

5. BIG DATA PROCESSING AND VISUALISATION

The outputs of observational oceanographic campaigns have clear value for the advancement of marine science. Large and consistent data sets are the backbone of oceanography, allowing scientists to identify trends and support complex climate models through assimilation and validation.

However, in addition to fundamental science, understanding the physical characteristics of our marine environment supports decision making in a variety of other sectors. For instance; temperature and salinity provide the basis for baseline monitoring and spill modelling within the oil and

gas sector. Equally, differentiating long-term and short-term trends is crucial when informing marine policy. Recent advances in autonomous systems enable scientists to collect an exceptional amount of data at greater temporal and spatial resolutions than would have been possible using traditional oceanographic techniques. However, for the majority of the decision making community, these data sets are too complex and inaccessible to be utilised.

To address data inaccessibility, the Scot-MRF community are collaborating with end-users to better understand how other marine sectors use and query marine data. Appropriate end-user engagement and effective translational research ensures that maximum impact is gained from past and ongoing research activities.

5.1 Case Study: Oceanographic Data Tools For Industry and Policy (ODaT)

Through a NERC innovation grant, scientists at SAMS are working with the oil and gas, marine policy and defence industries to develop oceanographic data tools that combine and translate complex autonomous and legacy (ship based) data in an intelligible and, crucially, workable format (i.e. easily integrated with existing systems).

The project focusses on the outputs of three NAGB supported oceanographic campaigns; FASTNet, EEL, and OSNAP. The extensive use of Seagliders and AUVs in these projects, in combination with more traditional ocean monitoring tools (for instance, fixed moorings and CTD transects) has resulted in the acquisition of large and complex datasets which are challenging and time-consuming to interpret.

The aim of the project is to develop bespoke oceanographic data tools for the oil and gas, policy and defence sectors which allow the mapping of observed ocean properties, at optimised spatial and temporal resolutions, while maintaining flexibility and ease of use.

The project architecture is based on the novel use of an oceanographic processing tool, Hydrobase2, which offers a standardised and rigorous approach to the interpretation of observational oceanographic data. Using this tool, scientists are able to construct statistically robust climatologies of physical ocean properties using historical data from disparate origins and formats. Scientists at SAMS have expanded the scope of Hydrobase2 to accept data from autonomous systems (Gary *et al.*, 2011 & Gary *et al.*, 2012) and are incorporating it into a flexible tool which will allow end-users to explore oceanographic data and map water properties using a clear and logical workflow.

The user interface of the tool takes the form of a series of data layers; each of which is dedicated to a specific mapping function. While some capabilities are common to all end-

users, it is anticipated that some layers will reflect individual requirements. Crucially, the ODaT project includes continual end-user engagement, involving key partners in the development process to ensure that the outcomes meet multi-sector requirements. The benefits to end users include increased situational awareness through improved knowledge of baseline properties and the ability to visualise environmental conditions with a greater resolution and flexibility than is currently possible.

6. FUTURE CHALLENGES

Unmanned autonomous systems are beginning to open a breadth of opportunities within the scientific sector. Understanding how we, as a scientific community, apply these new technologies in ongoing and new scientific research should support the ongoing development of such systems.

This paper presents a number of case studies that highlight the variety of operational methodologies being adopted by Scot-MRF, and how they are supporting environmental measurement, monitoring and decision making through fundamental and translational research. These case studies are not isolated. Increasingly, the broader marine sector is working with the science community to translate research outcomes to inform and support decision making activities.

It is the nature of marine science to continually pursue more complex questions and as we strive to better understand our marine environment, our reliance on novel technologies will inevitably increase. Research programmes now require technologies that can travel further, gather more data, and perform more accurate tasks. Cost effective technologies, which balance time and money with improved observational capabilities will become a fundamental challenge for autonomous system development.

In order to address these challenges, it is crucial that technology developers collaborate with science led facilities, such as Scot-MRF, to test, evaluate and assist research and development. That way, autonomous technologies can continue to support the increasingly challenging requirements of the marine science community and, in addition, science led decision making within the broader marine sector.

7. CONCLUSION

Autonomous technology is expanding our ability to observe and measure the marine environment. Maintaining effective collaboration between technology developers, data users and decision makers is fundamental to ensuring that the autonomous systems community continues to generate a positive impact within the marine sector. This paper presents a series of case studies aimed at highlighting the breadth of capabilities within Scot-MRF. The operational methodologies, sensor integration capabilities, and data processing and visualisation techniques being developed within Scot-MRF will continue to support the marine science community. Likewise, Scot-MRF will continue to work with

end-users to translate this knowledge and support decision making.

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