Beyond the Blue Belt: *Technology for Compliance and Enforcement – High-level Review*

Blue Belt Programme

March 2019

Marine Management Organisation

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1.0 Introduction

1.1 Aim of this review

New technologies have the potential to define the lasting legacy of the Blue Belt Programme, representing a real 'game-changer' for compliance and enforcement. If implemented effectively, new technologies could offer solutions to surveillance challenges that were previously virtually impossible to address. To do so, it is important that any technological solutions are fit for purpose in the context of the enforcement issues the UK Overseas Territories (UKOTs) seek to address, meeting the identified requirements, providing added value and useable on a regular operational basis.

The aim of this report was to review existing operational technology, and research and development (R&D) funded by UK or EU grants since 2005, that could be of relevance to the current challenges facing the Blue Belt Programme in achieving maritime situational awareness in the remote, very large areas that UKOTs are charged with managing *.

The report is intended for the technology sector, to provide a high-level overview of potential applications in this area, and as background to inform further work in developing bespoke Technology Roadmaps for the UKOTs that we are working with as part of the Blue Belt Programme. It is intended to give an overview of relevant technology and projects, rather than a fully comprehensive list. It is acknowledged that the technology field is rapidly evolving and that opportunities for technology application will continually evolve as a result.

The Technology Roadmaps project will review technologies in more detail, and set out opportunities in the short, medium and long-term for each UKOT – based on OT specific context and requirements, and taking account of legal considerations and cost-benefit-analysis.

1.2 Scope

There are two key challenges that are relevant to all UKOTs, namely how do you monitor the marine environment in these remote areas at a cost that can be sustained in the long term; and how do you monitor human activity within these remote areas so that any activity that is non-compliant with the relevant marine management regime can be identified, and then acted upon?

The scope of this review has been reduced to focus on the second challenge only, in light of the two very distinct technology streams that have been operating within the environmental and maritime security sectors for at least the last decade. Whilst there is undoubtedly the possibility for technology transfer between these two streams, in order to identify technology at the highest technology readiness level[1] (TRL) possible for the compliance and enforcement, the majority of the focus has been on solutions found within the maritime security technology stream.

* Based on information available as at February 2018.

All of the technologies discussed in this report have the potential to provide fisheries managers in the UKOTs with information which, from a compliance and enforcement perspective, can either be treated as intelligence or evidence depending on its reliability, accuracy and relevance. It is often the case that one piece of technology will not be able to provide a complete solution, but will work as part of a suite of approaches to provide information leading to situational awareness. The way this suite of technology is put together will depend largely on the requirements for the marine area in question and the operating budget available.

Intelligence can range from a general, low level indication that activity may be taking place in a particular area at a particular time, through to detailed, specific information about the activity of an individual vessel. For intelligence to meet an evidential standard, it must contribute to demonstrating the alleged illegality beyond reasonable doubt.

The technologies discussed in this report are capable of collecting information across this intelligence spectrum, and, generally speaking, there is an inverse relationship between the resolution of information and the spatial/ temporal coverage they provide. As such, no single technology can represent a solution in isolation. For example, non-specific, general intelligence from low resolution, high coverage options are likely to be required to effectively assess a risk level that can then feed into tasking of other assets (manned or unmanned) to corroborate and develop that into vessel specific intelligence, or, better yet, evidence.

This report is divided into two parts. The first is a high-level review of relevant technology types that currently exist at an operational TRL. The second part provides an overview of different R&D programmes that have been developing and proving maritime security or surveillance programmes. These often combine different solutions to provide a suite of technologies in order to meet operational requirements.

1.3 Monitoring, Control and Surveillance (MCS)

MCS approaches ultimately all lead towards compliance to fishery management measures: monitoring gathers information on the fishery that is used to assist in developing and assessing control through appropriate management measures, while surveillance uses this information to ensure that these controls are complied with[2]. This approach is as relevant for the management of activities within MPAs as it is for the management of fisheries as a stand-alone activity.

The Food and Agriculture Organization of the United States (FAO) describe these aspects as:

i. **monitoring -** the continuous requirement for the measurement of fishing effort characteristics and resource yields;
ii. **control -** the regulatory conditions under which the exploitation of the resource may be conducted; and
iii. **surveillance -** the degree and types of observations required to maintain compliance with the regulatory controls imposed on fishing activities.

The options available for an MCS system and the various combinations of these options are almost limitless. They include a range of separate or interlinked components of hardware in varying degrees of sophistication, various levels and types of human resources (both linked and separate to the hardware), a whole host of approaches to implementation ranging from military type enforcement to community driven compliance programmes and then finally, once the system is developed, to even more choices of how to manage the MCS system and organisation.

The FAO Fishery Manager's Guidebook[3] then goes on to list points that indicate the type of questions that MCS representatives, should be asking to ensure that the MCS concerns are considered when accessing any proposed plans:

1. What are the practical requirements needed to implement the management measures (this should be considered from the monitoring, surveillance, compliance and enforcement points of view) and are these available?
2. What are the previous records of success or failure of management measures and have the results been considered to inform new proposals?
3. What are the factors that will encourage compliance rather than demanding enforcement, what are the requirements to develop these, and are they feasible?
4. What are the consequences of non-compliance and have these been considered in relation to the effect that these will have on the status and viability of the fishery, i.e. what is the level of compliance that is required in order to support the management plan?
5. What is the cost of these management measures and/or non-compliance from both a financial and resource perspective and, from a financial perspective, who should cover these costs, government, industry, or both?

Finally, when revising or developing a strategy the FAO recommend the following simple questions should always be asked.

1. What is required in terms of the fishery you are managing?
2. What is feasible in terms of the legal framework?
3. What is realistic in terms of available resources?
4. What is practically possible to implement taking into consideration the political situation and the interested parties involved in the fishery?

1.4 The Blue Belt Programme UK Overseas Territories

The Blue Belt Programme supports delivery of the UK Government's manifesto commitment to provide long term protection of over four million square kilometres of marine environment across the UK Overseas Territories. It provides £20 million over four years (2016 to 2020) to:

- Improve scientific understanding of the marine environment;
- Develop and implement evidence-based, tailored marine management strategies including surveillance and enforcement; and
- Ensure management is sustainable and long term.

The Programme is initially focused on seven UKOT islands and archipelagos: British Indian Ocean Territory, South Georgia and the South Sandwich Islands, British Antarctic Territory, Pitcairn, St Helena, Ascension Island and Tristan da Cunha.

Crucially, the ideal solution for each UKOT is likely to be different, depending on both the nature of the enforcement risks they are exposed to (scale, season, etc.) and also the nature of on-island enforcement (e.g.: what is existing on-island capacity and how can this be enhanced in the longer term?). It is therefore absolutely fundamental that the solutions being sought are requirement driven, and that there is a sufficient understanding of the threats each individual UKOT faces so that a bespoke solution can be developed for each, otherwise there is a risk of trying to develop a solution without first fully understanding the problem.

That said, some threats and challenges are consistent between all seven territories. Generally speaking, the perceived IUU threat is transient, towards the outer edges of the EEZs (Exclusive Economic Zone) or maritime area and can occur over large spatial scales. When combined with further challenges of limited resources, particularly at-sea assets, isolated oceanic locations, variable and often challenging weather conditions, and financial constraints in the UKOTs – technological options really need to add value to the already stretched enforcement capability in order to provide a net benefit to the UKOT's marine management regimes.

2.0 Commercially available technologies

2.1 Unmanned Aerial Vehicles (UAVs)

2.1.1 Overview and Potential Applications

Aerial drones, or Unmanned Aerial Vehicles (UAVs), have seen significant technological developments in recent years, and there is considerable range in the scope, capability, design and cost of UAVs available. There are various instances of UAVs being used for MPA monitoring, compliance and enforcement.

From a compliance and enforcement perspective, UAVs have differential applications depending on their range:

- Short range UAVs are normally smaller and remote controlled with high quality recording equipment, which could be deployed from a patrol vessel to aid evidence gathering. The UAV could be used to gather evidence by providing an aerial view of the vessel and any activity on deck, potentially negating the need to board. If the objective is simply to determine whether or not the vessel is fishing, and possibly provide a positive identification, then this could feasibly be achieved using a UAV, eliminating the risks associated with boarding.

- Mid-range, rotary or fixed wing UAVs could be used to scout ahead of a patrol vessel for suitable targets, and therefore improve tasking at sea. These UAVs could probably also be used in the evidence gathering context described above. Coupling with additional technology such as radar would also greatly increase coverage.

- Long range, fixed wing UAVs with reconnaissance or surveillance capability could cover large areas and gather low level intelligence, particularly if satellite data can be used to improve tasking of aerial patrols. Facilities for launching and landing larger aircraft would need to be considered.

Most applications are therefore restricted to inshore activity (0-12nm), and even on the medium / long range commercial UAVs, range currently rarely exceeds 50 nm, which is likely to be a significant limiting factor. The short or mid-range UAVs are fairly well developed technology, and, could probably be purchased without much need for modification. A longer range option, however, is likely to require some specific development.

2.1.2 Operational uses

The Portuguese Hydrographic Office have recently completed a successful trial in which a commercially available fixed wing UAV was modified to give extended range for offshore oceanographic monitoring. During the trial, the UAV demonstrated capability to cover 500km in a 10 hour continuous flight, which is getting towards the capability required to reach the edge of a 200 nm Exclusive Fisheries Zone (EFZ). This is considerably further than other non-military systems that seem to be available.

University of Southampton have recently developed a series of 3-D printed drones, which are currently at the prototype stage but may have some longer term potential. One big advantage is that a bespoke design can be easily modified to address particular limitations – for example, if range is an issue, then the next iteration of the design can include a larger fuel tank. Once the design is established and trialled, the drones can be easily manufactured at relatively low cost.

The small 3-D printed 'SULSA' model has a wingspan of 1.2 m, has video/ image capture capability, and has been successfully launched off Fisheries Protection Vessels in the UK, HMS Mersey and HMS Protector. With a cruising speed of around 60 knots, the UAV can cover ground relatively quickly but its range is restricted by line of sight controls, limited battery life and it is only operational in winds up to around 25 knots, which could be limiting in UKOT conditions.

The larger 'Spotter' model is petrol powered and is capable of offering range of up to 400 km over six hours. This larger UAV is capable of operating in up to 30 knot winds, but does require a runaway for take-off and landing. The UAV weighs around 55 kg and is capable of speeds of up to 55 knots. As with SULSA, controls can be modified to be completely manual, completely automatic, or a combination of both. Due to aviation restrictions, Spotter's range and operating capability has not yet been fully tested – for instance, it has only been tested below 400 ft, although is capable of operating much higher than this.

A lot of work has been done on using UAVs in other conservation or compliance and enforcement scenarios, particularly to counter poaching for white rhinos in Africa, and some further research into how the technology has been applied in that scenario would probably be beneficial. Similarly, USA's National Oceanic and Atmospheric Administration (NOAA) have a programme dedicated to the development of offshore UAVs, and there is likely to be some opportunity to tap in to their experience.

As mentioned one of the limitations of the UAVs is their endurance and range. Although unlikely to represent a solution in the short term, something like a solar-powered blimp (small airship or barrage balloon) could become viable to provide general coverage over large spatial scales, as the technology advances.

2.1.3 Intelligence and Evidential Value

Of all the new technologies reviewed, the smaller UAVs probably present the greatest opportunity to gather evidence as opposed to intelligence, if they can be deployed from a suitable platform or patrol vessel. The medium or larger drones have the potential to be targeted in order either collect general intelligence directly, or corroborate existing intelligence, with possibly scope for passing the evidential threshold. It would seem unlikely that, at present, they have the range or endurance to offer general, low level intelligence gathering, and would need to be deployed to a specific risk or area.

2.1.4 Sustainability and Legacy Potential

The majority of the cost is likely to be the purchase, although data transfer, training and maintenance all represent longer term ongoing costs that must be quantified. Another possible issue with UAVs concerns having certified staff who are capable of operating them, a particular challenge when staff turnover is high.

2.2 Passive Acoustic Monitoring

2.2.1 Overview and Potential Applications

The basic principle behind this technology is that hydrophones in the water detect the mechanical sounds produced by fishing vessels and differentiate between these vessels and other commercial traffic. Depending on the equipment set up, it may be possible to pinpoint the source of the noise, and therefore provide intelligence as the location and extent of fishing activity in a particular area.

The remote nature of the UKOT waters potentially lend themselves well to the use of this technology when compared to near shore sites, as there is less background anthropogenic noise. Discrete bathymetric features such as banks, reefs and seamounts for example, may offer opportunities to explore the use of this technology.

Mechanical noise detection represents innovative compliance and enforcement capability that is currently at relatively low technology readiness levels, and as such there is relatively little information on its potential application in live operations. However, it has been used in several EU funded projects set out later in this report.

The geographical scales over which the technology could detect fishing activity would need to be modelled, as sound attenuation is affected by a variety of factors such as bathymetry, salinity and time of day. This will be a key factor in determining the extent to which it has practical application. If the sounds are only detectable over relatively short distances, then the application is likely to be limited to monitoring around geographically discrete oceanographic or bathymetric features (reefs, sea mounts). If, however, the effective area of detection could be increased to 100s km, rather than 10s, then there could be great potential in using this technology for on-going background monitoring.

If the passive acoustics could be accompanied with self-powered unmanned surface vehicles (USVs) to give wider spatial coverage further offshore, then this could expand their potential enormously, as the range over which activity can be detected is likely to be considerably increased.

The Zoological Society of London (ZSL) have used a modified Instant Detect system for acoustic marine surveillance. ZSL highlight that off the shelf sensors are available, although the available reports do not go in to great detail about the range, accuracy, spatial coverage and infrastructure. There are various other applications for passive acoustics, such as oil and gas, cetacean monitoring and, more recently, fish stock assessment. With some modification, it seems entirely feasible that aspects of these technologies could be modified to provide potential solutions, although it would seem unlikely that there is any off-the-shelf equipment that could provide an immediate solution, particularly for offshore monitoring. Aspects such as servicing and deployment would also need to be considered.

Consideration needs to be given as to whether the sound signatures can be received in real time or whether the passive acoustic receivers need to be retrieved and the data downloaded. There will be a cost implication depending on the required response time and it will impact how the data is used by regulators.

NATO’s Centre for Maritime Research & Experimentation (CMRE) have done work on vessel noise detection[4,5]. There are also a number of EU R&D programmes described in the next section which have used sophisticated passive monitoring devices in maritime surveillance networks.

2.2.2 Intelligence and Evidential Value

In the short term, acoustic detection is unlikely to yield any vessel specific intelligence or evidence, but could yield low-level background monitoring to provide general information about relative activity levels. For example it could highlight that there appears to be a lot of general activity in a particular area, which may be sufficient to task an alternative asset to develop the intelligence further. It is not likely, however, to yield information that in itself would identify a specific vessel or would represent evidence of a particular offence.

2.2.3 Sustainability and Legacy Potential

Passive acoustics offer some considerable potential, although this would be largely dependent on the costs involved, particularly for data transfer, maintenance and servicing. Once the initial capital costs have been absorbed, it does seem to have the potential at least to offer a relatively low-cost on going monitoring tool if the technology proved effective. The technology has the potential to offer similar information to satellite surveillance, but, potentially, at a much lower cost. From sustainability/ legacy perspective, passive acoustics should be explored further.

2.3 Self-Powered Unmanned Surface Vessels (USVs)

2.3.1 Overview and Potential Applications

Unmanned surface vessels (USVs) are essentially small boats or platforms that remain on the surface and are operated either by remote control, or by pre-programming in a specific route prior to deployment. Self-powered USVs are typically smaller, passive platforms that rely on wave motion or solar power to provide self-propulsion. As a result they have greater endurance, but are relatively slow and have fairly limited payload capability.

In terms of self-propelled USVs, two systems that may be of relevance include AutoNaut and WaveGlider.

- WaveGlider – Trials have demonstrated proof of concept in terms of the USV remaining at sea unattended for long periods, however applicability of the information gathered during the trial needs to be assessed from a compliance and enforcement perspective.
- AutoNaut – this vessel relies on wave power coupled with photovoltaic cells to provide energy for propulsion and the onboard electronics. The vessel can either be controlled by satellite communications or line-of-sight control, and has an automatic collision avoidance system. A 'Jura Class' 5m vessel was trialled in the Plymouth area for a three-week period, and demonstrated capability to:
    - Maintain a sustained speed of 4 knots
    - Communicate via satellite (plus over shorter range comms e.g. UHF)
    - Using a gyro-stabilised HD video camera, capture images and video at a range of 3 miles, which could be streamed over the Inmarsat network in real-time

  Using sensors, detect fishing vessel-sized targets out to 5 miles. This trial illustrated that it is reasonably easy to transport, launch and recover, either from the shore or at sea, but the sustained speed is less that the average IUU vessel and the detection distance is less than the visual horizon or vessel based radar capability. The Jura class vessel weighs around 30kg, though this can increase to around 110kg if fully loaded with equipment. The report recommended using the larger 7-10m class vessel for operational deployment.

In May 2017, ASV Global[6,7] trialled the deployment of a motor powered ASV offshore off the North coast of Scotland for a total of eight days to collect oceanographic data. Like AutoNaut, the trial offered real time HD images and video streaming, and with a claimed top speed of 6.5 knots and +30 day endurance, it may have a potential to offer greater coverage/ day.

Part of the potential for USVs lies in the capability to act as part of a wider network, and indeed it may be preferable to have more than one deployed at any one time. If there is only one at sea, and a vessel has identified where it is, then its capability to act as a deterrent in any other area in the zone would be compromised. If there is the expectation that there could be another somewhere in the area, then the deterrent would be, to some extent, maintained. If the concept were to be proved, then there could be economies of scale in procuring multiple units simultaneously.

As these USVs rely on either solar or wave power, they have theoretically unlimited endurance, although a fixed period of deployment is more likely, to allow for servicing. The AutoNaut vessel is capable of detecting vessels within 5 miles, with the quality of the images/ footage proportionately better as the vessel closes the contact.

Given the extensive continuous coverage offered by USVs, there seems to be significant potential of unmanned USVs in two particular circumstances:

1. Patrolling specific, discrete areas, e.g. reefs or seamounts. The USVs can be pre-programmed to follow a particular route, and if the unit is focussed on a relatively small area, the constraint of relatively slow speed and therefore limited coverage, is negated somewhat.
2. Boundaries. It should be possible to set the USVs up to patrol a specific boundary, such as the edge of the 200mn EEZ/EFZ. For example, if the zone has a 200nm radius, then the circumference of the zone is 1,256 nm. Autonaut can maintain a sustained speed of four knots, meaning it can cover 96 nm in one day, and therefore the circumference of the zone in 13 days. With two USVs in circulation, the entire boundary of the EFZ could be patrolled every week.

The set up trialled off Plymouth only allowed for contacts to be detected during the day, which is a significant limitation, although there may be options to develop this further. Performance in and limitations associated with sea-state and weather would be important to consider.

In terms of potential applications, it is likely that, at best, the information provided would be general intelligence (i.e. there appears to be some fishing vessel activity in this particular area), as opposed to vessel specific intelligence or evidence. It seems unlikely that a photograph taken at distance from a USV would be able to provide vessel-specific intelligence or information that would be sufficiently robust that it could be used as evidence, unless the USV could get close enough to get better resolution images.

As such USVs in isolation are unlikely to represent a complete solution, but could improve tasking of other assets and give reasonable levels of coverage over large spatial and temporal scales.

That said, if there was the capacity to remotely task the USVs, then there is a possibility that attempts could be made to task them to collect specific information, for example, if they happened to be close to some suspected activity. Their deployment could also be made more specific or refined remotely by factoring in intelligence from other sources. For example, focussing them on particular areas, such as along the edges of continental shelves where longliners are known to target or boundaries between isotherms.

Another challenge would be retrieving the data and analysing the information to extract the intelligence. Unless there was a method of automatically transmitting the information following instances of identifying suspected contacts, then the costs of providing a continuous stream of visual data over satellite communications is unlikely to be sustainable. Ideally the system would need to be set up to be able to recognise a potential contact and autonomously notify the control centre remotely, at which point a live stream of the information could be captured, transmitted and assessed. Ideally, there may also need to be some sort of rewriteable hard-drive that maintains at least the last 24 hours of footage, which can then be retrospectively extracted. Issues around interference with the equipment and entanglement in gear (accidental or deliberate) would also need to be explored.

There could be some potential to the technology, and, even if the applicability does have some known limitations, it could act as a considerable deterrent. It is, however, more likely to be useful from a scientific data collection perspective, as opposed to fulfilling and compliance and enforcement role.

2.3.2 Sustainability and Legacy Potential

It is highly likely, although not yet established, that the bulk of the cost would be purchasing the units themselves, although if live streaming data, the links for the satellite communications could be a significant ongoing cost. Additional costs that would need to be factored in include transport, servicing, communications (e.g. if they transmit images/ video via satellite communications), and costs of replacements/ additional units.

The technology has the potential to be largely managed, maintained and utilised independently by the OTs once established, although there is likely to be some requirement for ongoing technical and operational support for maintenance, tasking etc.

2.4 Motor-Powered Unmanned Surface Vessels

2.4.1 Overview and Potential Applications

In comparison to the Self-Powered USVs, Motor-Powered USVs tend to be larger, quicker, more capable remote controlled diesel or petrol powered platforms, which can deliver larger payloads, but have much more limited range and endurance.

There does not appear to be any information available on the use of Motor-Powered USVs in the context of MPA or fisheries management. The majority of motor powered USV appear to be limited to line of sight control, which raises serious questions about whether they could provide any additional value to traditional systems. With some of these vessels, capable of in excess of 50 knots, there are also some health and safety considerations, as well as the logistical challenges of getting the vessel to the OTs.

There could be some application in deploying the Motor-Powered USV from a patrol vessel to ‘scout out’ ahead of the vessel to better direct activity, or corroborate observations from other sources, e.g. satellites. However, given the limited range and endurance of this technology, there is unlikely to be much applicability for monitoring control and surveillance of fisheries. Self-Powered USVs appear to be a better option for low-level, long term intelligence gathering and monitoring, and aerial UAVs would probably be a better option to be deployed from a vessel to scout out ahead of a patrol vessel for potential contacts.

2.4.2 Intelligence and Evidential Value

As per self-powered USVs, in terms of both potential applications, it is likely that, at best, the information provided would be general intelligence, as opposed vessels specific intelligence or evidence.

2.4.3 Sustainability and Legacy Potential

As per self-powered USVs, It is highly likely that the bulk of the cost would be purchasing the units themselves. Although if live streaming data, the links for the satellite communications could be a significant ongoing cost. Additional costs that would need to be factored in include transport, servicing, communications (e.g. if they transmit images/ video via satellite communications), and costs of replacements/ additional units.

The technology has the potential to be largely managed, maintained and utilised independently by the OTs once established, although there is likely to be some requirement for ongoing technical and operational support for maintenance, tasking etc.

2.5 Natural Tags – Downstream Enforcement

2.5.1 Overview and Potential Applications

Natural tags provide a means of retrospectively determining which population, stock or geographical area an individual fish has come from. These are categorised as follows:

- **Genetic analysis** – stock delineation and species validation based on the genetic profile.
- **Otolith or scale microchemistry**. The elemental composition of the water, plus other internal and exogenous factors (e.g. temperature, salinity), affect the composition of the calcified structures within the fish. Due to the way in which scales and otoliths accrete, this profile becomes locked in, and generates an elemental fingerprint that remains with the fish over the life-cycle. The fingerprint can either be assessed as an integrated profile by dissolving the entire otolith or scale, or at specific points in the life-cycle by laser ablating particular growth increments. By comparing the elemental fingerprints from different areas or population, it is possible to retrospectively determine which group the individual belongs to.
- **Body-shape morphometrics**. Similar to otolith microchemistry, but using the overall body shape to delineate between fish. Individual fish are photographed and fixed landmarks are recorded on the image to turn the body-shape into a geometric shape. The average geometric shape of a particular group is then determined and compared to the average shape of other groups – for example, fish of the same species found in fast flowing water may have a thicker, more powerful tail than those from still water.
- **Stable isotope analysis**. Oxygen, Nitrogen and Carbon isotopes can determine the characteristics of a water mass and are differentially assimilated into organisms that live within that water mass. Again, if a geographical variation in isotopic profiles can be determined, then it is theoretically possible to retrospectively determine where the fish has come from.

Stable isotope, microchemistry and body-shape morphometrics are all relatively new techniques that have developed in the past 10-20 years. There is a large body of scientific literature relating to all of the above techniques, although this is predominantly in the context of stock assessments, population biology and analysis of movements.

Stable isotope, body-shape morphometrics and otolith and scale microchemistry all essentially offer the same capability, and, to some extent, suffer the same limitations. Fundamentally, the extent to which all these techniques can be applied depends on marked differences in the characteristics between groups, and the temporal stability of the signature.

From a compliance and enforcement perspective, the most relevant applications are in:

- Validation of species, i.e. what species is fish X?; and
- Determining whether fish have indeed come from the area they have been purported to have caught i.e. where has this fish come from?

Genetic analysis possibly offers the greatest promise as a useable enforcement tool. Genetics are already used in a variety of terrestrial and marine conservation scenarios, and some work has already been done on implementing genetic testing as a fisheries enforcement tool. There are therefore simple, robust and predefined process for gathering the samples in a manner that would be evidentially admissible.

2.5.2 Intelligence and Evidential Value

With the exception of genetic testing, these techniques are only ever likely to be able to provide intelligence, as opposed to evidence, that fish has been mis-recorded. The margin of error and degree of uncertainty involved are unlikely to yield information with the required confidence to treat it as evidence in isolation (though the cumulative effect of each may be sufficient).

Genetics are much more certain, and have the potential to provide intelligence and evidence in the context of the compliance and enforcement applications listed above. Some training would need to be disseminated around sample collection, chain of evidence etc., but the sample (evidence) collection would not be a particularly difficult problem to solve.

2.5.3 Sustainability and Legacy Potential

As long as there is a process in place for processing and analysing the samples, then these techniques all represent a fairly low cost, long term option for the OTs that would probably sit alongside the scientific work already being undertaken.

That said, there are unlikely to be significant traceability issues, and access into closed areas seems to be a more immediate problem. Very few vessels land or are inspected at sea in the UKOTs the Blue Belt Programme is currently working with, meaning these techniques probably have more application in the context of port state control measures, rather than any applicability to the UKOTs directly. If access to UKOT fisheries were increased in the future, then these techniques could provide assurance that the vessels were acting compliantly, so there may still be some interest even in those where there is currently no licenced fishery. However this may depend on species of interest.

2.6 Satellite Surveillance

2.6.1 Overview and Potential Applications

In principle, satellite surveillance has the potential to provide high level coverage of the UKOTs EEZs or maritime zones, though there are some limitations, not least the cost, and it should not be regarded as a standalone solution to remote monitoring and surveillance. In general terms, the following types of satellite sensors offer the greatest potential:

- Passive – relies on the detection of information transmitted from the vessel such as AIS or VMS.
- Optical – relies on a line of sight
- Synthetic Aperture RADAR (SAR) – not limited by light conditions or cloud cover

The FCO commissioned a satellite surveillance project at the start of the Blue Belt Programme. The project monitored each of the UKOTs for three months using satellite data and reviewed three years' worth of AIS data. The aim was to build up a picture of the activity of all vessels around the UKOTs and identify non-compliance, specifically IUU fishing, and provide recommendations on next steps to respond to these incidents. Subsequently, the MMO through the Blue Belt Programme has established a 'call-off' contract with OceanMind, to conduct further satellite surveillance in areas of high IUU risk at high risk times.

Satellite technology has also been adopted and trialled by other organisations working across the UKOTs over the last two to three years, including Pew Charitable Trust's *Eyes on the Seas* work in Pitcairn, and CLS and Oxford University in Ascension. There are numerous examples of satellite surveillance being used in marine and terrestrial conservation enforcement, the general concept is well tested and there has been some application in live enforcement scenarios.

Satellite data is interpreted to highlight detections that are consistent with the characteristics of either fishing vessels or vessels associated with fishing activity, with an associated confidence score. Coverage is defined as a percentage in a particular period – for example, 100% coverage per week would mean the entire EEZ or maritime zone is covered at least once per week, 200% is every area covered twice per week. Monitoring also extends beyond the EEZ, giving an indication of activity (fishing or associated 'infrastructure' such as bunkering vessels or reefers) that maybe nearby that could enter the zone. This aspect of the reporting gives an overview of the apparent general levels of fishing activity in particular areas at a given time.

OceanMind also integrate the raw visual satellite data with information from other sources such as AIS and VMS where such corroborating information exists. When this is the case, they can provide vessel specific information based on the identifier details provided.

The contract with OceanMind draws on commercial satellite imagery, purchased for areas of interest, as well as freely available data from e.g. the European Space Agency satellites.

Further work is required to understand whether free and low-cost satellites on their own would provide enough data to provide an effective surveillance tool for IUU. The Blue Belt Programme is therefore also working with SCISYS Ltd, to develop a prototype tool for IUU vessel detection based only on free and low-cost satellite data only. This project is aiming to determine if this data could provide an effective low cost, in house, satellite surveillance monitoring tool that might be operated in the OTs in the longer term. It will also include a ‘horizon scan’ of likely developments in satellite technology and coverage in future.

2.6.2 Intelligence and Evidential Value

Satellite surveillance has considerable scope to provide intelligence ranging from overall activity levels through to vessel specific activity that can be used for near real-time tasking of enforcement assets. It would however seem unlikely that even SAR or optical imagery could positively identify vessels and confirm they are engaged in fishing activity to the extent that it would, in isolation, provide evidence of an offence. Similarly, vessel detections relying on AIS data for vessel identification could probably only ever be treated as either intelligence or, at best, circumstantial evidence.

In order to allow for effective tasking of enforcement/ surveillance assets, more than one image is ideally required in order to indicate trajectory, and therefore projected position.

2.6.3 Sustainability/ Legacy Potential

Current use of satellite surveillance in the Blue Belt Programme is greatly increasing intelligence regarding activity within the UKOT EEZs. The current costs involved in procuring commercial satellite imagery and the subsequent analysis are high and unlikely to be sustainable long term. Lower cost imagery is available through, for example the European Space Agency Copernicus programme, and further exploration of this and other low cost satellite image providers, analysis options and operating modes offer significant potential in future.

2.7 Additional Technologies

The following emerging technologies have not been assessed in detail for the purposes of this report, but are technologies that we would like to see considered further as part of the OT Technology Roadmaps review:

- AIS monitoring/ analysis.
- Ground/ buoy based RADAR – Brooke et al. (2010) provides some indication of cost and capability, citing some systems could have coverage extending out to 200nm.
- Argo Floats – relatively cheap data collection devices that can be deployed at sea and left to collect scientific information. The technology itself is unlikely to have any direct application from a compliance and enforcement perspective, although the mechanism by which information is transmitted may be a useful model system for transmitting information gathered by other technologies such as passive acoustics.

- Phobos and Smartscan MEWS – detect RADAR and VHF/ HF emissions from vessels – could these technologies be installed to patrol vessels, and therefore potentially unmanned assets, to detect RADAR and VHF transmission at sea? There may be Regulation of Investigatory Powers Act (RIPA) considerations utilising technologies that intercept communications, though this would need to be explored in the context of the applicability of RIPA in the OTs.

3.0 UK funding

3.1 Engineering and Physical Sciences Research Council

The Engineering and Physical Sciences Research Council (EPSRC) is the UK's main agency for funding research in engineering and the physical sciences. EPSRC invests around £800 million a year in research and postgraduate training, to help the nation handle the next generation of technological change. They have funded £2.2 million of relevant R&D since 2011 across four projects. Lead institutes and titles of these projects are detailed below. Further information is included in Appendix A.

- Heriot Watt University: Target detection in clutter for sonar imagery.
- University College London, University of Birmingham: Maritime Security Sensor Network Based on Ultra-Wideband Electromagnetic Waves Forward Scattering phenomena.
- University of Newcastle: USMART - smart dust for large scale underwater wireless sensing.
- University of Loughborough: Autonomous landing of a helicopter at sea: advanced control in adverse conditions (AC2).

3.2 Natural and Environment Sciences Research Council

The Natural Environment Research Council (NERC) is the UK's largest funder of independent environmental science, training and innovation, delivered through universities and research centres. NERC has funded at least £23.6 million of relevant R&D that has some component of remote monitoring within it, either through the development of autonomous vehicles or remote sensing from satellites. However, the majority of this work is focused on measuring baseline environmental data (e.g. temperature, salinity, dissolved oxygen, nitrogen and chlorophyll, acoustic monitoring of fish or marine mammals, or video footage of benthic habitats) rather than monitoring human activity for surveillance purposes.

Whilst there are undoubtedly lessons that could be learned for maritime surveillance from this work, the technology transfer challenge in repurposing this technology reduces the TRL of these environmental monitoring solutions for surveillance purposes. When this challenge is put in the context of the large amount of R&D that is solely focused on maritime surveillance within the defence and engineering communities, such repurposing does not seem like an efficient use of funding.

That being said, NERC has funded six projects over the last ten years that are worth £1.4 million and appear to be directly relevant to maritime surveillance. Lead institutes and titles of these projects are detailed below. Further information is included in Appendix A.

- University of Bristol: Automation and standardisation of a passive acoustic monitoring (PAM) system.
- University of Strathclyde: Knowledge Exchange for Satellite Applications in the Marine Sector.
- National Oceanography Centre: Application of autonomous systems to monitor oil spills.
- National Oceanography Centre: Ocean Satellite Research Impact Study.
- University of Bristol: SeaDNA - Assessing marine biodiversity and structure using environmental DNA: from groundtruthing to food web structure and stability.

3.3 Innovate UK

Innovate UK is the UK's innovation agency. They drive productivity and growth by supporting businesses to realise the potential of new technologies, develop ideas and make them a commercial success. They have funded six relevant projects to a value of £1.3 million as set out below. It should be noted that the resulting intellectual property from this funding will sit within the private sector rather than the public sector or academia.

Lead institutes and titles of these projects are detailed below. Further information is included in Appendix A.

- Globavista: Globavista - Visualisation for Big Data Maritime Location Based Services.
- Autonomous Surface Vehicles Limited: Unmanned Safe Maritime Operations Over The Horizon (USMOOTH).
- Archangel Imaging Ltd: LELA 2 for Maritime Security and Safety.
- Rnc Avionics Limited: Smart On-Board UAV Thermal Signature Analysis for Surveillance, Tracking and Navigation.
- ESROE Limited: The use of radar ESM sensors for civil maritime surveillance.
- Autonaut Limited: MOST (AV) Autonaut SMART Proof of Market.

3.4 Centre for Defence Enterprise / Defence and Security Accelerator

The Centre for Defence Enterprise (CDE) was part of the Defence Science and Technology Laboratory (DSTL), which is an executive agency of the Ministry of Defence. Their aim is to ensure that innovative science and technology contribute to the defence and security of the UK. The CDE funded innovative research could lead to a cost-effective capability advantage for UK armed forces and national security. It has now been replaced by the Defence and Security Accelerator, which is still part of DSTL.

Lead institutes and titles of these projects are detailed below. Information on these projects is largely classified and therefore not in the public domain. What further information is available is included in Appendix A.

- BAE Systems: Evaluation of a method to identify unlawful activity at sea for strengthening the security of maritime operations.
- University of Southampton: Self-powered autonomous surface & underwater vehicles for persistent observation.

3.5 Studentships

As well as funded R&D projects, there are a number of PhD studentships running with both EPSRC and NERC that could be of interest. PhD studentships cannot be expected to produce high TRL technology that is commercially viable, however, they are useful for exploring the boundaries of new innovation in a relatively cost efficient manner.

Lead institutes and titles of these projects are detailed below. There are no specific funding costs associated with PhD studentships on the RCUK database, but further details available are included in Appendix A.

- University of Bath: Autonomous Surveillance of Marine Mammal Populations in South Africa.
- University of Birmingham: Passive coherent location systems (PCLS) for area surveillance and detection.
- University of East Anglia: Sounds in the sea: how can we listen from ocean gliders?
- University of Southampton: Multi-vehicle swarm behaviours for monitoring of rapidly evolving ocean phenomena.

4.0 EU Funding

4.1 Framework Package 7

The 7th EU Framework Programme for Research and Technological Development (FP7) lasted for seven years from 2007 until 2013 with a total budget of over €50 billion. There were five specific programmes which constituted the main building blocks of FP7: Cooperation, Ideas, People, Capacities and Nuclear Research. The core of FP7, representing two thirds of the overall budget, is the Cooperation programme. It fosters collaborative research across Europe and other partner countries through projects by transnational consortia of industry and academia. Research was carried out in ten key thematic areas:

- Health
- Food, agriculture and fisheries, and biotechnology
- Information and communication technologies
- Nanosciences, nanotechnologies, materials and new production technologies
- Energy

- Environment (including climate change)
- Transport (including aeronautics)
- Socio-economic sciences and the humanities
- Space
- Security

The security theme had a budget of €1,400 million addressing the need for a comprehensive security strategy encompassing both civil and defence security measures. Each year of the programme, funding calls were made within each theme. Relevant funding calls within FP7 related to maritime security through the lifetime of the programme were:

- Topic SEC-2007-3.3-02 Surveillance in wide maritime areas through active and passive means
- Topic SEC-2009.3.2.1: Main port area security system
- Topic SEC-2009.3.2.2: Sea border surveillance system
- Topic SEC-2009.3.4.1 Continuity, coverage, performance (incl. UAV), secure data link
- Topic SEC-2010.3.1-1 European-wide integrated maritime border control system – phase II
- Topic SEC-2012.3.1-1 Increasing trustworthiness of vessel reporting systems - Capability Project
- Topic SEC-2012.3.5-1 Development of airborne sensors and data link – Integration Project
- Topic SEC-2013.5.3-2 Testing the interoperability of maritime surveillance systems - Pre-Operation Validation
- SST.2008.1.2.1. - Preventive and emergency interventions to protect marine, coastal and land environments
- SPA.2010.1.1-05 - Contributing to the “S” in GMES – Developing pre-operational service capabilities for Maritime Surveillance
- FP7-PEOPLE-2013-ITN - Marie-Curie Action: "Initial Training Networks"

Seven relevant projects were funded over €110 million under the Security theme, with an additional €4.8 million being allocated to a project under the Transport theme (emergency interventions), €15.5 million being allocated to three projects in the space theme and €3.6 million being allocated to a project within the training network theme. In total, €134.4 million of potentially relevant R&D was funded under FP7 between 2008 and 2017. Lead institutes and titles of these projects are detailed below. Further information is included in Appendix A.

- Ente Parco Nazionale Arcipelago Toscano, Italy: Automatic Oil-Spill Recognition and Geopositioning integrated in a Marine Monitoring Network (ARGOMARINE).
- Carl Zeiss Optronics, Germany: Autonomous maritime surveillance system (AMASS).
- Thales Systemes Aeroportes, France: Wide Maritime Area Airborne Surveillance (WIMAAS).
- Selex, Italy: Sea Border Surveillance (SeaBILLA).
- DCNS, France: Integrated System for Interoperable sensors & Information sources for Common abnormal vessel behaviour detection & Collaborative identification of threat (I2C).
- Indra Sistemas, Spain: Protection of European seas and borders through the intelligent use of surveillance (PERSEUS).
- Ministerio Del Interior, Spain: Collaborative evaluation of border surveillance technologies in maritime environment by pre-operational validation of innovative solutions (CLOSEYE).

- BMT Group, UK: Smart unattended airborne sensor network for detection of vessels used for cross border crime and irregular entry (SUNNY).
- GMV Aerospace and Defence, Spain: New Service Capabilities for Integrated and Advanced Maritime Surveillance (NEREIDS).
- E-GEOS, Spain: Development of Pre-operational Services for Highly Innovative Maritime Surveillance Capabilities (DOLPHIN).
- Thales Alenia Space Italia, Italy: Simulator for Moving Target Indicator System (SIMTISYS).
- Deutsches Forschungszentrum Fur Kunstliche Intelligenz, Germany: European Academy for Marine and Underwater Robotics (ROBOCADEMY).

4.2 Horizon 2020

Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over seven years from 2014 to 2020. The current main Horizon 2020 work programme includes 17 thematic sections, one of which is Borders and External Security.

Relevant funding calls within H2020 related to maritime security were:

- BES-01-2015: Maritime Border Security topic 1: radar systems for the surveillance of coastal and pre-frontier areas and in support of search and rescue operations
- BES-02-2015: Maritime Border Security topic 2: affordable and easily deployable technologies for EU coastal border surveillance with reduced impact on the environment
- BES-03-2015: Maritime Border Security topic 3: Light optionally piloted vehicles (and sensors) for maritime surveillance
- SEC-19-BES-2016: Data fusion for maritime security applications
- EO-2-2016 - Downstream services for public authorities
- SMEInst-08-2016-2017 - Supporting SMEs efforts for the development - deployment and market replication of innovative solutions for blue growth

Two relevant projects have so far received over €17.7 million of funding under the Border and External Security theme, with an additional €4.8 million being allocated to a project under the Earth Observation theme, €1.5 million being allocated to a project under the Space theme, €159,795 to a Marie Curie Fellowship and €71,419 being allocated to a project under the SME instrument. In total, €29.7 million of potentially relevant R&D has so far been funded under H2020 . Lead institutes and titles of these projects are detailed below. Further information is included in Appendix A.

- National Center For Scientific Research Demokritos, Greece: Bridging Innovative Downstream Earth Observation and Copernicus enabled Services for Integrated maritime environment, surveillance and security (MARINE EO).
- Jacobs University Bremen, Germany: Towards Intelligent Cognitive AUVs (TIC-AUV).
- Exus Software Ltd, UK: Radars for long distance maritime surveillance and SAR operations (RANGER).
- Leonardo - Societa Per Azioni: Maritime Integrated Surveillance Awareness (MARISA).
- Aster Spa: Galileo-based passive radar system for maritime surveillance (spyGLASS).

5.0 Conclusion and Next Steps

This review shows that there is a large, and relatively mature, R&D community within both the private and public sectors stretching across Europe relating to maritime surveillance and monitoring human activity at sea. Much of this effort has focused on securing the EU's maritime borders, but it is not unreasonable to assume that technology developed within these projects could be directly relevant to the Blue Belt programme or the MMO's compliance and enforcement activity in domestic waters.

Crucially, the ideal technology solution for each UKOT is likely to be different, depending on both the nature of the enforcement risks they are exposed to and also the capability and resources of on-island enforcement. It is therefore fundamental that the solutions being sought are requirement driven, and that a bespoke solution can be developed for each.

The Blue Belt Technology Roadmaps project will review technologies in more detail and set out opportunities in the short, medium and long-term for each UKOT, based on UKOT specific context and requirements, and taking account of legal considerations and cost-benefit-analysis. It will also consider cross-cutting requirements related to data management, intelligence sharing and asset tasking.

Marine Management Organisation

Appendix A: UK and EU Funded Projects

UK Funded Projects

Engineering and Physical Sciences Research Council

Title	Description	Start	End	Lead Institute	Funding
Target detection in clutter for sonar imagery[8]	This project demonstrated that target detection could be performed by analysing the seabed in sonar imagery and looking for anomalies in the local signal. This was demonstrated to DSTL on real data. The findings were taken forward by SeeByte Ltd, a company specialising in advanced software for the defence sector.	2011	2013	Heriot Watt University	£120,989
Maritime Security Sensor Network Based on Ultra-Wideband Electromagnetic Waves Forward Scattering phenomena[9]	The research supported by this grant help understand the radar signature of small boats and inflatables, i.e. how different type of radar systems can detect these targets of interest against the background of sea clutter. This can provide useful information to optimize the detection of such targets, mostly used by smugglers, trafficers, pirates, and for other illicit activities.	2012	2015	University College London, University of Birmingham	£ 703,848
USMART - smart dust for large scale underwater wireless sensing[10]	The detection of underwater threats by dense networks of sensors is an application which is currently difficult to realise due to the cost, size and power consumption of current devices. This project makes the vision of underwater sensor nets defending strategically important ports and waterways a realistic one.	2017	2020	University of Newcastle	£1 284,428
Autonomous landing of a helicopter at sea: advanced control in adverse conditions (AC2)[11]	Enabling the autonomous landing of a helicopter on the deck of a ship would bring the advantages of unmanned helicopters into a vast range of applications in the maritime environment. This will complement surface and undersea maritime vehicles to form a 3-D autonomous capability at sea. Environmental monitoring and vessel surveillance can be more efficiently performed by unmanned helicopters with less cost.	2017	2018	University of Loughborough	£100,907

Natural and Environment Sciences Research Council

Title	Description	Start	End	Lead Institute	Funding
Automation and standardisation of a passive acoustic monitoring (PAM) system[12]	This project explored potential modifications of a military marine passive acoustic system (SSQ 906G Low frequency analysis and recording (LOFAR) Sonobuoy), produced by the partner organisation Ultra Electronics Sonar Systems, for wider commercial use	2013	2013	University of Bristol	£15,882
Knowledge Exchange for Satellite Applications in the Marine Sector[13]	The Fellowship aimed to create impact from existing NERC research which uses satellite data to provide information about the marine environment	2015	2015	University of Strathclyde	£153,697
Application of autonomous systems to monitor oil spills[14]	Work with Oil Spill Response Limited, to carry out a wide ranging review of the scope of autonomous systems used commercially and in research to identify systems and sensors that may be applied in response to oil spills or routine monitoring.	2017	2017	National Oceanography Centre	£26,965
Ocean Satellite Research Impact Study[15]	This work identified a number of areas in NERC-funded remote sensing research, which have potential future government applications.	2014	2016	National Oceanography Centre	£123,847
SeaDNA - Assessing marine biodiversity and structure using environmental DNA: from groundtruthing to food web structure and stability[16]	Project will survey marine environment using traditional (e.g. nets) and eDNA methods in the Southern Ocean. They will directly compare data from eDNA methods to those from traditional methods to ask if eDNA accurately captures the fish and invertebrate communities, and if the method has the added ability to inform us on the presence of species that are typically rare or difficult to sample, some of which may be new to science.	2015	2019	University of Bristol	£1,000,000

Marine Management Organisation

Innovate UK

Title	Description	Start	End	Lead Institute	Funding
Globavista - Visualisation for Big Data Maritime Location Based Services[17]	The project will combine satellite AIS data, terrestrial AIS data, global metrological information, vessel data, piracy intelligence, port and terminal information, territorial water and EEZ information in a single repository to enable the production of value added data, historical trend information and forecasting capabilities.	2015	2016	Globavista	£339,263
Unmanned Safe Maritime Operations Over The Horizon (USMOOTH)[18]	This project will address USV technologies alongside human operators introducing a holistic solution to robustly address the safety constraints blocking current USV deployment.	2015	2017	Autonomous Surface Vehicles Limited	£819,037
LELA 2 for Maritime Security and Safety[19]	HyRIZON is a smart hyperspectral system to combat smuggling, piracy, pollution, illegal fishing, human trafficking, and other maritime crimes. It is particularly suited to Long Endurance Low Altitude UAVs or USVs.	2017	2017	Archangel Imaging Ltd	£19,530
Smart On-Board UAV Thermal Signature Analysis for Surveillance, Tracking and Navigation[20]	Developed a novel integrated on-board imaging system thermal signature analysis for detecting heat trails left by a vehicle/vessel and explore this in real time for adjustment of its flight plan. Once the object of interest has been identified, the direction of its movement is analysed using video analytics. The results will be used to autonomously alter the UAV pre-defined surveillance flight plan to ensure that the object is continuously tracked	2013	2014	Rnc Avionics Limited	£99,996
The use of radar ESM sensors for civil maritime surveillance[21]	This project will investigate the market for radar ESM sensor technology, developed for the military domain, in civil maritime surveillance	2015	2016	ESROE Limited	£24,546
MOST (AV) Autonaut SMART Proof of Market[22]	The project will focus on four market segments: legal, commercial, scientific and defence and security and will lead us to a far deeper understanding of market need, prioritisation of sensor offerings, and a clear way forward for commercialisation	2016	2017	Autonaut Limited	£24,237

Centre for Defence Enterprise / Defence and Security Accelerator

Title	Description	Start	End	Lead Institute	Funding
CDE31195: Evaluation of a method to identify unlawful activity at sea for strengthening the security of maritime operations[23]	n/a	2012	n/a	BAE Systems	£71,730.00
CDE28875: Self-powered autonomous surface & underwater vehicles for persistent observation[24]	n/a	2013	n/a	University of Southampton	£88,376

Studentships

Title	Start	End	Lead Institute	Funding body
Autonomous Surveillance of Marine Mammal Populations in South Africa[25]	2017	2020	University of Bath	EPSRC
Passive coherent location systems (PCLS) for area surveillance and detection[26]	2017	2020	University of Birmingham	EPSRC
Sounds in the sea: how can we listen from ocean gliders?[27]	2016	2020	University of East Anglia	NERC
Multi-vehicle swarm behaviours for monitoring of rapidly evolving ocean phenomena[28]	2016	2020	University of Southampton	NERC

EU Funded Projects

Framework Package 7

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
ARGOMARINE[29]	Automatic Oil-Spill Recognition and Geopositioning integrated in a Marine Monitoring Network	The aim was to develop a network to monitor and protect heavily used shipping lanes, and to institute a data management system for public use in order to protect bodies of water from oil spills. Algorythms were designed that used synthetic aperture radar and a vessel detection method to enable the automated identification and tracking of oil spills. An autonomous sensing platform was developed that could detect hydrocarbons in seawater. The sensing platforms also incorporated acoustic monitoring (to detect vessels) and other environmental sensors. Finally, an overall 'Marine Information System' was developed. This tool incorporated all the data generated by ARGOMARINE into a publically available system for monitoring and data management.	Ente Parco Nazionale Arcipelago Toscano, Italy	n/a	€ 4,864,612	09/09	11/12
AMASS[30]	Autonomous maritime surveillance system	This project designed a reliable, continuous maritime monitoring solution. This included a flotation platform, optronics, hydrophones, communications, power management and image exploitation, as well as command and control. The system depends on a line of buoys – each equipped with the latest visual and acoustic sensors – located offshore to gather data on movement and activities in territorial waters. When AMASS detects a suspicious vessel, it relays images directly to a control centre on shore, authorities to take swift and appropriate action.	Carl Zeiss Optronics, Germany	n/a	€ 5,465,308	03/08	08/11

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
		Among the project's innovations is a thermal imaging camera. This uses very little energy, is lightweight, has long life expectancy, possesses a built-in image stabiliser and can withstand the harsh conditions at sea. The buoys are also equipped with state-of-the-art passive stabilisers.					
WIMAAS[31]	Wide Maritime Area Airborne Surveillance	The main aim of the project was to develop key technologies to prepare the future for the operational use of Unmanned Aerial Systems (UAS), innovative mission aircraft and space assets, as key building blocks integrated in a System of Systems approach. It provided the airborne building block of maritime surveillance with the potential for reduced operational costs, more autonomy and improved efficiency through the introduction of air vehicles with reduced or zero onboard crew.	Thales Systemes Aeroportes, France	n/a	€ 4,001,123	12/08	11/11
SeaBILLA[32]	Sea Border Surveillance	This project addressed security on the high seas through early warning systems and sharing information. Key priorities included drug trafficking, illegal immigration, and/or illicit activities in the Atlantic Sea, Mediterranean Sea and English Channel. There were 4 key areas: 1) Visioning a roadmap of illegal scenarios and outlining the required surveillance capabilities for each; 2) detection of small illegal boats through improved land, sea and space surveillance; 3) the consolidation of sensor networking and information, from detecting abnormal behaviour to improving data processing; and 4) testing and validation of new technologies. Emphasis was placed on investigating detection and how it can be performed either by developing new solutions or elaborating solutions via the integration of existing technologies. The focus was on space-, air-, land- and sea-based surveillance tools. To this end, work included the development of a novel algorithm	Selex, Italy	BAE Systems, UCL, Portsmouth University	€ 15,558,125	06/10	02/14

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
		for change detection and ship detection from spaceborne sensors, comparison of manned and unmanned aerial means, and assessment of remotely piloted aircraft system performance in selected scenarios. In terms of sensors, activities involved networking between radar and sensors to track small boats close to coastlines and a behaviour analysis algorithm to help relevant stakeholders detect suspicious boats.					
I2C[33]	Integrated System for Interoperable sensors & Information sources for Common abnormal vessel behaviour detection & Collaborative identification of threat	This project proposed an innovative sea border surveillance system implementing key existing and developing vessel tracking technologies to identify and report on potential threats. 1) Shore based sensor platforms grouping new sensor technologies such as long range radar to track small crafts AIS stations and conventional coastal radar. This platform performs permanent all weather traffic surveillance over wide maritime zone up to 200 nautical miles. 2) Deployable sensor platforms to perform local node observation campaigns to compliment shore based surveillance. Four platforms were deployed: aircraft and vessel patrols, USV and Zeppelin, which offers absolute quiet flight with no vibration for high resolution observation quality and a payload of 2 tons for sensors and communication devices. 3) Development of a common operational traffic picture to correlate vessels tracks from shore based and deployable sensors plots. 4) Ability to detect abnormal vessel behaviour and trigger automatic alarms to operator for validation. 5) Ability to to understand suspicious events, early identification of threats and issue periodic interpretation files to authorities for decision. 6) Ability to transfer useful data sets through communication network based on Distributed	DCNS, France	n/a	€ 15,962,707	10/10	09/14

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
		Systems intercommunication Protocol (DSiP) and VSAT/Digital Video Broadcast technologies.					
PERSEUS[34]	Protection of European seas and borders through the intelligent use of surveillance	The project combined existing national systems and platforms providing new capabilities that surpass the existing European Border Surveillance System's (Eurosur) capabilities. The system is capable of improved detection and identification of small boats and aircrafts and enhanced automated detection of abnormal vessel patterns. Improved threat assessment and tracking capabilities can generate a common situational picture. Recommendations were validated through a series of exercises focused on drug trafficking, illegal immigration and delivering surveillance continuity. End users had privileged access to existing surveillance systems and assets, optimising coverage. An evolution mechanism was included in project work to enlarge the user base and integrate emerging technologies during its lifetime. New Command and Control Centres were developed, adapting legacy systems and enhanced existing platforms. Over 40 different technologies associated with maritime surveillance were analysed. Recommendations about the legal and political framework of the proposed surveillance and related technologies were made, establishing links with other FP7 bodies, in particular those associated with border control.	Indra Sistemas, Spain	n/a	€ 43,434,221	01/11	06/15
CLOSEYE[35]	Collaborative evaluation of border surveillance technologies in maritime environment by pre-	The goal of the project was not to promote the direct purchase of surveillance systems, but to validate future solutions by means of experimentation with innovative proposals in a real operational environment. The project assessed the Procurement, Operation, Validation cycle in an innovative way. The goal was to define real needs, identify mature solutions, define	Ministerio Del Interior, Spain	n/a	€ 12,205,071	01/13	02/17

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
	operational validation of innovative solutions	new validation schemes, and advance guidelines for defining reference performance levels and future flexible public procurement schemes The project succeeded in defining, developing and integrating solutions for the detection, identification and tracking of small non-collaborative vessels at the EU's southern maritime border. Innovative solutions encompassing platforms, sensors and ICT extended the range of cost-effective surveillance; enhanced the discrimination of vessel traffic; supported decision-making; contributed to improved situational awareness and the tactical situational picture at coordination centres; improved the sharing of real-time information and faster reaction times.					
SUNNY[36]	Smart unattended airborne sensor network for detection of vessels used for cross border crime and irregular entry	This project is developing solutions to upgrade current EU border monitoring capabilities. Keeping affordability and interoperability in mind, the project aims to deliver pre-processed information with meaningful decision-support tools that requires less border surveillance manpower and expertise. To achieve its aims, SUNNY is developing smart UAVs with a two-tier sensor network. The first-tier sensors, carried by vertical take-off and landing UAVs, detect suspicious targets over large areas and provide global situation awareness. Subsequently, the second-tier sensors track the targets and gather additional information to better assess possible threats and identify anomalies using novel algorithms. The new low-weight, low-cost sensors will be integrated into UAVs to provide high-resolution images in all weather conditions, day and night. They will exploit the latest wireless technologies and architectures to ensure rapid transfer of quality data and imaging.	BMT Group, UK	BMT Group, Queen Mary University London,	€ 13,846,678	01/14	12/17
NEREIDS[37]	New Service Capabilities for	This project aimed to enhance European capabilities for automatic ship monitoring in addition to providing	GMV Aerospace	n/a	€ 6,026,984	06/11	05/14

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
	Integrated and Advanced Maritime Surveillance	advanced decision-making tools and developed numerous remote-sensing processing technologies to be used for marine surveillance and law enforcement. Technical targets included developing a test benchmark for assessment of new algorithms that were interoperable with other operational systems. Several remote-sensing candidate technologies were identified that were suitable for law enforcement and related applications. Highlights include a detection system using SAR to locate and track small targets, and automatically categorise targets. The consortium achieved advanced fusion approaches able to cope with multi-sensor data and other complexities. Other new capabilities included constraint-based track reconstruction, complex anomaly detection, and propagation of vessel routes for compilation and analysis. The project's advanced database structure permitted multi-user and multi-purpose approaches. A real-time graphical user interface yielded views of processed scenes comparable to real life. Team members developed and tested the system over nine campaigns at a variety of locations, and using realistic detection scenarios.	and Defence, Spain				
DOLPHIN[38]	Development of Pre-operational Services for Highly Innovative Maritime Surveillance Capabilities	The project outlined operational requirements for maritime surveillance capabilities. New software algorithms were developed so that generated data can be used by external European and national systems, while the software itself will feed the DSMs for each of the three identified policy areas: border surveillance, traffic safety and fisheries control. Gaps addressed include more timely and reliable information, improvement of situational awareness and increase of reaction capabilities through the provision of reliable DSMs.	E-GEOS, Spain	Qinetic	€ 6,991,197	06/11	11/13

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
		Innovative high-tech solutions include better radar processing, feature extraction and recognition for fast and/or small boats, multi-sensor data fusion for traffic safety and sea-state modelling. The project's solutions will enable users to localise vessels more accurately, detect smaller ships.					
SIMTISYS[39]	Simulator for Moving Target Indicator System	The project aimed to develop a software solution to improve early warning systems and services connected to Copernicus. This included looking at current gaps such as inadequate space data acquisition where piracy is rife. Barriers and issues were reviewed in the study of sensing systems and the entire information management chain, covering observation range, sea conditions, data processing, moving targets' detection and tracking algorithms. Radar systems mounted on a single satellite or a constellation can be an invaluable way to monitor our oceans. The SIMTISYS simulator is expected to support the use of space-borne radar as a source of critical information during rescue operations. Furthermore, this is expected to pave the way for the development of advanced operational services that could redefine current Copernicus services.	Thales Alenia Space Italia, Italy	Telespazio Vega UK	€ 2,489,926	06/11	11/13
ROBOCADEMY[40]	European Academy for Marine and Underwater Robotics	The Robocademy Innovative Training Network will establish a European training and research network to develop key skills and enabling technologies in underwater robotics for the scientific and economic exploration of the oceans (e.g. offshore oilfield of the future). Through the close collaboration of leading research institutes, academia, industry, and small-medium enterprises (SME) in robotics, marine technology, marine science, and offshore industry, Robocademy will provide firstclass training and research opportunities for Early Stage Researchers (ESR).	Deutsches Forschungszentrum Fur Kunstliche Intelligenz, Germany	Heriot Watt University, NERC, SeeByte	€ 3,610,611	01/14	12/17

Horizon 2020

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
MARINE EO[41]	Bridging Innovative Downstream Earth Observation and Copernicus enabled Services for Integrated maritime environment, surveillance and security	This project has the following objectives: (1) Develop, test and validate two sets of demand-driven EO-based services which cover Marine Monitoring and Security Copernicus thematic areas, adopted on open standards, bringing incremental or radical innovations in the field of maritime awareness and leveraging on the existing Copernicus Services and other products from the Copernicus portfolio, (2) Propose a set of “support” / “envelop” services which will better integrate the above mentioned EO and Copernicus-enabled services to the operational logic and code of conduct. Such services shall also bring “closer” the demand side (Public Authorities) with the EO data providers (Copernicus - contributing missions) and EO data experts and analysts (Service providers/ industry and SMEs) creating a dynamic environment for a single digital market to grow, (3) Strengthen transnational collaboration in maritime awareness sector by facilitating knowledge transfer and optimization of resources for the public authorities which, participate in the buyers group.	National Center For Scientific Research Demokritos, Greece	n/a	€ 4,865,093	01/17	11/20
TIC-AUV[42]	Towards Intelligent Cognitive AUVs	The Fellowship will address the need for greater autonomy and capabilities, improving the cognitive and intelligent layer of marine robotics. Research activities are: 1) semantic world representation and reasoning, in order to represent the operating environment, taking into account uncertainty at different layers (sensor data, partial view, system evolution); 2) intelligent active localisation techniques, in order to define a specific set of actions aiming at robot localisation in the environment; 3) fault management, in order to detect, classify and react to possible in-mission faults and various problems.	Jacobs University Bremen, Germany	n/a	€ 159,795	03/17	02/19
RANGER[43]	Radars for long distance	This project will combine innovative radar technologies with novel technological solutions for early warning, with the aim of delivering a surveillance platform offering detection, recognition, identification	Exus Software Ltd, UK	Exus Software Ltd	€ 7,992,312	05/16	10/19

Acronym	Title	Description	Lead institute	UK partner	Funding	Start	End
	maritime surveillance and SAR operations	and tracking of suspicious vessels, with capabilities exceeding current systems. It will be a platform, consisting of 2 radar technologies, a novel over the horizon radar combined with a multiple input multiple output radar exploiting the latest photonics advancements, and an early warning system exploiting deep and adaptable machine learning schemes able to automatically detect radar targets.					
MARISA[44]	Maritime Integrated Surveillance Awareness	The aim is to is to provide the security communities operating at sea with a data fusion toolkit, which makes available a suite of methods, techniques and modules to correlate and fuse various heterogeneous and homogeneous data and information from different sources, including Internet and social networks, with the aim to improve information exchange, situational awareness, decision-making and reaction capabilities. The proposed solution will provide mechanisms to get insights from any big data source, perform analysis of a variety of data based on geographical and spatial representation, use techniques to search for typical and new patterns that identify possible connections between events, explore predictive analysis models to represent the effect of relationships of observed object at sea.	Leonardo - Societa Per Azioni	n/a	€ 9,765,658	01/17	10/19
spyGLASS[45]	Galileo-based passive radar system for maritime surveillance	This proposal brings forward a passive bistatic radar (PBR) based on Galileo transmissions for maritime surveillance. The exploitation of existing transmissions for PBR applications is becoming increasingly attractive due to their low costs, covert operation, and reduced environmental pollution. Galileo is particularly suited for the proposed task since it comprises a satellite constellation, ensuring that any point on Earth is permanently illuminated by a number of satellites. This feature potentially enables surveillance both in coastal areas and the open sea. In this proposal a ground based receiver is considered for coastal monitoring while the receiver is placed on mobile platforms to assure open sea surveillance. The feasibility of such a system will be evaluated and the required techniques will be studied and developed in order to propose an original and innovative solution to solve a major European problem using European technology.	Aster Spa	University of Birmingham	€ 1,510,250	01/15	12/17

Marine Management Organisation

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