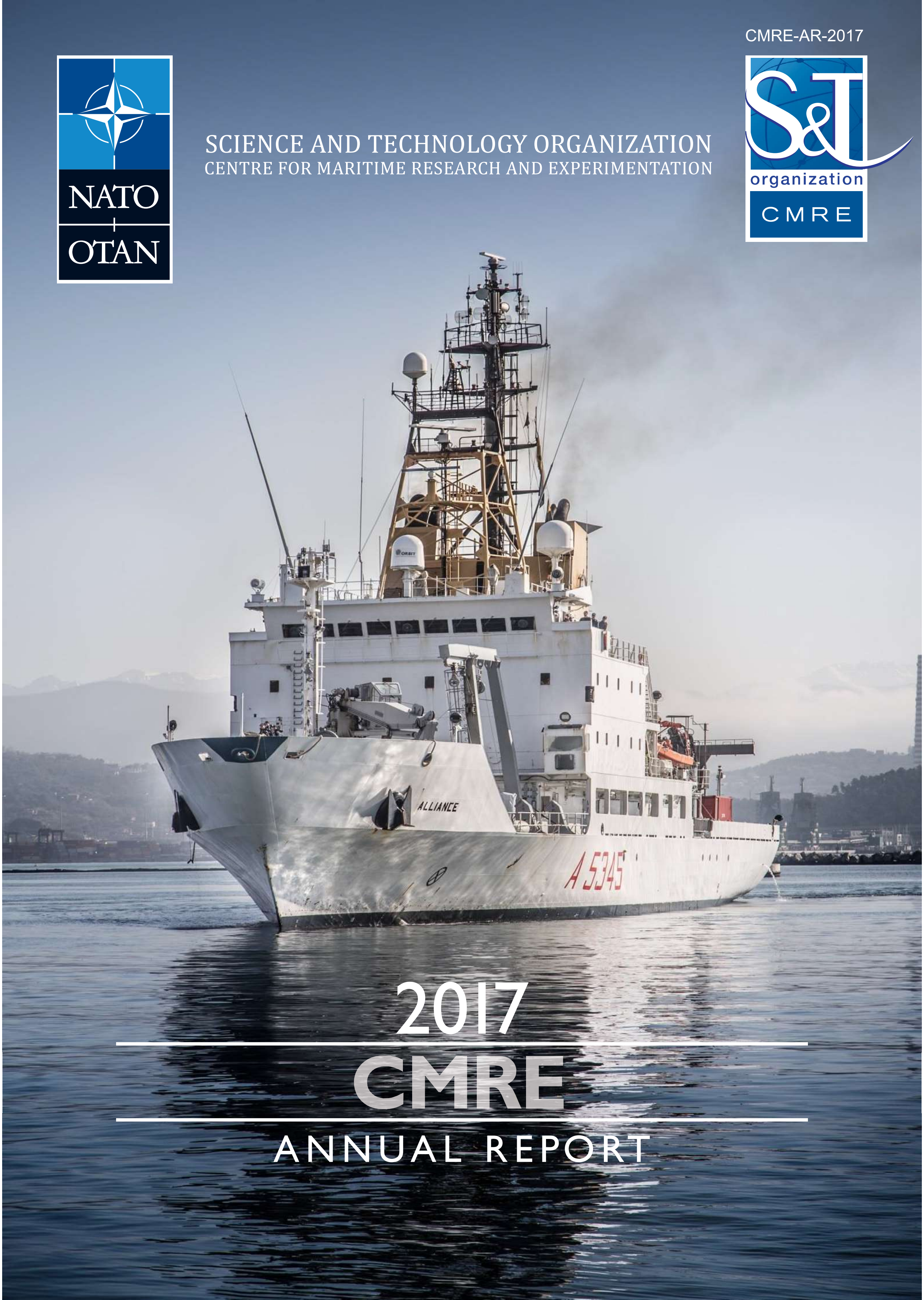
CMRE-AR-2017

NATO
OTAN

SCIENCE AND TECHNOLOGY ORGANIZATION
CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

S&T organization CMRE



2017 CMRE

ANNUAL REPORT

S&T organization

CMRE

March 2019

I began my role as Director, Centre for Maritime Research and Experimentation (CMRE) on 1 November 2017. I consider it a privilege to serve in this position. The mission of CMRE is to organise and conduct scientific research and technology development to deliver innovative and field-tested S&T solutions to the defence and security needs of the Alliance. I know from personal experience that in order to deliver S&T solutions to the military, there must be close and continuing contact between the users and the scientific researchers. The requirements of the final customers play crucial roles in steering laboratory activities, making clear and open communication between operational and scientific communities paramount. Wide-ranging conversations about the intended use of systems in development or the experiment being planned must flow between the customer and the lab to ensure the continued relevance of scientific work. In 2017, the Centre began to broaden the scope of its work from low technology readiness level (TRL) research to demonstrating promising new technologies to operators and industry through an operational exercise programme, conferences and workshops. This is an important step for CMRE to remain relevant to the operational community it serves.

CMRE demonstrated many resounding successes in 2017. Operational relevance was a key theme, including: successful participation in anti-submarine warfare (ASW) serials during NATO exercise Dynamic Mongoose; demonstration of digital underwater communications in NATO's submarine search and rescue exercise, Dynamic Monarch; deployment of autonomous mine hunting capabilities in the Ariadne mine countermeasures exercise led by the Hellenic Navy; and exploitation of maritime decisions aids such as the Rapid Acoustical Prediction Service (RAPS) and the Maritime Patterns of Life (MPOLIS) tool by users at NATO's Maritime Command (MARCOM) and the

Standing NATO Maritime Groups (SNMG) 1 and 2. Furthermore, 2017 was a pivotal year for the Centre's ships, the Coastal Research Vessel (CRV) Leonardo and the NATO Research Vessel (NRV) Alliance, as they completed their first full year of operations under the Italian Navy Flag and operated by Italian Navy crews. It also marked the return of the NRV Alliance to operations in the High North, with battlespace characterization demonstrations in high latitudes for our NATO S&T programme and in collaboration with the Italian Hydrographic Institute. The final month of 2017 was spent preparing NRV Alliance for a charter by the US National Science Foundation to the Iceland and Greenland Seas from January – March 2018. This was Alliance's first trip to the Arctic in the winter in over 20 years!

Looking towards the next years, CMRE undoubtedly will remain a vital organisation to NATO and the Nations by delivering innovative solutions to the challenges of maritime defence and security. The Centre has a key role to play as the maritime collaboration hub for NATO –both in the laboratory and in operational settings at sea. As maritime unmanned systems (MUS) technologies mature, Nations are beginning to procure these systems for operational use. The system-of-systems characteristics of MUS and the requirements for a capability architecture in which MUS can be integrated seamlessly alongside existing legacy systems cater to the strengths of multinational cooperation. Such an approach would ensure the interoperability of MUS solutions adopted by the Nations. In recognition of this in late 2018, defence ministers of 13 NATO nations signed a Declaration of Intent to collaborate in the development of MUS. CMRE looks forward to playing a key role in this collaboration.

I am proud of the work CMRE has done during the past year and am honoured to have been given the responsibility to lead this outstanding organisation. I intend to build on its success by ensuring that the Centre continues to deliver cutting-edge scientific research and operationally relevant experimentation in support of the Alliance's maritime defence and security challenges. I am also committed to improving the business model, with continued diversification of customers and increased access to investment funding to allow for the periodic refreshment of CMRE's S&T infrastructure and facilities.

With pleasure, I submit this report summarizing the scientific, engineering, and business activities accomplished in 2017, along with a detailed financial analysis of the first five years in which CMRE was wholly customer-funded.

Dr. Catherine Warner
Director, CMRE

Programme of work

CMRE's Scientific Programme continues to be dominated by work for ACT, with ten projects responding directly to NATO's Minimum Capability Requirements 2016. The Centre participated also in consortia of seven European Commission projects across a broad spectrum of scientific disciplines, and in partnership with BEL, CAN, FRA, ITA and US bodies, with some chartering of NRV ALLIANCE by USA. Reports on each project are in the Annex. Highlights include:

Cooperative Antisubmarine Warfare

A multi-static network of autonomous underwater vehicles (AUV) was showcased to NATO's Standing Maritime Forces and integrated into tactical operations for validation in an operational setting.

A new decision support tool was demonstrated for planning manned and unmanned ASW operations, to visualise expected performance and allow military operators and scientists to optimise platform dispositions.

A new digital underwater acoustic communications capability, which may render escape and rescue operations more effective, was successfully demonstrated in a NATO submarine escape and rescue exercise.

Collaborative Naval Mine Countermeasures

A demonstration of collaborative mission execution between autonomous systems for naval mine countermeasures was realised in experimentation at sea.

An automatic target recognition (ATR) tool using deep learning (DL) techniques, to ease the load of the operator in detecting and classifying mines with side-looking sonars for wide-area search, was developed.

A planning and evaluation doctrine for autonomous platforms operating side-looking sonars offering improved minehunting performance over that of current MCMVs was drafted

Maritime Situational Awareness

Shipping information, from a wide range of sources and of varying quality, was exploited to identify anomalies, detect suspicious behaviour, and estimate vessel destination. NATO military staff joined civilian stakeholders, including shipping companies, port authorities and maritime intelligence analysts, for a Table Top eXercise, with the goal of better characterising human belief assessment and imperfect information.

A scalable and adaptive multisensor-multitarget tracking approach for maritime surveillance, adaptable to different environmental conditions, was developed using the efficient belief propagation method.

Maritime ISR

US-sponsored Seabed Characterization Experiments proved the concept of using acoustic payloads on underwater gliders to characterize seabed geoacoustic properties.

The use of a fleet of gliders, equipped with acoustic payloads to localize underwater acoustic anomalies, was analysed with the conclusion that the concept is feasible.

Ocean Engineering

The Centre demonstrated technologies to improve AUV on-station endurance, energy replenishment and fast wireless underwater data transfer with high degrees of autonomy and interoperability.

A standards-based capability to support Modelling and Simulation, Verification and Validation, and Concept Development and Experimentation for autonomous systems was developed.

Strategic Development

Introduction

In 2017, the Centre maintained momentum and remained viable against a backdrop of strong financial pressure. Success was achieved with the new operating model for the Centre's ships, which generated a modest net revenue from chartering in the midst of a demanding operational schedule. The Centre continued to deliver the Programme of Work (PoW) on time and with high quality, gaining peer appreciation through Maritime S&T Committee (MSTC) review. Publications in 2017 continued at previous levels.

External recognition for the quality of CMRE's work is apparent from an STO Scientific Achievement Award for the ASW programme, and the Marine Technology Society (MTS) Compass International Award for the Centre's dedication and contribution to the marine industries of MTS members.

Finally, success was demonstrated through closer engagement with MARCOM during maritime exercises and operational experimentation in the high latitudes, which has led to greater understanding and support from the operational community. At the same time, the Centre's network of global academic relationships continued to expand.

Savings, efficiency, and risk

In 2017 CMRE successfully adapted to reduced revenue from ACT through cost-saving measures and some streamlining of business processes. These measures also compensated for the inherently higher overhead costs of a customer-funded organization. Additionally, the current operating model does not include funding for investment to replace ageing equipment and infrastructure, nor to equip CMRE to address emerging S&T interests. This can be tolerated in the short term but endangers the Centre's mission in the long term. Additional revenue was obtained from chartering the Centre's ships NRV ALLIANCE and CRV LEONARDO. In 2017, total ship revenue was 377 k€, a figure that is expected to increase in coming years. The ships are competitive in the current market but this revenue stream is inherently risky as it depends on the reliability of the aging vessels.

Strategic overview

For 2017, the Centre continued to work with ACT to address areas of maritime strategic interest while continuing to diversify its revenue streams, products and services.

From a technical standpoint, 2017 saw several exciting emerging fields, such as the shift in focus from operating individual autonomous vehicles to:

- Collaborative intelligent heterogeneous autonomy,
- The fusion of disparate information streams subject to uncertainty,
- Covert underwater communications.

The Centre also responded to customer requests to widen its focus to cover not only innovative low TRL research, but also a new approach to more directly expose promising technologies to operators and industry through an inclusive operational experimentation (OPEX) programme, conferences and workshops.

Programme of Work and Diversification Initiatives

The Centre's drive to develop diversity in its clients and revenue streams led to several new initiatives, described below.

Operational Engagement

To better support ACT's transformational role in 2017, the Centre participated in the NATO ASW exercise Dynamic Mongoose, which provided the stage to demonstrate the Centre's capabilities in autonomous networked submarine detection. Additionally, the NATO submarine rescue exercise Dynamic Monarch allowed the Centre to demonstrate its work in underwater communications standards in the form of the JANUS digital communications protocol. This expanded business model is in response to requirements set by ACT and MARCOM, and is designed to provide a short-cut in the traditional technology transfer chain by bridging the gap between prototype technologies and operational systems.

Out-Reach Programme: Industry and Nations

As part of this broader development and involvement of industry and national stakeholders, the Centre partnered with a commercial event organiser to deliver an international conference; 'Naval Domain Intelligence' in Livorno in October 2017, attended by Standing NATO Maritime Group 2 and key industry players. The aim of the engagement was to:

- Identify opportunities for collaboration among Nations and Industry;
- Provide a discussion forum for Nations to share plans and aspirations in order to identify opportunities for coordination; and
- Identify opportunities for S&T development in the MUS domain that could be included in CMRE's Programme of Work.

Multinational Projects

At the April 2016 MSTC meeting, the Director of CMRE asked the Nations to propose areas of interest for collaboration. The following topics were identified:

- Low Frequency Synthetic Aperture Sonar
- Secure Underwater Communications
- Battlespace Characterisation at High Latitudes

In 2017 CMRE held workshops in these areas with the goal of establishing Multi-National Joint Research Projects (MN-JRP).

Maritime Unmanned Systems Declaration Letter of Intent

It is widely recognised that Maritime Unmanned Systems (MUS) have enormous potential to contribute to solutions in the domains of Anti-Submarine and Naval Mine Warfare. However, the majority of NATO Nations have not yet defined their vision on how to harness this potential. Pursuing MUS capabilities by individual Nations would cost more and require additional work to ensure interoperability. Exploitation of MUS by NATO requires a capability architecture in which multinational MUS can be integrated seamlessly alongside existing legacy systems. To this end, a Letter of Intent was written, with the engagement of the Assistant Secretary General, Defence Investment, by which signatories have declared their intent to jointly investigate collaboration opportunities leading to the introduction of MUS capabilities to the Alliance. So far, thirteen Nations have signed, and the first meeting of the Steering Committee will take place in February 2019 at CMRE. The Director/CMRE has a seat on the Steering Committee.

NATO Maritime Information Services

CMRE is well placed to play a prominent role in TRITON, a NATO-funded programme that will deliver NATO's future maritime Command and Control system. The Centre is currently in dialogue with key stakeholders including ACT, MARCOM and NCIA, to develop a programme of work in this area.

Coalition Warrior Interoperability (CWIX) Exercise Participation

With the support of ACT, CMRE expanded its participation in CWIX 2017 as an opportunity to reach out to operators and expose promising technologies that the Centre is developing, such as the Rapid Acoustical Prediction Service (RAPS). Both CWIX and CMRE's participation in the recent Dynamic Mongoose ASW exercise delivered positive results for ACT and MARCOM.

European Commission – Maritime Demonstrator Ocean 2020

CMRE was successful in winning the European Commission's (EC) Maritime Demonstrator (MD) Ocean2020 project. This initiative is funded by the EC and will be executed in two sea trials, one each in 2019 and 2020. This is the initial phase of the EC's (much larger) Preparatory Action on Defence Research (PADR) which will focus on defence research and the sustainment of military capabilities in Europe. PADR is expected to develop into a larger "Research Window" in the next EC Framework Programme.

High Latitudes campaign

The High Latitudes area emerged in 2017 as the 'place to be', with support and strategic direction from ACT and MARCOM. Good progress was made during the 2017 NORDIC Recognised Environmental Picture Exercise (NREP), which included the Italian Hydrographic Service, along with a number of Nations. NREP took the NRV ALLIANCE to 76°N.

Ships' Services

A major achievement of 2017 was the success in marketing NRV ALLIANCE and CRV LEONARDO ship services to the Nations. The US National Science Foundation (NSF) has chartered NRV ALLIANCE in 2018 for a lengthy scientific cruise in the high North. This activity is expected to contribute significant revenue.

Demand in the research ship charter market varies, as for any commodity, from year to year. The Centre is fortuitously benefitting from a period in which the NATO vessels are sought after, partly due to a global shortfall in capacity. The vessels are also competitively priced as a result of recently implemented cost savings and efficiency measures.

Financial Planning and Savings

The financial pressure on CMRE continued in 2017, as the Centre adapted to ACT's revenue 'glideslope', with ACT's revenue contribution reduced to €18.5M by 2020. This will be the culmination of a reduction by some 30 percent of ACT's business with the Centre over a 5 year period.

Revenue

ACT Future Solutions (FuSol) remains the Centre's core customer. In 2017, the ACT Maritime S&T Programme of Work represented 89 percent of total revenue, with the remainder coming from other NATO Organisations and Nations, the European Commission (EC) and ship services. In 2018, the budgeted ACT FuSol programme will be reduced to 80 percent of total revenue. This percentage is planned to decrease to 74 percent in 2020. An overview of the Centre's finances is presented in the next section.

Financial Overview

Main Achievements

NATO's decision to move CMRE to a customer-funded business model in 2013 presented significant challenges for business processes, and managerial and financial accounting. However, the Centre has been successful in making the transition to customer funding and has diversified its customer base to include many national- and EC-funded projects.

Of particular note is the transition of vessel NRV ALLIANCE from a contracted crew to an Italian Navy crew, resulting in savings on operations. The introduction of a vessel reserve within the net equity of the Centre has allowed CMRE to maintain a stable, competitive day rate across the cycle of dry docks and has provided funding for the transition to Italian Navy operation.

The Centre's financial statements show that the Centre is in a sound financial position with adequate resources for operations, including resources to maintain its vessels. However, the Centre does not have resources to invest in modernisation of S&T infrastructure, nor the ability to conduct internally funded, innovative research. The efficiency of the Centre in terms of its customer rates, overhead ratio and vessel day-rates has improved, as described below.

Main Challenges

Maintaining an adequate business volume was a challenge in 2017. In order to operate with economies of scale and deliver value for money, the assets and capabilities of the Centre must be fully employed. Expanding business with Nations and other NATO programmes remains a priority.

In order for CMRE to continue to act as a collaboration hub and deliver value to the Nations' science and technology programmes, capability developers, and military operators, NATO must invest to modernise CMRE's S&T infrastructure. The NRV Alliance is 30 years old and many of the Centre's autonomous vehicles are almost 20 years old. Replacement of high-cost facilities, vessels and equipment is not included in the Centre's customer rates. Finding alternative funding sources for these initiatives is paramount.

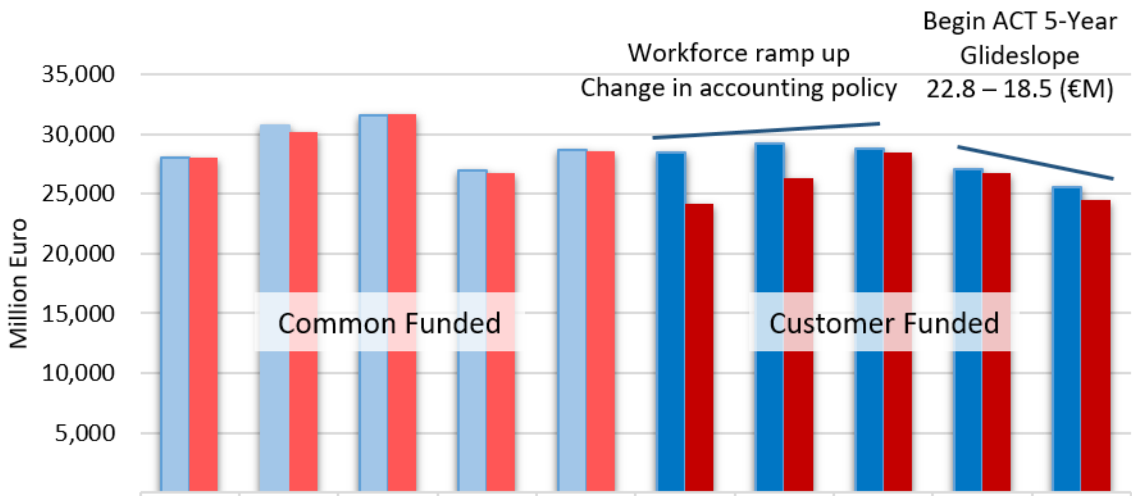
The Budget and Finance Department is making preparations to implement a significant update to FINS, its Oracle-based financial system, in 2019 – 2020, which will provide a project-based financial environment and provide improvements in transparency and reporting. This will result in more effective and efficient project management and will aid business analysis.

Revenue

Prior to 2013, the Centre was common-funded, at a level typically of around €28M. Revenue increased above this primarily due to end-of-year supplemental funding and revenue to procure equipment, maintain vessels and conduct dry docks (from a small programme of supplemental work for the Nations).

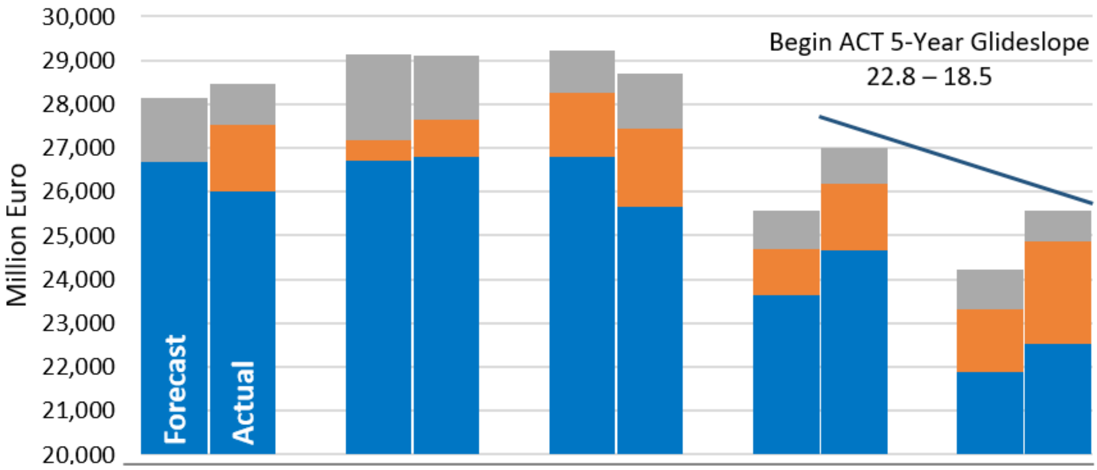
Beginning in 2013, the Centre moved to project-based customer funded model. In the same year, NATO implemented International Public Sector Accounting Standards (IPSAS). A 10-year history of Revenue and Expense, shown in Figure 1, reveals large differences between revenue and expense in 2013 and 2014, which were driven by the change in accounting policy (revenue recognition) and the need to hire staff following a hiring pause during NATO's agency review (2010/11). In later years, the Centre's largest customer (Allied Command Transformation) began execution of a phased reduction in its programme of work, which systematically reduced overall revenue and expenditure.

In 2017, the Centre's turnover was €25,578,638 against an initial Financial Plan forecast of €24,220,000. The Centre out-performed its plan as a result of additional business with NATO, Nations and the EC. Forecasting revenue has been challenging particularly for EC consortia projects given the long lead-time between proposal and award, and a highly competitive selection process. Figure 2 compares the revenue forecast made in the financial plan with the revenue reported in the financial statements. Beginning in 2016 the Centre applied a more conservative revenue estimation process in light of lessons learnt, to reduce risk during the planned reduction in the ACT programme. In these years, diversification efforts also began to bear fruit and revenue exceeded the forecast. In 2017, CMRE revenue exceeded the plan by €1.1M or six percent.



	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
Revenue	28,015	30,697	31,611	26,955	28,717	28,477	29,164	28,774	27,054	25,579
Expenses	28,069	30,129	31,657	26,731	28,539	24,204	26,299	28,409	26,687	24,525

Figure 1 - Ten year history of Revenue and Expense (€M)



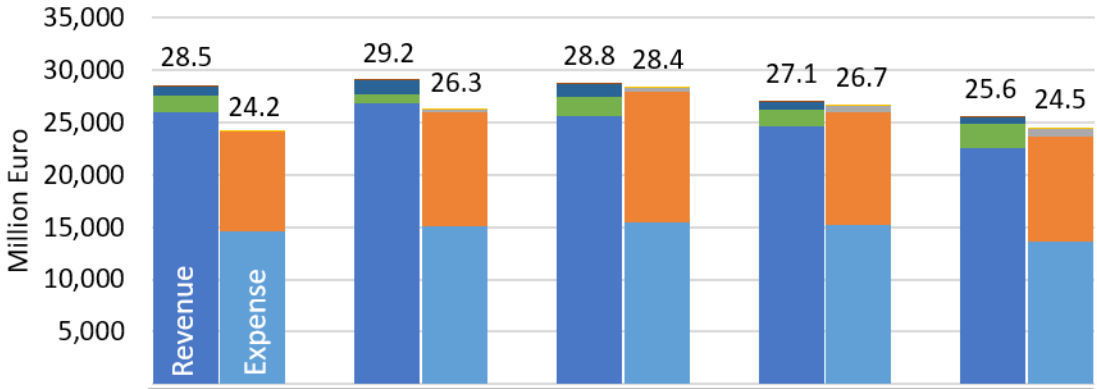
	FY 2013 Plan	FY 2013 Actual	FY 2014 Plan	FY 2014 Actual	FY 2015 Plan	FY 2015 Actual	FY 2016 Plan	FY 2016 Actual	FY 2017 Plan	FY 2017 Actual
NATO Bodies	26.670	25.993	26.709	26.805	26.788	25.665	23.639	24.655	21.888	22.538
NATO Nations		1.547	482	851	1.475	1.774	1.051	1.538	1.441	2.326
International Org	1.459	929	1.957	1.460	950	1.248	892	821	891	698
Financial Revenue		7		48		87		39		17
	28.129	28.477	29.148	29.164	29.213	28.774	25.582	27.054	24.220	25.579

Figure 2 - 5 Year Summary of Financial Plan Forecast Revenue and Actual Revenue (Note that the scale starts at €20 M to show more detail).

n Figure 3, the impact of the change in accounting policy can be seen in supplies and services expenses. Following the conclusion of the annual sea-going programme, CMRE restocks, repairs and maintains the vessels and major sea-going equipment such as gliders, AUVs and instruments. A significant portion of the replenishment goods arrive early the following year. These expenses are then recorded in the following year.

The personnel expenses in fiscal year 2013 show the impact of the NATO-wide soft hiring pause in 2011/2012 and the impact waiting for security clearances before staff could assume their duties. Large numbers of Visiting Researchers made up the shortfall. From 2017, personnel expenditure declines in response to the reduction in the ACT programme.

From 2015, revenue and expenditure are more closely aligned. Financial revenue includes interest and exchange rate gains,



		FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
Revenue						
NATO Bodies		25.993	26.805	25.665	24.655	22.538
NATO Nations		1.547	851	1.774	1.538	2.326
International Org		929	1.460	1.248	821	698
Financial Revenue		7	48	87	39	17
		28.477	29.164	28.774	27.054	25.579
Personnel Expenses						
NATO Civilian (Note 1)		13.051	13.782	14.578	14.853	13.185
VRP/Consultant		1.057	486	302	226	250
Sea Going Allowance		122	120	127	94	151
Engineering Contractor			119	125	(Note 2)	
ILAB Contractor		384	600	300		
		14.614	15.107	15.432	15.173	13.586
Supplies & Services						
PoW Projects		1.801	862	375	1.080	1.202
Administration		1.378	1.633	1.753	1.354	1.679
Vessels		4.593	4.759	5.926	4.723	3.620
Engineering		1.125	1.543	1.779	1.838	1.846
ILAB	(Note 2)	612	2.079	2.649	(Note 2) 1.802	(Note 2) 1.757
		9.510	10.877	12.482	10.798	10.103
Depreciaion		55	278	457	690	726
Financial Costs		26	37	38	26	109
		81	316	495	716	835
		24.204	26.299	28.409	26.687	24.525

Figure 3 - 5 Year Summary of Revenue and Expense (€M)
Note 1. NATO Civilian expenses include recruitment, joining and removal costs.
Note 2. Beginning in 2016, contractor support was moved into supplies and services as a result of audit. observations.

CMRE's main customer is Allied Command Transformation (ACT), with the work built around two main ACT Programmes:

1. Autonomous Security Networks

a) Antisubmarine Warfare (ASW)

b) Mine Countermeasures (MCM)

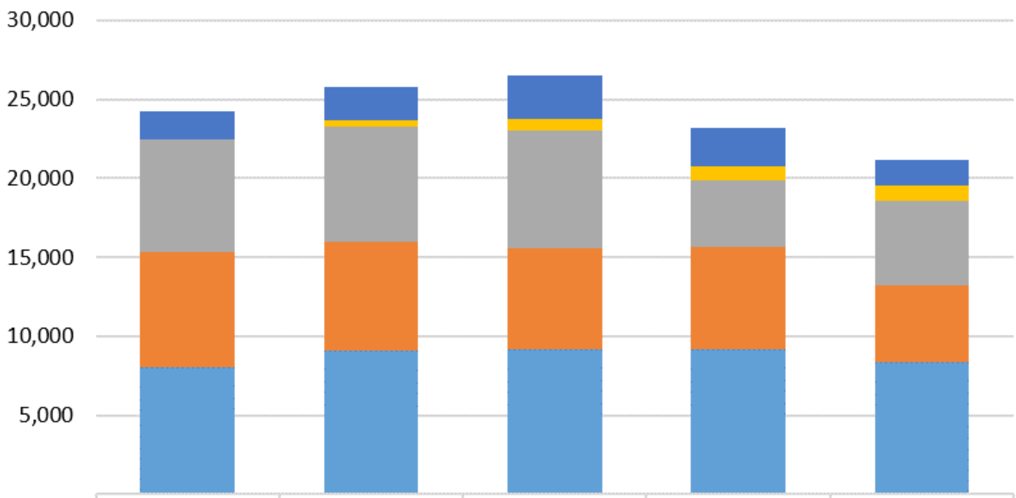
c) Persistent Autonomous Reconfigurable Capability (PARC)

2. Environmental Knowledge Operational Effectiveness

a) Data Knowledge Operational Effectiveness (DKOE)

b) Environmental Knowledge Operational Effectiveness (EKOE)

The revenue realised in each CMRE programme area from 2013 to 2017 is shown in Figure 4. The impact of the planned reduction in the ACT programme is seen in 2016 and 2017.



	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
DKOE	1,784,064	2,064,575	2,795,649	2,430,000	1,674,598
PARC		374,000	749,300	946,000	910,781
EKOE	7,146,072	7,306,861	7,404,473	4,200,000	5,389,409
MCM	7,237,904	6,913,970	6,397,166	6,428,000	4,860,263
ASW	8,075,838	9,091,241	9,193,556	9,207,557	8,361,705

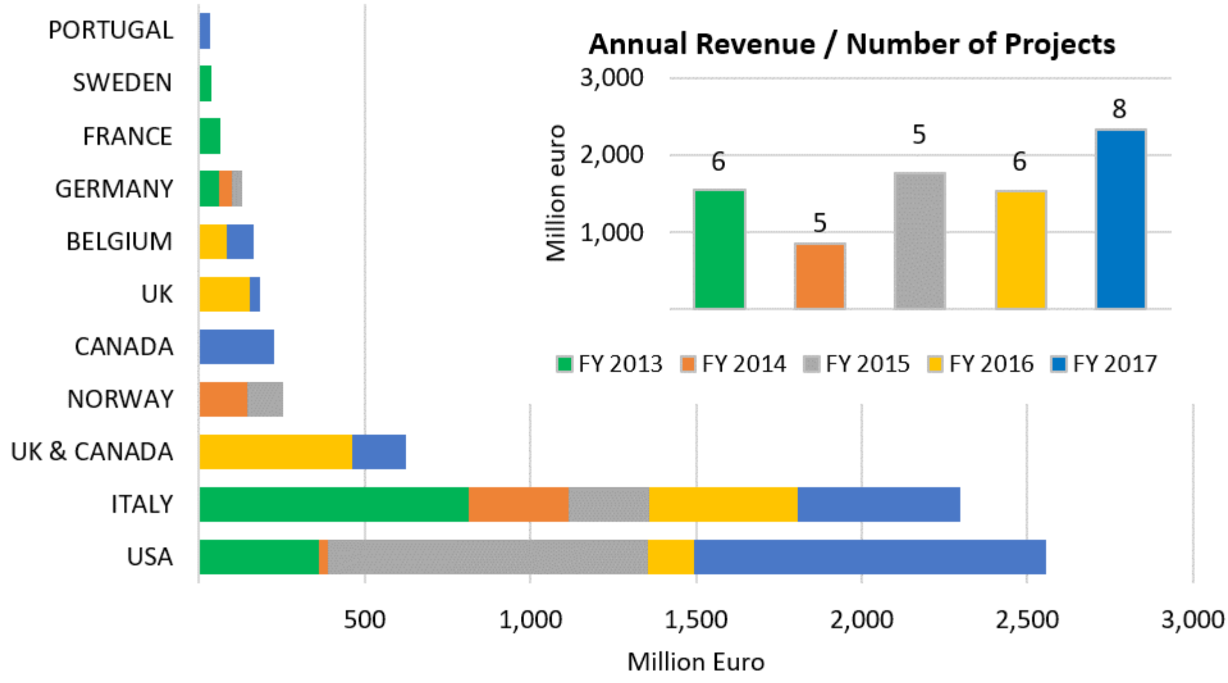
Figure 4 - Summary of Trends in the ACT Programme (€M)

Figure 5 shows revenue from the Nations over the past five years. The trend has been a gradual increase from €1.547M in 2013 to €2.236M in 2017.

In 2017, the total number of projects from Nations was eight, up from six in 2013.

The contributions of EC Consortia projects to the Centre's revenue are shown in Figure 6. The Centre participated in the Framework 7 Programme for Research and Technology Development (FP7) and in Horizon 2020. Horizon 2020 is implementing the European environmental research and innovation policy with the goal of establishing an environmentally sustainable economy in Europe.

CMRE's revenue from the EC initially declined with the rollout of Horizon 2020; however, there are significant opportunities in 2018 and beyond through the EC's Preparatory Action on Defence Research (PADR).



5 - Revenue from National Projects between 2013 and 2017

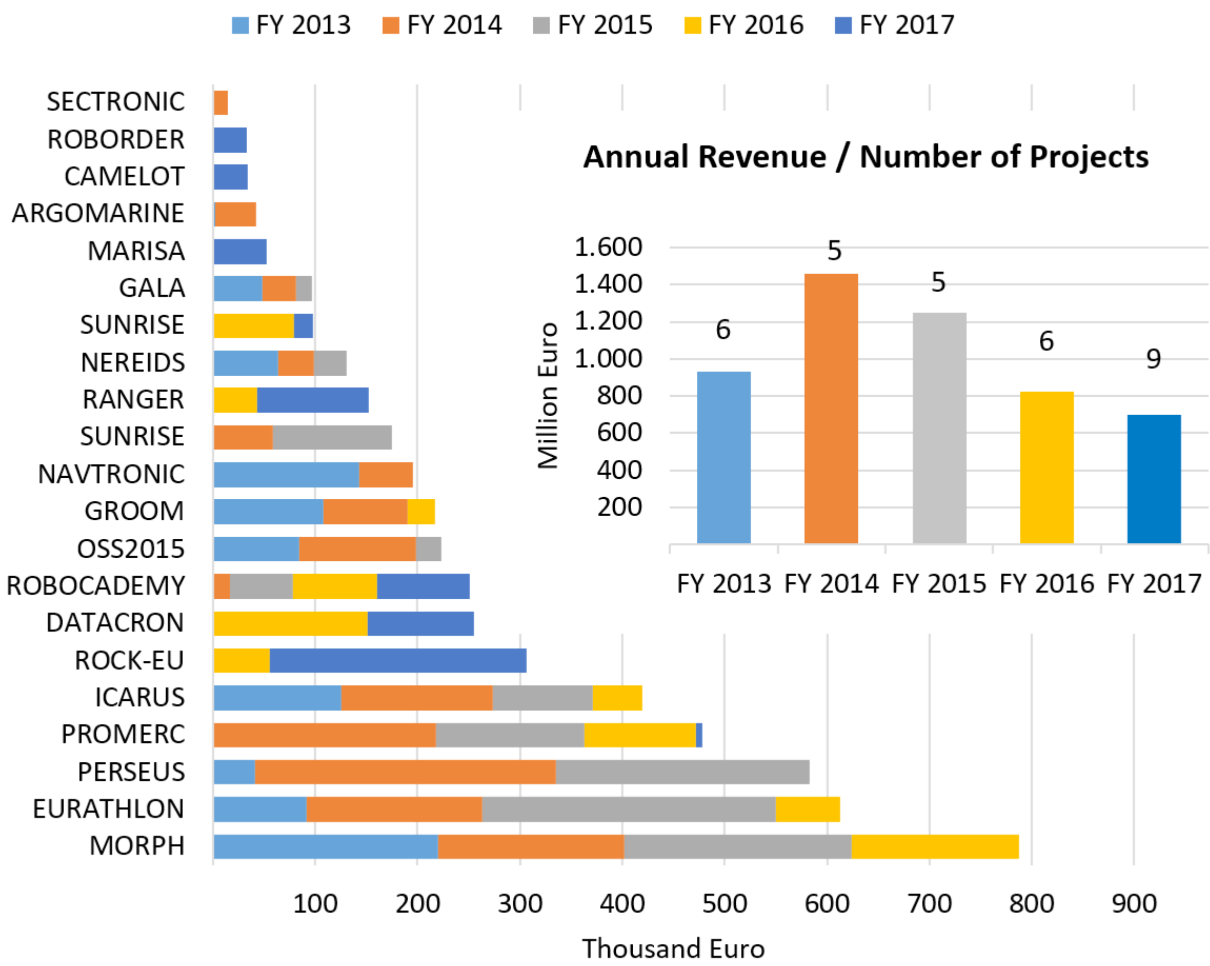


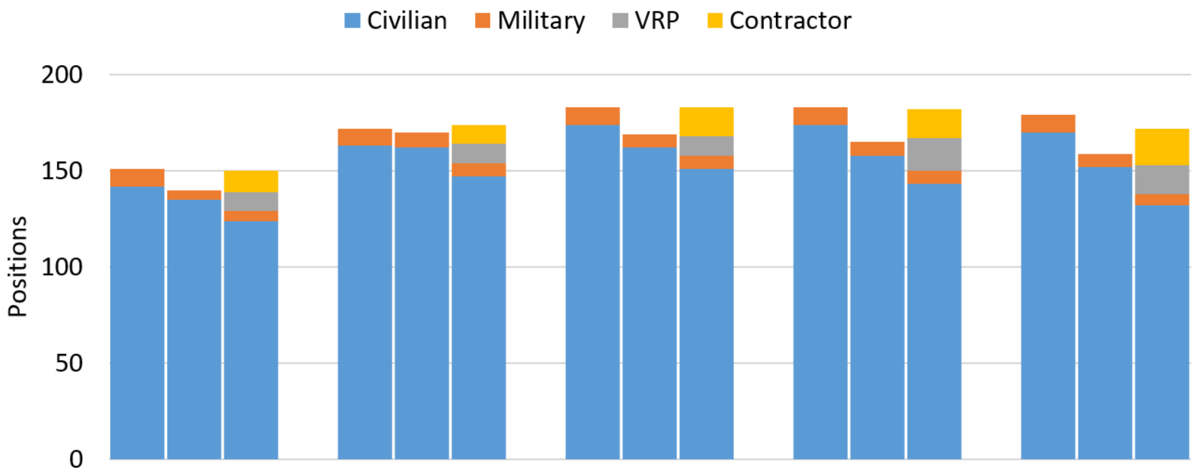
Figure 6 - Revenue from EC Projects between 2013 and 2017

Workforce

The Centre, in agreement with the NATO Science & Technology Board (STB), establishes a yearly Personnel Establishment (PE) based on the needs of the Centre. This defines a ceiling on the number and distribution of positions and includes room to hire additional staff should additional work be won during the fiscal year.

The Centre establishes its initial funded workforce via the annual Financial Plan (FP). The FP is a forecast of planned revenue and expenditures including personnel. In execution there are many factors that affect which new hires can assume their duties in-year and when. The most significant factor is the need to receive a security clearance before assuming duty. Provision of security clearances is a national responsibility and can take from six months to more than a year.

To ensure CMRE can meet its contractual obligations, the Centre has a long-standing programme to hire visiting researchers on a temporary basis, with contract duractions ranging from three months to one year.



	FY 2013			FY 2014			FY 2015			FY 2016			FY 2017		
Workforce	PE	FP	Actual	PE	FP	Actual	PE	FP	Actual	PE	FP	Actual	PE	FP	Actual
Civilian	142	135	124	163	162	147	174	162	151	174	158	143	170	152	133
Military	9	5	5	9	8	7	9	7	7	9	7	7	9	7	6
VRP			10			10			10			17			15
Contractor			11			10			15			15			19
	151	140	150	172	170	174	183	169	183	183	165	182	179	159	173

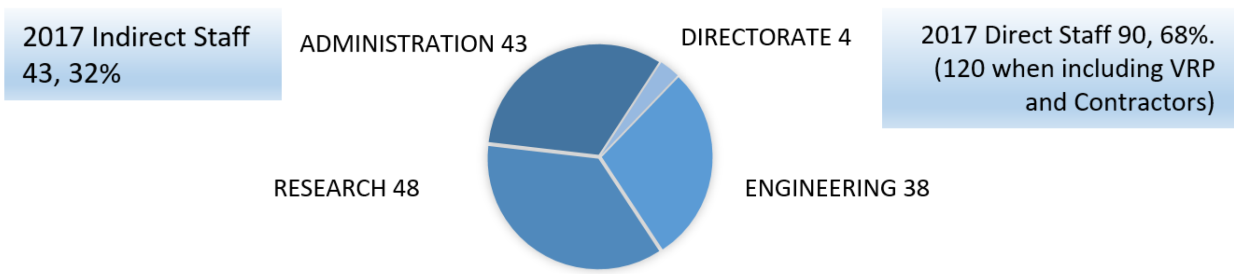


Figure 7 - Overview of the CMRE Workforce, PE = Personnel Establishment, FP = Financial Plan

Contractors and consultants are also used extensively. CMRE has several contractual arrangements for security-cleared personnel based on specific profiles. These mechanisms provide the agility needed to meet customer requirements. Figure 7 shows the workforce profile for the past five years. The pie chart at the bottom of Figure 7 shows the breakdown of positions in 2017 by organisational area. Administration is the indirect workforce and represented 32 percent of the NATO civilians on board at the end of 2017. The direct workforce is made up of scientists, engineers and directorate staff and represents 68 percent of NATO civilians. Additional visiting researchers (VRP) and contractors augment the direct workforce. The total workforce count exceeds the financial plan forecast because multiple VRP's and contractors may be employed for short periods.

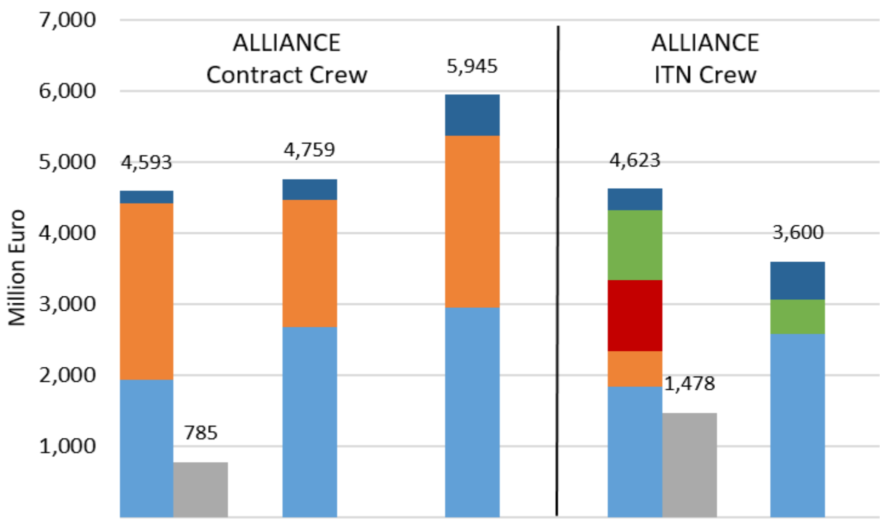
Vessels

The Centre operates two research vessels, Coastal Research Vessel LEONARDO and NATO Research Vessel ALLIANCE.

Figure 8 shows the operational and maintenance costs for the vessels, including the cost of transitioning ALLIANCE to Italian Navy crewing and dry docking costs.

The largest cost for ALLIANCE was the cost of the contract crew. From 2014, ALLIANCE operated in an Enhanced Efficiency Model in which the vessel was fully crewed during planned periods of availability and minimally crewed when not required for at-sea operations, commensurate with Flag state requirements. The impact of this model can be seen in 2015 when ALLIANCE went to sea for 160 days. Even with the increased operational tempo, crew costs were lower than in 2013 when ALLIANCE went to sea for 124 days. Beginning in early 2016 the contract crew was phased out and replaced by an Italian Navy complement. CRV Leonardo transitioned to an Italian Navy crew in 2012.

Dry docking of ALLIANCE takes place twice in a five year cycle. LEONARDO major upkeep is included in the O&M figures.



Vessel O&M	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
Alliance O&M	1.944	2.683	2.952	1.837	2.576
Alliance Crew	2.474	1.790	2.411	498	
Leonardo O&M	175	286	581	294	531
Transition Costs				1.001	
ITN Conversion				993	493
Total O&M	4.593	4.759	5.945	4.623	3.600
Alliance Dry Dock	785			1.478	
Sea Days					
Alliance	124	77	160	122	193
Leonardo	104	164	170	136	130

Figure 8 - Vessel Operations and Maintenance Costs

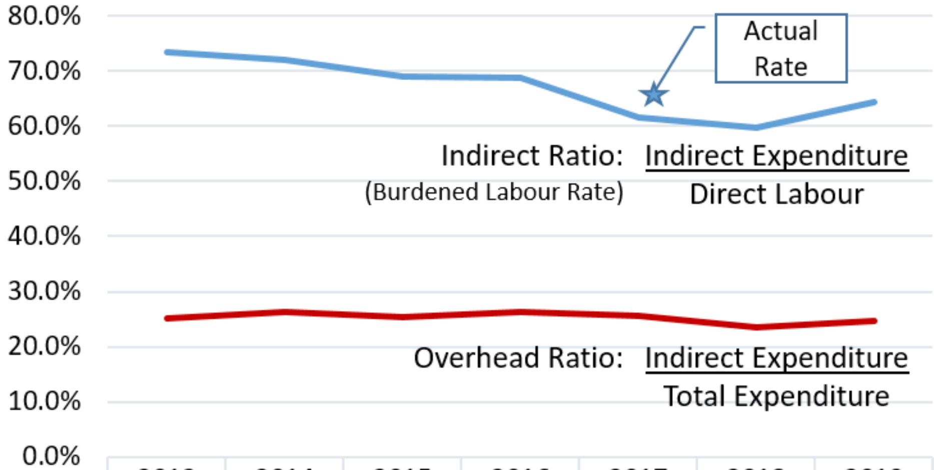
Customer Rates

CMRE uses two types of customer rates to recover costs. Since labour is the main component of the Centre's projects, a burdened labour rate (labour cost plus overhead) is calculated each year as shown in Figure 9 and Table 1.

Some customers, notably the EC, require the use of an overhead ratio and provide a standard 25 percent overhead reimbursement on project costs. The Centre's rates are compatible with this overhead ratio.

Daily rates for the most frequently requested grades are shown in Figure 9. The trend is reducing over time. This is the result of a leaner workforce structure and changes in compensation policy that reduce the cost of new hires. The foundation of the rates is the average actual compensation paid for each grade. This varies with family composition and length of service.

An analysis of customer rates shown in Table 1 shows the effect of unfilled civilian positions. These occur primarily in the direct workforce so the actual payroll cost for direct staff is reduced, which increases the actual burdened labour rate. Even though the burdened labour rate increases in execution, total labour costs decreased leading to savings in execution. CMRE augments its civilian workforce with temporary visiting scientists and contactor support to mitigate the vacancies.



	2013	2014	2015	2016	2017	2018	2019
Indirect Ratio	73.5%	72.0%	69.0%	68.8%	61.6%	59.8%	64.3%
Overhead Ratio	25.1%	26.2%	25.4%	26.4%	25.7%	23.5%	24.7%
A4	1.455	1.392	1.381	1.356	1.388	1.385	1.318
A3	1.223	1.185	1.163	1.098	1.101	1.075	1.073
A2	931	945	912	841	833	839	856
A1	753	593	611	573	598	572	626
B6	871	893	886	832	891	817	825
B5	752	708	752	695	699	677	715

Figure 9 – Summary of approved customer rates 2013-2019

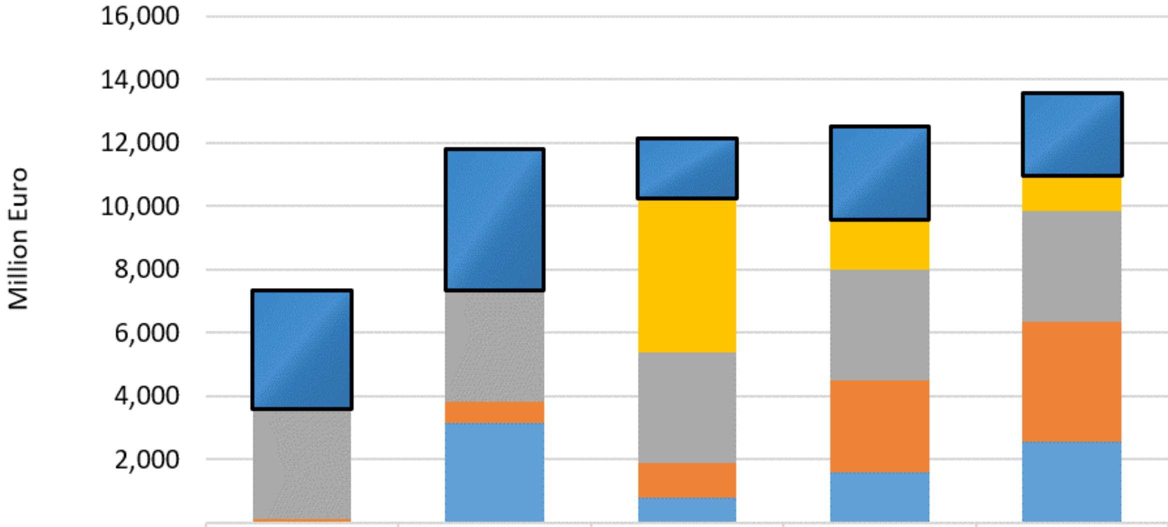
Table 1 Burdened Labour Rate Comparison - Civilian Staff (M€)

2017 Customer Rates	Total Workforce	Direct Staff	Indirect Staff	Overhead Costs	Rate
Financial Plan (avg salary)	14.380	10.104	4.276	1.950	61,6%
Price Proposals (avg salary)	14.788	10.512	4.276	1.950	59,2%
Actual Payroll	12.707	8.751	3.955	1.875	66,6%
Variance	2.082	1.761	321	74	

Net Equity

The Centre applies International Public Sector Accounting Standards (IPSAS) to its activities. CMRE's Net Equity, which is the difference between the value of business assets and liabilities, is a measure of its health. To improve transparency, the Centre's Net Equity has been arranged into five different accounts or reserves as shown in Figure 10.

The commitments reserve includes resources set aside to pay for goods that are ordered in one year, but arrive in the next. The depreciation reserve provides an offset for future depreciation expenses for the Centre's assets. The net equity fund, €3.5M, was established by the Science and Technology Board as a buffer for unforeseen expenses and may be accessed only with board consent. The vessel reserve provides for future major upkeep activities and is where CMRE accumulates funds from regular vessel operations and disburses them for dry docks and other major expenses. This allows the Centre to maintain a level vessel day rate across multiple years.



	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
General Reserve	3,736	4,456	1,894	2,927	2,612
Vessel Reserve			4,853	1,609	1,115
Net Equity Fund	3,500	3,500	3,500	3,500	3,500
Depreciation Reserve	109	675	1,092	2,904	3,769
Commitments Reserve		3,151	808	1,575	2,572
Total Net Equity	7,345	11,783	12,147	12,514	13,568

Figure 10 – CMRE net equity

The general reserve, which is accumulated from gains/losses on activities, provides a buffer for operations, for example by absorbing project losses. These funds can provide resources for investment in equipment and facilities. The general and vessel reserves are used in operations.

When CMRE was established, the general reserve was created from profit made by the predecessor (NURC) chartering the vessels. The general reserve grew due to savings on operations and growth in business. In 2015 a significant portion of the general reserve was used to establish the vessel reserve in anticipation of the transition to operation by the Italian Navy and to fund a major upkeep period (dry dock). Since then the general reserve has been used as a source of funds for investment.

Three significant investment initiatives are under consideration. First, the IT Rationalisation Project was briefed to the NATO S&T Board in March 2018 and is focused on a move to enterprise shared services, new ways of working including virtualisation and improved information management processes and tools, and improvements to our security posture.

Second, to improve our facilities, the Centre, in partnership with the host nation, is investigating the transfer and conversion of an unused building near CMRE for hosing and de-hosing acoustic arrays. This would replace a facility that has degraded due to unstable foundations.

Third, CMRE is exploring submissions to the NATO Security Investment Programme (NSIP) to modernise its science and technology tools and facilities.

Conclusion

CMRE has successfully transitioned to a customer funded business model and is financially sound in the short-term. This business model does not provide for major capital investment such as vessel or autonomous vehicle replacement, nor major facilities acquisition or renovation. This is the key challenge for NATO policy makers if Nations wish to retain an in-house maritime research centre for collaboration and experimentation.

Contracting

In 2017, the CMRE Contracting and Customs office processed approximately 970 contractual actions, worth a total of 10.7M Euro.

Contracts have been awarded to companies from 21 different nations - the first three being Italy (38 percent), UK (31 percent) and the US (12 percent) – using six different currencies.

In the same year, CMRE signed contracts and inter-agency agreements with other NATO bodies for approximately €0.9M as part of the Shared Services initiatives for the provision of support services in areas such as Information Technology (IT), Human Resources (HR) and Legal.

In the same year the office also managed approximately 200 customs and transportation related actions in support of the Centre's activities.

Key Procurement highlights

Ship maintenance contract

In 2017 CMRE awarded, for the first time (previously the contract was awarded and managed by the ACT Procurement Office), the contract for Technical Support to NATO's research vessels NRV ALLIANCE and CRV LEONARDO, worth approximately €15M over the five years from 2017-2021, including dry-dock maintenance. The contract was awarded to the firm Anglo Eastern (UK) Limited, based in Glasgow, via international competition using best value source selection procedures. The previous contractual arrangements for NRV ALLIANCE technical support, administered by ACT's Contracting Officer, were fully based on cost-reimbursement (apart from the firm-fixed price management fee). The CMRE 2017 contract instead shifted risk to the contractor by envisioning planned preventive maintenance, the most costly item of the contract, as a firm-fixed price item. After 11 months of contract performance and having just processed the task order for the 2018 dry-dock (1.4M Euro), we can report the contract is progressing in a satisfactory manner for both NATO and Anglo Eastern (UK) Limited.

Custodial & Porterage services

As part of the CMRE2025 proposed efficiency cost saving measures, the five-year Custodial and Porterage services requirement has been revised and the contract re-competed internationally, delivering an average annual saving of approximately 160K Euro compared to previous years.

Electricity

The power and electricity contract was re-negotiated with the Italian provider ENEL at a more favourable rate than the previous arrangement with the Italian Navy, resulting in an average annual saving of €62K (approximately 24 percent compared to the previous six years). This target saving was also included in the CMRE2025 report.

IT professional support Basic Ordering Agreements (BOAs)

In November 2017, CMRE launched a competition for a new five-year framework agreement to provide IT support services to the Centre. The competition resulted in 16 BOAs, to be awarded in March 2018, based on best value, each potentially worth from €400K to €750K per year. These BOAs provide flexibility to augment CMRE's professional IT pool with highly qualified IT engineers and other professionals in eight areas, including software developers, modelling and simulation experts, computer/network technicians, scientific computing experts and network/security specialists.

Research Vessels

For the CMRE vessels, NRV ALLIANCE and CRV LEONARDO, 2017 was a pivotal year, as they completed their first full year flying the Italian Navy (ITAN) Flag and operated by military crews under the terms of the Memorandum of Understanding. It also marked the return of ALLIANCE to operations in the High North, and to increased tempo of experimentation in an operational environment.

CRV LEONARDO

The year started for LEONARDO with a special survey dry dock undertaken in the Italian Navy Base in La Spezia and executed by CMRE's Ship Management Office. Having emerged from this dock on time, on budget and fully reclassified, the vessel was tasked with Italian Navy activities for much of May and June. This was followed by an activity in support of the US DoD's Defence Prisoner of War/Missing in Action Accounting Agency (DPAA), when the special skills and equipment of CMRE and the Italian Navy were utilised to investigate aircraft wrecks from previous conflicts. The mission was very successful and identified previously undiscovered wrecks around the coasts of Italy and Corsica. The data are still being evaluated, but it is hoped that once verified, the families of missing service people in the US may be given more information about their loved ones.

The remainder of the year was spent conducting NATO scientific tasks in local waters. Finishing the year's activity with 129 days at sea, LEONARDO continued to prove its own utility as a versatile and efficient platform for small scale scientific projects at sea.

ALLIANCE

NRV ALLIANCE commenced the year in support of noise measurements for ITAN ships and submarines. This was followed by a multinational trial in Greece in support of the CMRE MCM programme. After a short maintenance period, ALLIANCE returned to the North Atlantic and the High North. Participation in Exercise Dynamic Mongoose, trials for the EKOE programme and ITAN activities as far north as 76 degrees were some of the highlights of a busy summer period. It also reprised the CMRE and ITAN ability to operate the vessel at long range in remote locations.

In October, ALLIANCE participated in experimentation in an operational environment with the Standing NATO Maritime Group 2 (SNMG2) conducting activities in the Eastern Mediterranean before returning to La Spezia for repairs following a main engine failure. Although back in port, activity did not let up as the ship was prepared for further polar operations in extreme conditions during the early part of 2018. Completing 171 days at sea, ALLIANCE remains a core component of CMRE's scientific capability.

A redesign of the technical support arrangements for both vessels was also seen in 2017. In order to provide a more efficient and responsive arrangement, a NATO international competition was launched to provide a bespoke technical support contract. The competition produced a more cost efficient and effective method of delivering support to the vessels through the introduction of the ISO 9001 2008 accredited Asset Management system for the vessels. The vessels remain in high demand for NATO, National and academic use, demonstrating their capabilities on a worldwide basis.

Security Office

Apart from advising and supporting on security matters, the Security Office implements physical, personal, and CIS (Communication and Information System) security, ensuring compliance with NATO regulations and directives.
As the Centre is located in an Italian Navy (ITN) compound, Centro di Supporto e Sperimentazione Navale (CSSN), the Security Officer also fills the role of ITN Liaison Officer; coordinating with local authorities and Navy commands, including the chain of command of the Centre's ships. The Security Office also coordinates closely with the Carabinieri assigned to the Centre by the Host Nation for physical security and guard duty.
Given the large number of trials, visits and events, as well as the security inspection by the NATO Office of Security (NOS), 2017 was a busy and productive year.
The Security Office coordinated and planned internally for the NOS inspection held at CMRE in July 2017. Actions and initiatives taken from previous years, improvements in the security posture and increased cooperation between departments and offices (ILab, Registry, and Contracting) resulted in a successful inspection. The NOS Team reported positive results and expressed appreciation to the entire CMRE Security Staff.
The Security Office contributed to the security and coordination with CSSN for the preparation and execution of the European Project SUNRISE final review meeting and demonstrations held in February 2017. The logistics and support were explicitly mentioned by the EC project officers and reviewers.
The Security Office also participated in the organization and management of the visit to the Centre by the World Maritime University. As most of the students were from non-NATO Countries, coordination and security support was critical to ensure a smooth and successful visit. The Centre received appreciative messages from WMU for the invaluable contribution to the capacity- and knowledge-building for their students.
Security and the CIS Security Officer worked closely with the ITN HQ, Technical/Operational Commands, CMRE's Ship Management Office and ILab to support the program for NRV ALLIANCE's C2 upgrade, which included installation of classified communication systems. Based on agreements with ITN and the ship program requirements, ITN satellite and radio equipment have been provided on loan. The required minimum C2 capabilities in radio and satellite communications were achieved on the vessel before its departure for the High North deployment in May 2017, which included two major scientific trials and the participation in NATO exercise Dynamic Mongoose 2017.
The Security Office continuously strives to increase security awareness and practices at the Centre. Security plays a role in all Centre event and trial plans and execution. As a standard policy, the Security Office regularly reminds staff that Security is a "continuous responsibility for everyone".

Information & Communication Technology

Introduction

The Centre has a long-standing capability in scientific computing and data management, as an enabler of research and experimentation. The capability supports data collection from sensor platforms, exploitation of the data through high-performance computing, and delivery of data-driven predictive models and decision support tools. The Information Laboratories Office (ILAB), established in 2013 as part of the new CMRE organizational structure, is responsible for supporting the Programme of Work through the conception, design, development and delivery of state-of-the-art technologies in computing and networking, ensuring interoperability, security and compliance with relevant NATO policies and regulations.

Technology outlook and financial savings

All IT services of the Centre, including scientific services, were externally operated under an outsourcing agreement with the NATO Communications and Information Agency (NCIA) from 2010 to February 2013. During 2013, ILAB took direct responsibility of all scientific infrastructure and services.

The transition proved to be challenging for two reasons. First, the scope of scientific IT systems and services was not defined in a detailed manner in the previous Service Level Agreement with NCIA. This lack of oversight by CMRE resulted in divergence between the user requirements and the technical solutions provided. Second, the transition occurred during the timeframe when CMRE was implementing financial constraints in the new customer-funded business model. This limited the resources available to optimize and re-engineer the existing infrastructure to better fit the needs of the scientific and engineering staff. Although the transition to internal management of scientific IT did not impact delivery of the programme of work, the pressure to realise financial savings across CMRE resulted in significant cuts to the IT budget over many years. As shown in Figure 1, the Centralized Scientific IT budget suffered a reduction of 60 percent over the 2012-2016 period.

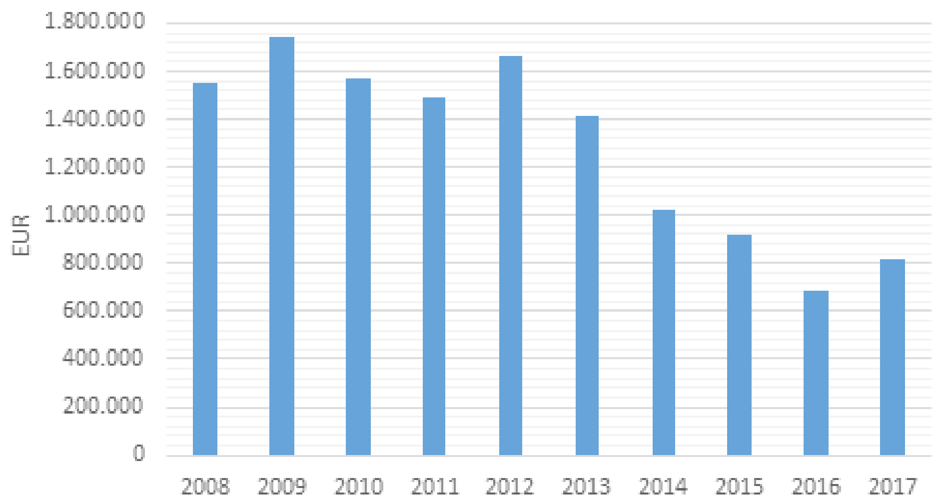


Figure 1 – 10 years history of centralized scientific IT budget.

As a result of the decrease in IT funding, the capability of the centralized scientific infrastructure could no longer meet the increasingly-demanding needs of the Programme of Work. The effects of obsolescence also started to become evident, with an increase in the number of hardware failures. Consequently, as projects identified new requirements that were not met by the centralized infrastructure, they started to make financial provisions directly in their project budget, to implement short-term ad hoc solutions outside a comprehensive IT governance framework. The result was a proliferation of project-specific systems, which were difficult to maintain across their life-cycle, and, as shown in Figure 2, an overall increase of IT spending.

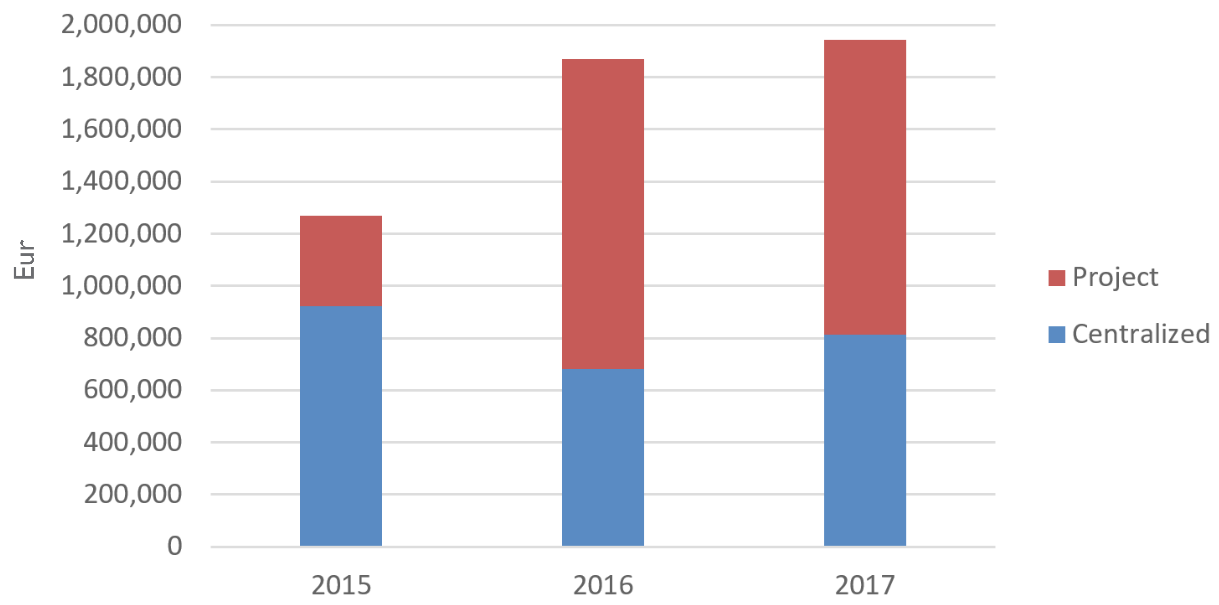


Figure 2 – Three-year scientific IT spending in centralized and project budgets (2015-2017)

In 2017 CMRE developed an IT Modernization (ITM) plan which included a review of its working practices and infrastructure requirements. This included a review of information and communication technology (ICT) requirements both internally and in the context of the NATO Enterprise.

The modernization strategy, driven by the evolution of technology and aligned to NATO Enterprise strategy, was developed with the assistance of industry experts from IBM, who conducted two in-depth reviews. The first focused on organizational aspects including an assessment of the current state of CMRE IT capabilities, identification of efficiencies and metrics of success. The second review focused on software development practices resulting in recommendations on organizational plans, transition to Platform-as-a-Service and Software-as-a-Service paradigms, and identification of ways to improve integration of best practices for security in all IT activities. To implement the strategy, CMRE decided to re-introduce the centralized procurement of ICT hardware, software and services effective 1 January 2018.

From the cost tracking perspective, project-specific IT requirements remain a direct charge inside the project structure. From the organizational perspective, centralization allows ILAB to group similar requirements to reduce duplication of effort, promoting convergence to a more homogeneous architecture that is simpler to manage and is more secure. Financial efficiency is achieved by grouping equipment purchases in larger competitive procurements.

A Security Audit conducted by the NATO Office of Security during the summer provided support and validation of CMRE's IT Modernization Strategy.

Scientific Network (SCINET) improvements and cyber-security posture

One of the first steps in implementing the IT Modernization Strategy was to upgrade the virtualized data centre of the Centre's unclassified Scientific Network (SCINET). The upgrade expanded the number of elements in the centralised computing centre, and introduced graphics processing units (GPU) for advanced computation applications in machine learning.

The upgrade of virtualized data centre was a first response to previously unmet requirements for a large number of computing cores. For data management, the Centre decided to expand the central scientific storage to an industrial-grade capability connected with high-speed links to the data centre. This enabled the replacement of many non-scalable storage systems, resulting in improved reliability and performance.

In terms of security, all centralized Communication and information Systems (CIS) of the Centre maintained security accreditation during 2017. However, the worldwide cyberattack via the WannaCry ransomware in May 2017, which had no effect on CMRE systems, solicited a review of CMRE's capabilities for data backup and archive. As a result, detailed requirements for a backup and archive solution were developed, for implementation in 2018.

Notwithstanding the improvements to centralized IT infrastructure in 2017, many research and engineering activities at CMRE continue to rely on legacy and non-centralized systems. Upgrading these systems requires additional investment in the future. Candidates for investment include a centralized classified IT architecture, in particular for the anti-submarine warfare (ASW) and mine countermeasures (MCM) programmes. Additionally, the individual IT systems that are used to program and control sensor payloads and robotic systems require investments to increase their performance and make them more secure.

CMRE recognizes that IT is transforming the global research landscape. Research that was previously enabled by physical solutions and data collection is being re-shaped by physical/digital convergence, exploitation of data, and co-creation with customers and research partners, supported by enhanced communication and collaboration channels. Staying relevant requires a change of internal ways of working, to ensure agility at scale and speed, supported by adequate IT infrastructure. It also drives the need to improve the delivery of CMRE's prototypes in the digital space, making them available on NATO's secure networks. In turn, this will require the adoption of secure software coding practices and closer cooperation with end users in the operational community.

Programme of Work support highlights

Highlights of ILAB's contribution to the 2017 Programme of Work include support to the trials of the MCM programme in Greece and Italy and to NATO Exercises in the High North (Dynamic Mongoose), with the first connection of NRV ALLIANCE to NATO's operational networks, which allowed greater integration of the vessel at the tactical level. Support was also provided to Operational Experimentation with the Standing NATO Maritime Group 2 (SNMG2), and to several other shore-based trials, building valuable experience in supporting work during military exercises and outside the Centre's research vessels.

Engineering - Recent advances in Underwater Autonomy

The next-generation of Autonomous Underwater Vehicles (AUVs) currently being developed at CMRE is equipped with a comprehensive suite of sensors. For many years CMRE has been developing AUVs with advanced onboard signal and data processing capabilities, and artificial intelligence-based autonomy engines capable of adapting to the environment in order to achieve high level mission tasks without human intervention. Considerable effort has also been dedicated to exploration of solutions promoting collaboration and cooperation between unmanned assets, which is a necessity for executing complex missions. However, despite encouraging results to date, much work remains, to be able to perform complex autonomous scientific and operational missions with underwater systems.

In this section, we describe recent work at CMRE towards the development of unmanned system-of-systems for the maritime domain with particular emphasis on the following areas:

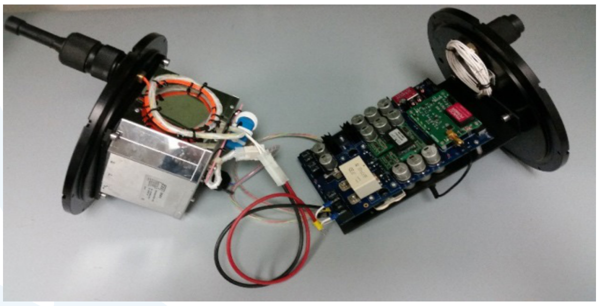
• Persistence
• Deep water navigation
• Cognitive underwater communication
• Launch and recovery

Persistence

CMRE developed a hardware-interoperable, scalable Wireless Power Transfer (WPT) system. The system is described as "hardware interoperable" because it is easily scalable and adaptable to different AUV sizes. For instance, the first 21" prototype was re-sized to fit in a man-portable AUV (an eFolaga) and a CMRE docking station.

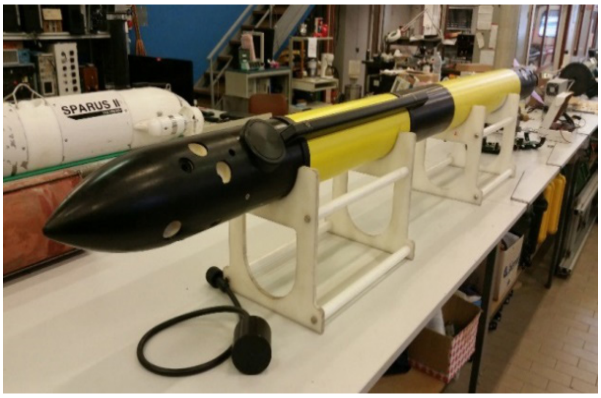
Description of the Wireless Power Transfer system

The Wireless Power Transfer (WPT) system is capable of transferring 500W continuously, without contact, through inductive coupling. A feedback system, integrated inside the induction coils, guarantees DC voltage stability at the load, independent of load and coupling conditions. Overall efficiency from the power supply output to load is around 90 percent at full load. Ferrite, windings and auxiliary feedback control are molded into a cylindrically shaped housing, with a diameter of 78mm and a height of 62mm, and are connected to the electronics by an underwater cable (including Litz electrical wire). The maximum spacing in salt water is 10mm.
The WPT is made of two components: the primary side is part of the docking station, while the secondary side is integrated into the AUV. The primary side, shown in the figure, is based on a variable frequency half-bridge resonant converter with series compensation of both primary and secondary leakage inductances. It is using the zero-voltage-switching (ZVS) technique that dramatically reduces the switching losses and EMI noise, leading to significant efficiency gains over other methods. The primary side housing is 240mm in diameter by 350mm long and contains a power supply filled with resin, capable of providing 1kW at 100 VDC, and a bridge control, including a microcontroller and the feedback system.



WPT primary side bridge electronics and power supply

The secondary side (with the exception of the external coil) is hosted inside the eFolaga section (155 mm diameter by 350 mm long). The section includes a motherboard with a high-efficiency synchronous rectifier and four battery chargers. The motherboard hosts a microcontroller and can talk both to the AUV and to the battery charger. Each battery charger can be programmed and adapted to any kind of battery technology. During testing, the four olymer Li-Ion battery packs were recharged in less than four hours. Thanks to the synchronous rectification design, the temperature inside the AUV never reached critical levels.



WPT integration in eFolaga AUV with hockey-puck shaped housing in the AUV and on the bench

WPT Integration in the AUV and docking station

Proper mechanical integration of the AUV in the docking station is essential to ensure high efficiency recharging, as the distance between the primary and secondary side of the WPT must be kept within a narrow envelope.

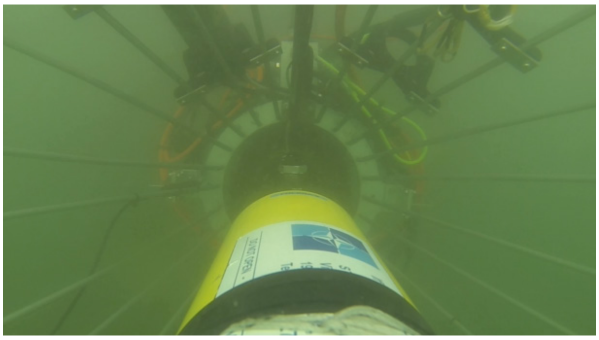
The Dream Catcher, or AutoLARS (Launch and Recovery System), was developed to be used in either mobile or fixed mode. For the mobile mode, it is equipped with propulsors, allowing it to move with six degrees of freedom, with the idea that after acoustically detecting the AUV, it would maneuver in the water to catch the vehicle, like an aircraft with an in-flight refueling system.

AutoLARS or "Dream Catcher" before its deployment in CMRE harbor

The AutoLARS was modified to optimise the capture of the eFolaga AUV, to provide more precise clamping action from the two actuators, and thus to have more accurate and repeatable mating between the two halves of the WPT transformer.

Demonstrations at sea

The 2017 work culminated in a two-week at-sea experiment in November, during which the AUV remained in the water for the whole period, switching from science activities, consisting of communicating with a farm of sensors fixed on the sea bed, to its "survival mode" mission, in which the battery was charged and on-board data transmitted before the scientific mission resumed. For this experimentation, the docking station was used in a fixed mode, meaning that the AUV was autonomously detecting its own position through acoustics and adapting its maneuvering to enter the catcher, before being secured by the actuators.



AUV docking underwater for battery recharging and data exchange in CMRE harbour during a two-week continuous demonstration in November 2017

Wireless Power Transfer way forward

A potential improvement for the WPT could be to increase power from 0.5 to 1kW, by using larger coils (~120mm diameter). A new design could incorporate the rectifier inside the coil, by making it slightly longer. In this way, the AUV would host only the battery chargers. Some tests suggest that it should be possible to design the coils including a Wi-Fi link. Primary side electronics could be redesigned in order to fit into a smaller space, provided that the Wi-Fi link proves to be reliable enough to replace the auxiliary feedback system.

Deep water navigation

Navigation of AUVs is challenging, requiring a trade-off between performance, cost and endurance. In most scenarios, the vehicles represent the movable assets of a wider infrastructure (i.e. autonomous sensor network) or are immersed in a structured environment, supporting a vessel with High Precision Acoustic Positioning (HiPAP) or Ultra-Short Base Line (USBL) positioning that can be used to enhance the localization and navigation capability of the vehicles. HiPAP provides highly accurate positions of AUVs, requiring only a vessel-mounted transducer and a subsea transponder mounted on the vehicle, while USBL enables simultaneous determination of range and bearing of an AUV.
It is important to define the type of localization information that can be collected from regular network traffic, to help the AUV to fuse navigation estimates from various data sources and increase overall localization and navigation performance.
In recent years, CMRE has worked to enhance the navigation performance of AUVs in challenging environments, such as in deep water where Doppler Velocity Log (DVL) bottom lock cannot be assumed, or operations in denied areas where acoustic beacons cannot be used.

Technical approach

The technical approach is based on the exploitation of additional/alternative localization devices (e.g. HiPAP, USBL, network-produced range measurements, etc.) to be fused within a real-time Extended Kalman Filter (EKF) capable of combining kinematic exteroceptive data (when available) with vehicle odometry. The filter was integrated onboard the CMRE OEX AUVs designed for ASW missions, and tested at sea for the first time in deep water during the NATO exercise Dynamic Mongoose, off the South coast of Iceland (June-July 2017). During this experiment, the filter, integrated in the 'back-seat' onboard each OEX AUV, was devoted to fusing information, in real-time, available from:

- AUV GPS position (available only on surface);
- Direction-of-arrival estimates of other nodes equipped with an acoustic modem (data from the USBL installed on each AUV);
- Round-trip-time (RTT) measurements provided by the underwater acoustic modems linking the AUV with all the other network nodes (when available);
- AUV position from HiPaP data coming from the mother ship, when available;
- Through-the-water speed measurements from the DVL.

Results

The filter ran up to 11 hours continuously during the missions conducted in deep water. Position error was typically less 30 m and rarely exceeded 100 m even during unavailability of the HiPAP measurements at the AUV. Here position error is defined as the difference between the Reference Path (RP) position and the output of an instance of the filter which was running on NRV ALLIANCE.
The EKF navigation filter developed to allow deep water positioning and navigation of AUVs was an important enabler for the CMRE autonomous heterogeneous network for ASW multistatic active sonar. Analyses revealed that the filter is capable of working with heterogeneous time-irregular and possibly delayed measurements, providing a reliable navigation state estimate. In the absence of DVL bottom-lock, the EKF was able to exploit a variety of opportunistic data even when the high-accuracy HiPAP and USBL systems of the mother ship were unavailable for relatively long periods up to one hour.

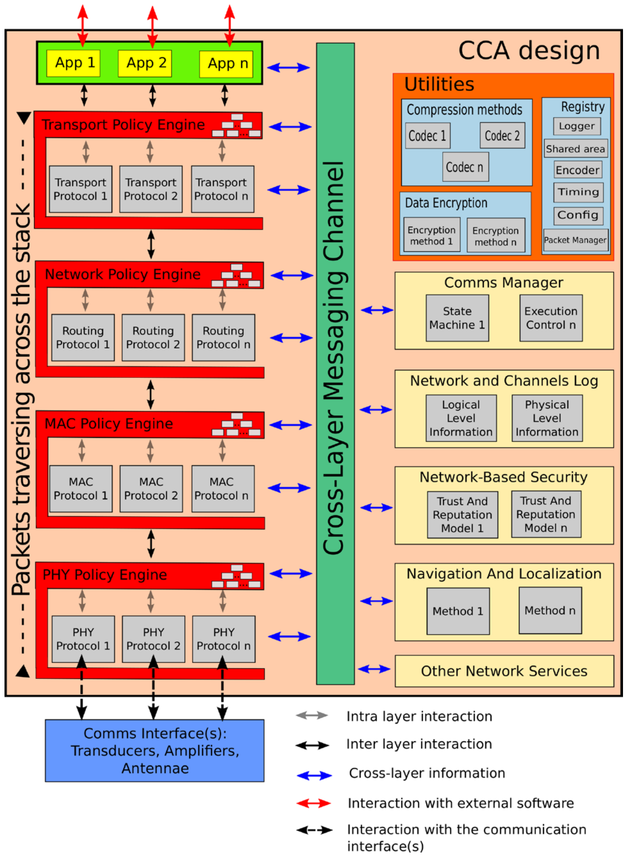
Secure cognitive underwater communications

As seen above, some of the effectiveness of distributed underwater autonomous systems comes from the fact that they can be deployed in large numbers and conduct cooperative tasks. In the case of underwater autonomous systems, cooperative techniques are challenged by the limitations of underwater communications. In the underwater environment, both radio and optical signals are greatly attenuated, leaving acoustics as the only means to communicate underwater for ranges beyond about 50 m. Nonetheless, acoustic communications suffer from long propagation delays and low data rates. Factors affecting the quality of the received signals, such as multipath propagation, frequency-dependent scattering loss and motion-induced Doppler, are difficult to model. A prevailing strategy to adopt to these challenging situations is to develop a system that can intelligently adapt the transmission schemes to the prevailing environmental conditions. Additionally, for short-ranges, optics and electromagnetic waves can achieve data throughputs several orders of magnitude above those offered by acoustics. The previous adaptive concept can logically be expanded to consider solutions that automatically select the appropriate communication modality to use when more than one is available.

Cognitive communication architecture (CCA)

Adaptation is the foundation concept for the Cognitive Communications Architecture (CCA), developed at CMRE.

The CCA is a C++ implementation of a Software Defined Modem (SDOAM), which is intended to provide improved flexibility, while maintaining some architectural organizing features of stacks that are analogous to the Open Systems Interconnection (OSI) paradigm. The use of a layered structure allows the user to simply substitute solutions to be adopted at a specific layer without affecting other layers. At the same time, the traditional OSI model is enhanced, with the support of more than one solution at each layer of the stack, and the possibility to use cross-layer interactions. This enables the entire stack to exchange contextual information, in order to work in a coordinated and more effective way. The selection of the solution(s) to use is dictated by cognitive capabilities (policy engines), enabling the stack to autonomously reconfigure and adapt to the environmental or operational situation.



The CCA design and its major components.

The CCA works as a "skeleton" inside of which protocols can be deployed to construct acommunications stack enabling an underwater network. The software is dependable and has been used in different sea trials (REP16-Atlantic, REP17-Atlantic, Dynamic Monarch 17 and CommsNet17) in support of operations with both JANUS-enabled hardware and with commercial modems. When used for JANUS, the CCA implements the software component of a JANUS acoustic modem. When used with commercial modems, the CCA provides a driver and upper protocol functionality. For any of these applications the hardware demands are modest. The CCA has been implemented on the Raspberry-Pi and other Advanced RISC Machine (ARM) single board computers. ARM computer boards are low cost, low power, highly efficient platforms for computing on board unmanned systems with demanding size, weight and power (SWAP) constraints.

One of the next steps in CCA development is to support more demanding modulation schemes. To this end CMRE is investigating more powerful hardware that is capable of meeting challenging real-time processing requirements.
Several experimental techniques for adaptive networking have been tested inside the CCA, with promising results. These include: adaptation at the physical layer with a deep-learning-based method to select the appropriate waveform, from a library of options, to use given the measured channel conditions; a dynamic address allocation method for ad hoc underwater networking; and a method for efficient cooperative localization based on exchange of acoustic communication signals.

Secure communications

Techniques for secure communications are well established in the terrestrial radio-frequency domain. However, these security techniques are generally inapplicable to underwater communication, due to the peculiarities of the underwater acoustic channel, and in particular its limited throughput. As a result, CMRE is exploring the CCA's ability to provide cross-layer information as a means of selecting the appropriate encryption and authentication technique given prevailing communications conditions. Since the application of encryption and authentication increases message size, the threat risk must be balanced against the performance degradation imposed by the additional security overhead. Integrity of communications in operations, protection against denial-of-service attacks, detection of malicious behaviors and identification of compromised nodes are all areas of interest for CMRE.

Digital communication standardization

The CCA is also a facilitator of interoperability, a requirement for NATO, by providing a common approach to protocol implementation and protocol switching.
Up until recently, no digital underwater communications standards existed. This represented a significant bottleneck towards the effective deployment of cooperative networks of underwater assets.
CMRE took the lead to establish the first-ever interoperability standard, called JANUS (known in formal terms as STANAG 4748) which was promulgated as a NATO standard in March 2017.

The JANUS standard is deliberately robust. The digital coding technology that is used is well-known and can easily be adopted by a wide range of existing systems. The physical layer coding scheme is known as Frequency-Hopped (FH) Binary Frequency Shift Keying (BFSK). FH-BFSK has been selected for its robustness in the harsh UW acoustic propagation environment and simplicity of implementation. The JANUS standard is open and publically available, including the specification of the signal encoding and message format. The intent is to allow anyone to experiment with JANUS transmitters and receivers for the benefit and growth of the underwater communications community.
CMRE has promoted the use of JANUS to deliver new services in the maritime world. These include broadcast of Automatic Identification System (AIS) and Meteorological and Oceanographic (METOC) data to the subsea domain. The uses of JANUS in support of automated SOS during submarine distress cases has been also proposed and demonstrated during exercise Dynamic Monarch, the world's largest submarine rescue exercise.

Launch and recovery

This section describes technologies implemented at CMRE to upgrade the Centre's ability to deploy AUVs from vessels, improving safety and reliability while mitigating weather constraints.

Problem statement

In order to support its various research programmes, CMRE operates a fleet of Maritime Unmanned Systems (MUS), ranging from Surface Vehicles (USV) to gliders and Autonomous Underwater Vehicles (AUVs).
Until recently, CMRE's unmanned systems were deployed and recovered from support ships in a conventional manner, by means of a deck crane, with the assistance of a RHIB (Rigid-Hull Inflatable Boat). Recovery in this fashion is often the most critical and incident-prone phase of a maritime robotic deployment, and may restrict operations to low sea state conditions (up to Sea State2) and daylight hours.

As CMRE MUS became more advanced, and were expected to operate for longer durations in more challenging environments, such as NATO naval exercises and in the Arctic, the need arose to provide safer, RHIB-less operations, in moderately heavy sea conditions, and for a wider range of host vessels.

Implementation

The marine robotics community has proposed and demonstrated a variety of Launch and Recovery System (LARS) technologies in recent years, at the surface or submerged, sometimes requiring sophisticated software and hardware onboard the AUV, and adaptations on the supporting vessel.
CMRE has contributed to the development and demonstration of an advanced LARS system.
In order to enable rapid operational readiness, preference was given to proven technology, with emphasis on interoperability and portability. This enables AUV deployment not only from CMRE vessels, but also from ships of opportunity including military platforms.
The result is a general-purpose LARS for AUVs up to 21", based on an articulated hydraulic ramp that slides and tilts from the ship's transom.
The system is interoperable with a wide range of host vessels, with an onboard hydraulic power pack, standardized deck fittings, variable geometry in ramp extension and tilting angle, interchangeable cradles, and ship-independent lifting capability, all of which allows concurrent multi-AUV operations.
The CMRE LARS has a base frame that can be fastened to the ship's deck directly or via an ISO Container interface frame. The base frame, supports the hydraulic power pack and the operator control station. It allows the longitudinal translation of a trolley with a two-stage chute that can be tilted up and down by means of two hydraulic cylinders. The chute can be extended in and out to allow the deployment of the LARS in close proximity to the water, compensating for different ship's deck heights above water. A pull-in winch is mounted at the inner end of the chute to hoist the vehicle onto the chute.
For recovery of the 21" AUVs with the LARS, the vehicle nose sections are modified to integrate a releasable component, attached to the vehicle mechanical frame by a towline. When the detachable element is commanded to release, the float separates from the vehicle through wave motion, or by remotely commanding the vehicle in reverse. The towline is captured from the ship by means of a grappling hook or gaff, and the float is brought onboard. Finally, the towline is engaged into the ramp's hydraulic winch, and the AUV is slowly pulled onto the ramp and onboard the ship.
The main characteristics of the CMRE LARS are summarized in Table 1.

Table 1

Table 1 - CMRE LARS Main Characteristics		
Description	Unit	Value
AUV Maximum Mass	kg	800
AUV Maximum Dimensions (Dia x Length)	m	0.533 x 6.0
LARS Mass	kg	2500
LARS Dimensions (L x W x H)	m	6.3 x 2.1 x 1.5
LARS Electrical Power Requirements	V, Hz kW	380-440, 50-60, 7.5
Maximum Ship's Deck Height	m	5.0

Results at sea

The LARS was operated for the first time in 2017, during NATO ASW exercise Dynamic Mongoose, off the coast of Iceland. The LARS was used to launch and recover two Ocean-Explorer-C (OEX-C) AUVs. It was immediately recognized as a major improvement over CMRE's standard operating procedures, providing reliable, safe and fast RHIB-less operations, even in Arctic seas. Although conditions did not exceed Sea State 2, reliable operations up to Sea State 4 are deemed achievable in the future.

LARS deployed from NATO Research Vessel ALLIANCE

LARS deployed from NATO Research Vessel ALLIANCE

LARS way forward

The LARS is now considered standard operational equipment for the Centre's ASW unmanned systems program, and is compatible with all 21" AUVs. To extend the interoperability of the LARS, an upgrade is planned for 2018 to integrate a small crane to enable ship-independent lifting and handling of the AUVs, and enable concurrent servicing of multiple AUVs. There is also a plan to integrate the LARS into an ISO shipping container.

Conclusion

Over the past decade CMRE has developed and demonstrated many technologies that enable the future use of persistent, deployable, and recoverable unmanned underwater systems of systems. CMRE demonstrated the capability to efficiently recharge AUVs while underwater through the use of a wireless power transfer docking station, dramatically increasing the AUV's persistence while avoiding the requirement for regular recovery. A new navigation technique that could allow AUVs to navigate and position accurately in a deep-water environment was demonstrated. The Centre also demonstrated an efficient, secure, and adaptive inter-operable underwater communications capability that is critical for the future use of multiple collaborative AUVs. The last result presented is the demonstration of a highly adaptable launch and recovery system for AUVs up to 21" diameter.

Visitors, meetings and conferences

January

Exploratory Team on Security Aspects of Unmanned Systems Meeting

February

Visit by LGEN Jeffrey Lofgren, US A, Deputy Chief of Staff for Capability Development, HQ SACT

Long-term Glider Missions for Environmental Characterisation (LOGMEC) Meeting

Nordic Recognised Environmental Picture (NREP) 17 Cruise Planning Meeting

Systems Concepts and Integration (SCI) -288 Panel Meeting: 'Autonomy in Communications Limited Environments' Focus Group

Final meeting EC Project SUNRISE

March

Specialized Course for ITN Submarine Officers, Italian Navy

Naval Mine Warfare Staff Officers Course, EGUERMIN

Visit from the World Maritime University (WMU), UN, Malmoe, Sweden

April

Joint Research Project (JRP) Working Group for Planning & Evaluation (P&E) issues with AUVs for MCM

International Research Ship Operators (IRSO) Polar Code Workshop

High Resolution Low Frequency Synthetic Aperture Sonar (HRLFSAS) for MCM Workshop

Maritime S&T Committee (MSTC) Meeting

French Navy Technical Expert Team Visit

Seminar by Prof. Paul Mitchell, University of York, UK

May

3rd Workshop on NATO Future ASW Vision Paper

Table Top Exercise (TTX) in support of Maritime Situation Awareness (MSA)

Visit by Dr. Robert Pickart, Senior Scientist, Woods Hole Oceanographic Institution, US

NATO Systems Analysis and Studies (SAS) Research Task Group 114 (Assessment and Communication of Risk and Uncertainty to Support Decision-Making)

June

NATO Information Systems Technology (IST) Exploratory Team 099 (Mission Assurance and Cyber Risk Assessment)

Secure Underwater (UW) Communications Workshop

Seminar by Dr. William Kuperman, Professor of Oceanography, Director, Marine Physical Laboratory, SCRIPPS Institution of Oceanography, US

August

LCAS Joint Research Multinational Project and Planning Meeting

September

Seminar by Prof. Natalia and Gennady Andrienko, IAIS Frauenhofer, Germany

Seminar by Dr William Kuperman, Professor of Oceanography Director, Marine Physical Laboratory, Secretary of the Navy/Chief of Naval Operations Chair for

Ocean Science from the SCRIPPS Institution of Oceanography, US

October

Decision Support and Risk Assessment (DeSRA) for Operational Effectiveness Conference

Workshop on Military Applications of Underwater Glider Technology (WMAUGT)

Joint Meeting of the Data Assimilation Task Team (DA-TT) & Observing System Evaluation Task Team (OSE-TT) of the Global Ocean Data Assimilation Experiment (GODAE) Ocean View

Naval Domain Intelligence Conference: CMRE Workshop and Open Day

Machine Intelligence for Autonomous Mine Search (MIAMS) Joint Research Project (JRP)

November

NATO Systems Concepts and Integration Research Task Group 280 (System-of-Systems Approach to Task-Driven Sensor Resource Management for Maritime Situational Awareness)

Seminar by Prof. Jean-Claude Gascard from LOCEAN, Université Pierre et Marie Curie of Paris (UPMC), France

December

Strongmar winter school on underwater systems and communication science

Unified Vision 18 (UV18) Scenario & Vignette Development Workshop

Seminar by Prof. Peter Tyack on Marine Mammal Bio Acoustics and Naval Operations, University of Saint Andrews, UK & Woods Hole Oceanographic Institute

Internal Publications

Full reports

CMRE-FR-2017-001
Vicen Bueno, Raul; Cimino, Giampaolo; Cecchi, Daniele; Merani, Diego; Soto, Jose
NATO Coalition Warrior Interoperability eXploration, eXperimentation, eXamination, eXercise (CWIX) 2017: exercise plan for the NATO-CMRE-GliderC2 capability participation.

CMRE-FR-2017-002
Vivone, Gemine; Braca, Paolo
Multiple sensor extended target tracking exploiting random matrix model.

CMRE-FR-2017-004
Pelekanakis, Kostantinos
Coded modulation development for covert underwater acoustic communications.

CMRE-FR-2017-007
Vivone, Gemine; Millefiori, Leonardo M.; Braca, Paolo; Willett, Peter K.
Association of radar/SAR ship detections with AIS using the Ornstein-Uhlenbeck process for route propagation: performance metrics and experimental results.

CMRE-FR-2017-008
Soldi, Giovanni; Meyer, Florian; Braca, Paolo
Adaptive multisensor multi-target tracking with belief propagation.

CMRE-FR-2017-009
Strode, Chris; Oddone, Manlio
Real-time decision support Exercise Dynamic Mongoose 2017.

Memorandum reports

CMRE-MR-2016-019
Tesei, Alessandra; Meyer, Florian
Study of passive sensing system on long-endurance - low-power platforms.

CMRE-MR-2016-021
Pennucci, Giuliana; Sanjuan Calzado, Violeta
Implementation of ocean optics protocols to estimate spectral absorption coefficients of particles, suspended matters and phytoplankton pigments in ALOMEX'15 water samples: results and comparisons with satellite retrievals.

CMRE-MR-2017-001
Dugelay, Samantha; Reardon, Eric; Furfaro, Thomas; Pailhas, Yan; Carreras, Marc
Olives Noires 2016: experimental descriptions and preliminary results.

CMRE-MR-2017-003
Borrione, Ines; Oddo, Paolo; Russo, Aniello; Coelho, Emanuel
Combined analysis of LOGMEC16 oceanographic glider and satellite data and their correlation.

CMRE-MR-2017-004
Trees, Charles C.; Fournier, Georges R.; Rupp, David; Friman, Sonja
A Re-examination of the Brillouin Scattering LiDAR Pier Demonstration: New Insights.

CMRE-MR-2017-006
Bourque, Alex
Solving the moving target search problem using indistinguishable searchers.

CMRE-MR-2017-008
Pennucci, Giuliana; Jiang, Yong-Min
Extracting acoustic source level of shipping noise for dynamic ambient noise modelling.

External Publications

Conference papers

Millefiori, Leonardo M.; Braca, Paolo; Arcieri, Gianfranco
Scalable distributed change detection and its applications to maritime traffic.
2017 IEEE International Conference on Big Data

Bourque, Alex
Solving the moving target search problem using indistinguishable searchers.
21st Conference of the International Federation of Operational Research Societies

Cecchi, Daniele; Garau, Bartolome
CMRE sea trials with gliders 2017.
4th Workshop on Military Applications of Underwater Glider Technology

Jousselme, Anne-Laure; Ben Abdallah, Nadia
Automated reasoning under uncertainty in support to Maritime Situation Awareness
Workshop on Bridging the gap between human and automated reasoning

Oddone, Manlio; Bruzzone, Agostino G.; Coelho, Emanuel; Cecchi, Daniele; Garau, Bartolome
An underwater buoyancy-driven glider simulator with Modelling & Simulation as a service architecture.
I3M 2017 - 14th Intl Multidisciplinary Modelling & Simulation Multiconference

MacLeod, Matthew R.; Bourque, Alex
Utility assessment of maritime unmanned vehicles in anti-submarine warfare.
NATO Operations Research and Analysis Conference.

Ferri, Gabriele; Munafo, Andrea; Tesei, Alessandra; LePage, Kevin D.
A market-based task allocation framework for autonomous underwater surveillance networks.
OCEANS 2017 Aberdeen

Ferri, Gabriele; Ferreira, Fausto; Djapic, Vladimir
Multi/domain robotics competitions: the CMRE experience from SAUC-E to the European Robotics League Emergency Robots.
OCEANS 2017 Aberdeen

Munafo, Andrea; Ferri, Gabriele; LePage, Kevin D.
AUV active perception: exploiting the water column.
OCEANS 2017 Aberdeen

Sliwka, Jan; Petroccia, Roberto; Munafo, Andrea; Djapic, Vladimir
Experimental evaluation of Net-LBL: an acoustic network-based navigation system.
OCEANS 2017 Aberdeen

Campagnaro, Filippo; Calore, Matteo; Casari, Paolo; Sanjuan Calzado, Violeta; Cupertino, Giacomo; Moriconi, Claudio; Zorzi, Michele
Measurement-based simulation of underwater optical networks.
OCEANS 2017 Aberdeen

Machado, Diogo; Furfaro, Thomas; Dugelay, Samantha
Micro-bathymetry data acquisition for 3D reconstruction of objects on the sea floor.
OCEANS 2017 Aberdeen

Bates, Jeffrey R.; Hines, Paul C.; Canepa, Gaetano; Tesei, Alessandra; Ferri, Gabriele; LePage, Kevin D.
Doppler estimates for large time-bandwidth products using linear FM active sonar pulses.
UACE 2017 - Underwater Acoustics Intl Conference & Exhibition

Hines, Paul C.; Murphy, Stefan M.; Bates, Jeffrey R.; Coffin, Matthew
Ambiguity functions, wide band and narrow band approximations, and high duty cycle sonars.
UACE 2017 - Underwater Acoustics Intl Conference & Exhibition

Canepa, Gaetano; Tesei, Alessandra; Troiano, Luigi; Biagini, Stefano; Aglietti, Federico
Comparison of computation time and accuracy of the real time implementation of two beamforming algorithms.
UACE 2017 - Underwater Acoustics Intl Conference & Exhibition
Pelekanakis, Kostantinos; Bates, Jeffrey R.; Tesei, Alessandra
Adaptive equalization for continuous active sonar.
UACE 2017 - Underwater Acoustics Intl Conference & Exhibition

Williams, David P.
Demystifying Deep Convolutional Neural Networks for Sonar Image Classification.
UACE 2017 - Underwater Acoustics Intl Conference & Exhibition

Journal articles

Vivone, Gemine; Millefiori, Leonardo M.; Braca, Paolo; Willett, Peter K.
Performance assessment of vessel dynamic models for long-term prediction using heterogeneous data.
IEEE Transactions on Geoscience and Remote Sensing

Ambrosin, Moreno; Braca, Paolo; Conti, Mauro; Lazzeretti, Riccardo
ODIN: Obfuscation-based privacy preserving consensus algorithm for Decentralized Information fusion in smart device networks.
ACM Transactions on Internet Technology

Petroccia, Roberto; Alves, Joao; Zappa, Giovanni
JANUS-based services for operationally-relevant underwater applications.
IEEE Journal of Oceanic Engineering

Lal, Chhagan; Petroccia, Roberto; Pelekanakis, Kostantinos; Conti, Mauro; Alves, Joao
Towards the development of secure underwater networks.
IEEE Journal of Oceanic Engineering

Ferri, Gabriele; LePage, Kevin D.
On data-driven control strategies for AUVs to track targets in sonar surveillance scenarios.
IEEE Journal of Oceanic Engineering

Zhao, Xueyuan; Pompili, Dario; Alves, Joao
Underwater acoustic carrier aggregation: achievable rate and energy efficiency evaluation.
IEEE Journal of Oceanic Engineering (Ucomms special issue)

Petroccia, Roberto; Potter, John R.; Petrioli, Chiara
Performance evaluation of underwater MAC protocols: at-sea experiments.
IEEE Journal of Oceanic Engineering

Ferri, Gabriele; Munafo, Andrea; Tesei, Alessandra; Braca, Paolo; Meyer, Florian; Pelekanakis, Kostantinos; Petroccia, Roberto; Alves, Joao; Strode, Chris; LePage, Kevin D.
Collaborative robotic networks for underwater surveillance: an overview.
IET Radar and Sonar Navigation, Special issue on Sonar Multisensors Applications and Techniques.

Been, Robert; Tesei, Alessandra; Williams, David P.; Cardeira, Bruno; Galletti, Domenico; Grati, Alberto; Cecchi, Daniele; Garau, Bartolome
Continuous surveillance of surface vessels using passive acoustics on board persistent unmanned platforms.
IET Radar, Sonar & Navigation, Special issue on Sonar Multisensors Applications and Techniques

Falchetti, Silvia; Alvarez, Alberto
The impact of covariance localization on the performance of an ocean EnKF system assimilating glider data in the Ligurian Sea.
Journal of Marine Systems

Hunter, Alan J.; Connors, Warren A.; Dugelay, Samantha
An operational concept for correcting navigation drift during sonar surveys of the seafloor.
IEEE Journal of Oceanic Engineering

Pailhas, Yan; Dugelay, Samantha; Capus, Chris
Impact of vehicle motion on synthetic aperture sonar imagery.
Journal of the Acoustical Society of America

Wang, Guanyu; Zhu, Jiang; Blum, Rick S.; Willett, Peter K.; Marano, Stefano; Matta, Vincenzo; Braca, Paolo; Xu, Zhiwei

Maximum likelihood signal amplitude estimation based on permuted blocks of differently binary quantized observations of a signal in noise.
IEEE Signal Processing Letters

Pichon, Frederic; Jousselme, Anne-Laure; Ben Abdallah, Nadia
Several shades of conflict.
Fuzzy Sets and Systems

Alves, Joao; Zappa, Giovanni; Pelekanakis, Kostantinos; Cazzanti, Luca; Fountzoulas, Y.
BER prediction for non-stationary underwater acoustic channels: a decision tree approach.
IEEE Journal of Oceanic Engineering

Borrione, Ines; Oddo, Paolo; Russo, Aniello; Coelho, Emanuel
Understanding altimetry signals in the north-eastern Ligurian Sea using a multi-platform approach.
Deep Sea Research Part I

Meyer, Florian; Kropfreiter, Thomas; Williams, Jason L.; Lau, Roslyn A.; Hlawatsch, Franz; Braca, Paolo; Win, Moe Z.
Message passing algorithms for scalable multi-target tracking.
Proceedings of the IEEE

Clementi, Emanuela; Oddo, Paolo; Drudi, Massimiliano; Pinardi, Nadia; Korres, Gerasimos; Grandi, Alessandro
Coupling hydrodynamic and wave models: first step and sensitivity experiments in the Mediterranean Sea.
Ocean Dynamics

Bourque, Alex
Solving the moving target search problem using indistinguishable searchers.
European Journal of Operational Research
Williams, David P.
The Mondrian detection algorithm for sonar imagery.
IEEE Transactions on Geoscience and Remote Sensing

Storto, Andrea; Oddo, Paolo; Cipollone, A.; Mirouze, I.; Lemieux-Dudon, B.; Masina, S.; Pinardi, Nadia
Extending an oceanographic variational scheme to allow for affordable hybrid and four-dimensional data assimilation.
Geoscientific Model Development

Knoll, Michaela; Borrione, Ines; Fiekas, Heinz-Volker; Funk, Andreas; Hemming, Michael P.; Kaiser, Jan; Onken, Reiner; Queste, Bastien; Russo, Aniello
Hydrography and circulation west of Sardinia in June 2014.
Ocean Science

Papa, Giuseppe; Meyer, Florian; Braca, Paolo; Hlawatsch, Franz
Distributed Bernoulli filtering using clutter-rejecting likelihood consensus.
IEEE Transactions on Signal and Information Processing over Networks

Cooperative Anti-Submarine Warfare

MARITIME UNMANNED SYSTEMS FOR ASW

Dr Alessandra Tesei

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

As an outcome of ACT investment in robotic ASW networks since 2012, this project explores the use of Maritime Unmanned Systems (MUS) to address "Countering Mobile Underwater Threats" as outlined in NATO's Minimum Capability Requirements. The ambition of the project is to contribute to the spectrum of capability development through concept demonstration and validation.

Objectives

The objectives of the project in 2017 were to:

1. Advance the state-of-the-art in MUS and demonstrate their utility in operational contexts.
3. Contribute to the generation of a compelling business case for use of MUS.
4. Promote interoperability and standardisation of MUS for ASW within NATO.
5. Support national research and development activities into the use of MUS for ASW
6. Develop and implement state-of-the-art sensing algorithms to maximize the utility and performance of MUS sensor payloads.
7. Develop, implement, and test robotic Command, Control and Communications solutions for networked unmanned heterogeneous ASW systems to maximize their performance and interoperability.

Achievements

Collaborative Tracking/Track-Level Data Fusion

A Collaborative Autonomous Decision Making Engine was developed to enable the ASW AUVs to make decisions based on the tactical situation.

CAS vs PAS Performance Assessment

The performance of Continuous Active Sonar (CAS) waveforms versus traditional Pulse Active Sonar (PAS) waveforms was evaluated. Results show that CAS waveforms do not recover as much of their theoretical time-bandwidth gain when processed coherently over their entire duration as compared to the shorter duration PAS signals of equal energy. This limits some of the advantages of CAS over PAS under certain conditions.

Space-Time Adaptive Signal Processing

Triplet beamforming using space-time adaptive beamforming was developed to exploit the potential of the SLICTA triplet array. As compared to cardioid processing, adaptive processing has much better left-right ambiguity rejection, in particular near end fire.

Passive detection and Multi-Target Tracking

Building on the results for passive processing on low-power long-endurance platforms in 2016, the simultaneous tracking of multiple passively radiating targets was treated in a UACE conference paper.

Autonomous behaviour research for ASW

A framework for integrating cooperative area exploration, track prosecution and communications optimization tasks into an ASW autonomous multistatic sonar networks to was detailed in a formal report.

Environmental Characterization Services on board AUVs

A report on the provision of Real Time environmental services for ASW (MSTPALite) on board the Centre's AUVs was delivered.

Operational Utility

The utility of MUS for ASW missions in an operational setting was demonstrated in Exercise Dynamic Mongoose, which took place off Iceland in July 2017. Specifics included: demonstrating AUV navigation during the deep-water ASW serials where DVL bottom-lock is not available; longer endurance capability; a launch and recovery system from NRV ALLIANCE; deconfliction between MUS and manned platforms for Prevention of Mutual Interference (PMI) and for Water Space Management (WSM); an illustration that sensors that provide oceanographic information can also provide information on detection capabilities; an environmental characterization module ran in real-time onboard the AUVs; and the implementation of sonar real-time performance prediction on board the vehicles. The knowledge gained by CMRE during Dynamic Mongoose 2017 will contribute to the development of doctrine for MUS for ASW, and to standards for interoperability.

Exploitation and impact

A period of Operational Experimentation (OPEX) with Standing NATO Maritime Group Two (ASW-ODC17 OPEX, La Spezia/Crete/Marmaris, 12 October – 1 November 2017) achieved the following:

- Improvement of the multistatic active sonar autonomous network against real targets in two different environments.
- Interoperability though the first-ever integration of the Italian WaveFolaga AUV into the autonomous network.
- Extension of CMRE multistatic active sonar processing to process waveforms transmitted by Hull Mounted Sonar on warships and active dipping sonar from organic maritime patrol helicopters through cooperative "ping stealing".
- Real-time situational awareness of the disposition of unmanned underwater assets through the transmission of AUV positional information to the MCCIS C2 display on board the warships.
- Development of enhanced ASW training opportunities for NATO operational forces.
- Exposure of next-generation systems to NATO ASW forces.
- Provision of a collaborative venue for joint experimentation between the NATO maritime operational and scientific communities.

The ASW-ODC17 OPEX increased the level of mutual cooperation and understanding between Allied Command Operations' (ACO) Standing NATO Maritime Group Two and CMRE's ACT-funded maritime research and development programme on unmanned systems for ASW.

Conclusion / Future

At the customer's direction for the continuation of the project, a costed plan was produced, which emphasizes the development of a passive component of the ASW autonomous network based on glider and Wave Glider low-power/long-endurance platforms, equipped with acoustic payloads suitable for low-frequency acoustic passive monitoring.

COMMUNICATIONS AND NETWORKING IN THE MARITIME ENVIRONMENT

Mr. Joao Alves

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

Military underwater communication needs a common architecture built on NATO standards. Funded through ACT's Autonomous Security Networks Programme, this project seeks to define those standards while acting as an enabler for several of the Long-Term Aspects in the NATO 2016 Minimum Capability Requirements. The project makes key contributions in a field populated by academia, government R&D and isolated industrial efforts.

Objectives

1. To conduct research in the field of underwater communications, spawning collaborative efforts to the benefit of NATO and the Nations.
2. To promote interoperability and standardisation of military underwater communications in NATO.
3. To support the CMRE projects by enabling underwater multi-platform cooperation through communication.

Achievements

1. STANAG 4748 on "Digital Underwater Signalling Standard for Network Node Discovery & Interoperability" (JANUS) was promulgated and became part of NATO doctrine in ANEP-87 Edition A, representing the successful culmination of eight years of ACT investment in introducing standards into the 'wild west' of underwater communications.

2. A JANUS receiver was developed with superior performance in high Doppler and/or multipath channels.

3. In the REP17 Atlantic exercise, the underwater networking protocols for submarine communication scenarios were tested with a PRT SSK. The ability to transmit information to the SSK using JANUS was demonstrated, with the Automatic Identification System (AIS) picture of surface assets being sent down and submarine rescue Distressed/Disabled Submarine (DISSUB) messages exchanged using the JANUS protocol. The new software-defined underwater communications stack was used to drive the JANUS transmissions.

4. The project participated in the submarine search, escape and rescue exercise, Dynamic Monarch, with an ESP SSK, conducting several submarine rescue communications exchanges in accordance with NATO doctrine.

CMRE Operations during the submarine rescue exercise Dynamic Monarch 2017

CMRE Operations during the submarine rescue exercise Dynamic Monarch 2017

Exploitation and impact

JANUS opened the way for interoperable digital communications in support of submarine rescue operations with potential for automated transmission of digitally encoded critical data without the need of an operator. In the case of procedural communications (following operational scripts), JANUS can increase efficiency and avoid phonetic bias introduced by the different languages. The exploitation impact of such a concept is immense, potentially leading to a redefinition of current procedures and development of new doctrine.

Conclusion / Future

The introduction of interoperable underwater digital communications in submarine rescue scenarios facilitates safer and more effective operations. Information is more rapidly available, and where personnel may not be required for data exchange, more pervasive, paving the way for the seamless employment of unmanned vehicles.

DECISION SUPPORT

Mr. Christopher Strode

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

This project enhances the scientific understanding and tactical employment of Maritime Unmanned Systems (MUS) for ASW through Operational Research studies. As nations investigate such systems, they need to understand the performance space over which multiple vehicle configurations may be optimized, and which MUS capabilities offer the most promise. Further, a mechanism to enhance the effectiveness of operational ASW with existing assets through an ASW prediction service for exercises and operations will be delivered. This will enhance current command and control solutions to provide a simple interface to advanced sonar performance information. Finally, the continued improvement of NATO ASW capability through enhanced post-exercise reconstruction and Operational Analysis is called for.

Objectives

1. Operational Research study on the use of autonomous vehicles for ASW contributing towards a draft EXTAC.
2. Operational Analysis and exercise reconstruction with acoustic-level information.
3. Demonstrate the provision of real time active and/or passive predictions at sea.

Achievements

1. Rapid Acoustic Prediction Service. A web-based service-oriented architecture for MSTPA was developed building upon the federation of the MSTPA sub-elements. In Exercise Dynamic Mongoose 17, only the CMRE RAPS tool was able to predict correctly unusual detection performance associated with a very strong oceanographic front across the exercise area.
2. MSTPA Lite. An onboard environmental service, based on through-the-sensor rapid environmental assessment, was developed in 2017 and is now deployed onboard CMRE ASW AUVs.
3. ASW Exercise Reconstruction and Analysis. The serial reconstructions from Exercise Dynamic Mongoose 17 created by the InStride Debrief Team (IDT) were used as the basis of a CMRE-generated tactical debrief where RAPS was run to estimate platform performance of participating units against reported submarine positions.
4. Doctrine for Maritime Unmanned Systems for ASW. A draft EXTAC on unmanned systems for ASW has been prepared in conjunction with the Centre of Excellence for Combined Joint Operations from the Sea.

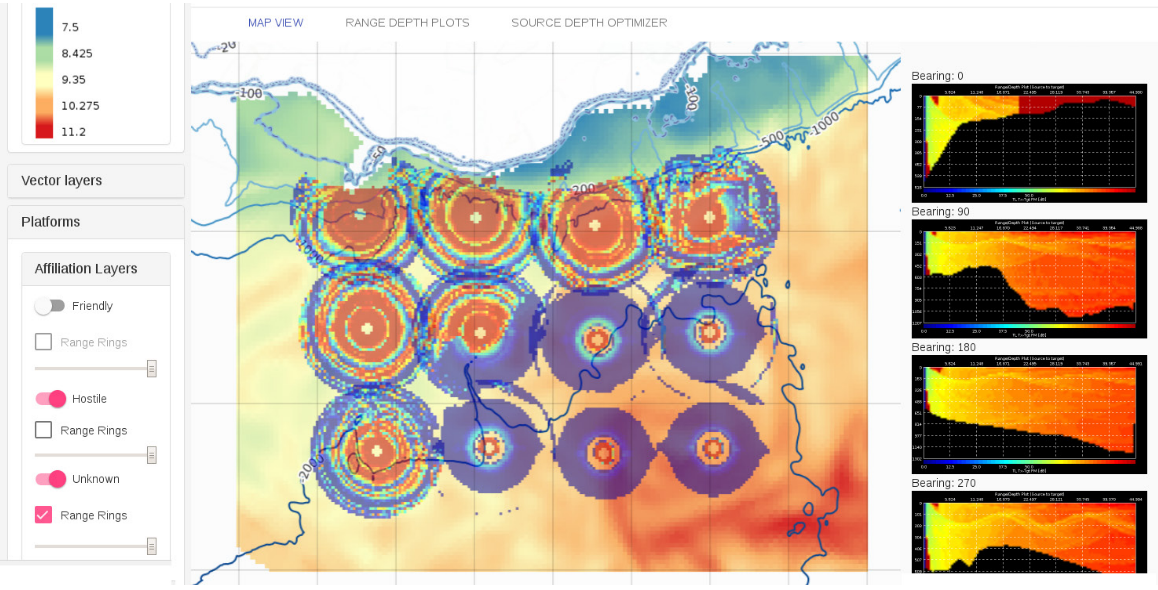
Exploitation and impact

The results of the operational analysis studies have contributed to the preparation of a draft EXTAC for unmanned ASW. It was shared with CJOS COE and was presented at the MAROPS WG in Jan. 2018. Plans are now being made to publish it.

The deployment of the RAPs tool on the NS sandbox network is being discussed with ACT. Successful installation could allow other NATO commands to experiment with it and to provide valuable feedback. The RAPS tool was also deployed at sea during DMON17 with great success onboard the Standing NATO Maritime Group 1 flag ship, HNoMS ROALD AMUNDSEN. The ability of the tool to provide operators with fast range-dependent performance predictions was greatly appreciated and eventually was preferred to their national tool.

Conclusion / Future

The Decision Support project continued to focus on the utility of unmanned platforms for ASW missions and on the development of the RAPS service, leveraging the federation of MSTPA modules from 2016. Operational analysis studies have taken the form of a cost-benefit analysis examining the effectiveness of AUVs for passive ASW as a function of their speed, array length, and numbers. This work will be expanded in 2018 in order to consider multiple vehicle types on a single cost-benefit surface. Further studies considered a higher level approach in which SMEs were asked to rate platform capabilities against ASW mission requirements. This culminated in tabular rankings for multiple MUS and mission configurations. The most promising platform/mission combinations from this study will be modelled in more detail in 2018. The RAPS tool has been developed following the earlier federation of MSTPA modules from 2016. In 2018, optimization studies will require as much processing power as possible.



Screenshot of RAPS tool showing Sonar Coverage variation over EXER AREA during DMON 17 off Iceland, July 2017)

Collaborative Scoping Study on a Concept for Arctic Underwater Acoustic Communications

Mr. Joao Alves

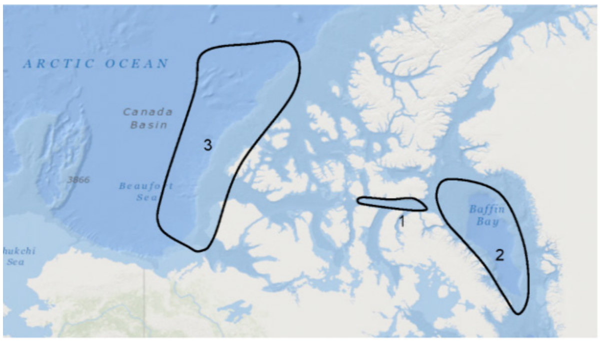
Cooperation: This project is being delivered in cooperation with Defence Research & Development Canada

Background

Defence Research & Development Canada (DRDC) aims to demonstrate an underwater acoustic communication network in the Arctic Ocean, including ice-covered areas, by 2020. To support this, an investigation of the technology available for underwater sensing nodes such as seabed hydrophone arrays, vertical line hydrophone arrays, and unmanned underwater vehicles (UUVs) was necessary. A network would link the sensing nodes over 100-400 kilometres, transferring information and providing navigation data for mobile nodes. DRDC needs to understand the trade-offs between frequency, diversity, directivity, range, data throughput and power/ endurance to inform the system design.

Objectives

To develop a concept, options and recommendations for long-range underwater acoustic communications in the Arctic Ocean, including ice-covered areas.



The areas studied:
Barrow strait (1), Baffin Bay (2) Beaufort Sea (3)

The application of the communications capability is for an autonomous network of sensor nodes. The work was limited to three months and provided an initial scoping study of the problem.

The study took into account the latest knowledge on the so-called "new Arctic" conditions. Four characteristic acoustic environments were defined: Arctic Ocean basin and a littoral Arctic zone, both in summer (open water) and winter (ice-covered). DRDC contributed to the definition of the environments.

Achievements

A report generated jointly by CMRE and DRDC describes the preferred solutions in terms of protocols (physical and network) and hardware including the preparation of a simulated environment with relevant channel realisations.

Scientific analysis:

- Selection of candidate waveforms based on simulation analysis with channel realisations.
- Analysis of networking needs/benefits and disadvantages (e.g. multi-hop for long distances, redundancy).

Engineering analysis:

- Selection of candidate COTS elements based on suitable size, weight, and power (SWAP) and core requirements such as frequency and bandwidth.
- Experimental concept validation.

Exploitation and impact

The results will inform future choices in terms of implementation and deployment of underwater communication networks in the high North regions, providing a clear indication of the trade-off space between performance, endurance, practicality, and other factors.

Conclusion / Future

This study demonstrates CMRE's ability to work directly with the Nations, addressing problems that can benefit from the specific expertise existing at CMRE. There is the willingness from both CMRE and Canada to continue this fruitful collaboration, validate results at sea and possibly explore new concepts with further studies.

Network Long Baseline

Dr. Kevin LePage

Cooperation: This project is being delivered in cooperation with the US Office of Naval Research and the US Naval Research Enterprise

Background

Underwater navigation is challenging for Autonomous Underwater Vehicles (AUVs) with traditional approaches relying on 'proprioceptive information' such as that from an Inertial Navigation System (INS) or from static beacons with known locations as external references, all of which require a trade-off between performance, cost, and operational applicability. An alternative investigated at CMRE, called Net-LBL, has shown that the inclusion of localisation data into a network can enhance AUV navigation even at long ranges and with sporadic communications. In fact, a network-based navigation system for AUVs has multiple potential advantages.

Objectives

1. Development of software for AUV-deployed, real-time implementation of the network long-baseline concept.
2. Development of navigation algorithms to allow the vehicles to fuse their odometric data (forward speed, heading, etc.) with range measurements from the network.
3. Evaluation of the system and of its components (i.e. navigation algorithms, network modules) and their validation through simulation and testing.
4. Testing the system at sea in a controlled environment and in operational scenarios.

Achievements

1. Novel architecture design for an underwater acoustic network to include localisation services.
2. AUV navigation algorithms able to exploit network-based localisation data.
3. Software modules integrating the proposed design and algorithms into networks and AUVs.
4. Simulation results.
5. Analysis of results from tests at sea.

The algorithms use open-source and open architectures so that the concepts can be ported and integrated into other networks and used by other potential collaborators. Outputs may foster additional research both in AUV navigation and in AUV autonomy built on top of network-enabled localisation services. Reports include underwater network architecture development, AUV navigation and localisation algorithms, component evaluation, and the results of tests at sea.

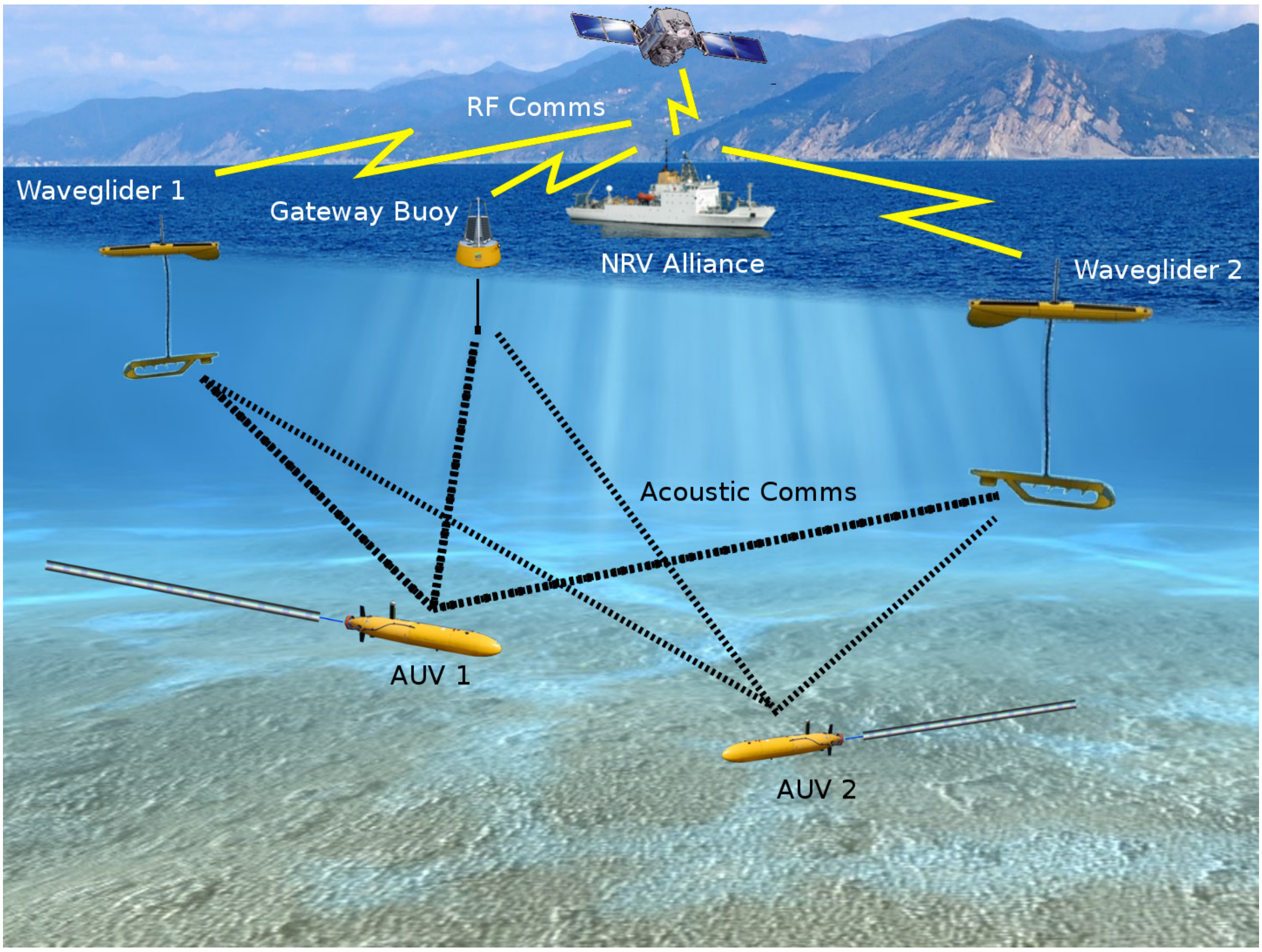
Exploitation and impact

Net-LBL proposes an innovative concept for AUV navigation. A preliminary evaluation of the major parameters of interest such as error characterisation, navigation performance with varying number of nodes or MAC layers, will help to characterise its robustness, limitations and potential applications. The Net-LBL project also represents a step forward to:

- Increase the capability of underwater networks;
- Facilitate greater persistence and autonomy of unmanned vehicles in operational missions;
- Enlarge unmanned vehicles operational areas, e.g. to deep water where bottom tracking is no longer possible, and into denied areas, where traditional infrastructure-based approaches are unavailable;
- Allow both cheaper and more capable vehicles to exploit deployed infrastructures to a greater degree.

Conclusion / future

The Net-LBL project is aligned well with several objectives of the US Naval Science & Technology Strategic Plan especially in the Focus Areas of Information Dominance – Cyber, Assure Access to the Maritime Battlespace, and Autonomy and Unmanned Systems. There is potential for further collaboration with ONR whose Ocean Battlespace program is currently emphasizing "Persistent undersea acoustic surveillance" and "Deployable autonomous distributed systems".



Cartoon of the Cooperative ASW network nodes involved in the NetLBL

Autonomous Mine Countermeasures

Collaborative Autonomous Mine Countermeasures

Dr David Williams

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

The Collaborative Autonomous Mine Countermeasures (CAMCM) project supports both the ACT Autonomous Security Networks Programme and national research programmes. The project contributes at a range of TRLs, from low level academic R&D to testing functional prototypes through experimentation at-sea. The programme is pivotal in advancing maritime autonomy for Mine Countermeasures (MCM) and addresses several aspects of NATO's Minimum Capability Requirements. In 2016, the focus of the project was altered to allow rapid development of collaborative autonomy for MCM. Additionally, the work has been aligned with the common draft NATO C2 vision.

Objectives

The primary objective of this project is to advance the utility of robotics in MCM through the development of autonomy. This includes the development of both single phase and multi-phase (collaborative) methods for mission execution, and mechanisms for merging the results and/or Measures of Effectiveness (MOE) of the phases, including the results from heterogeneous robotic platforms and sensors. As the project evolves, the autonomy capability will be applied to increasingly difficult operating environments and with an increasing number of heterogeneous vehicles, with the intent of expanding the range of environments that are considered "huntable" by CMRE's MCM toolbox.

Achievements

1. Advanced autonomy (REMUS). New, reacquisition approaches for standard REMUS100 platforms were demonstrated, in particular a 'sidescan focusing' manoeuvre in an open-loop mission, using contact location information gathered from an earlier MUSCLE survey.
2. Detection, Classification and Deep Learning. The work on Deep Learning intensified in 2017 with a renewed focus on the analysis of various informational layers, the transfer of knowledge from MUSCLE data to other types of acoustic imaging sensors and the combination of multiple convolutional neural networks for improved classification performance.
3. Heterogeneous AUV Operations in the Greek MINEX. An implementation of the newly developed Decoupled Collaborative Autonomy Framework (D-CAF) was tested in Exercise ARIADNE. Further, CMRE participated in an operational readiness trial with legacy systems from multiple nations and provided images and information on found targets. A new vehicle, the Black Collaborative Autonomy Testbed (BlackCAT) was launched, enabling further research on autonomy behaviours for target reacquisition, 3D target reconstruction and identification, and obstacle avoidance.
4. In-situ Planning and Evaluation (MUSCLE). In 2017 in-situ evaluation focused on estimating residual risk based on syn-

thetic aperture sonar (SAS) data collected by an AUV.

5. SHOEX. This shore-based experiment demonstrated a new MCM fly-away capability ready for overseas experiments in 2018. Additionally, D2CAF (the second version of the previous D-CAF) was successfully tested, connecting the BlackCAT and MUSCLE AUVs..

Exploitation and impact

In the long term, the BlackCAT will be available for Nations to integrate additional side-looking sensors or test their own onboard processing and autonomy behaviours. The Deep-Learning-based Automatic Target Recognition (ATR) continued to provide outstanding results and generated significant interest from Nations. A higher probability of target reacquisition was demonstrated; the planning and evaluation work advanced and is now starting to implement novel map concepts for future AUV-based MCM. Novel informational layers created in-mission onboard MUSCLE have also been successfully implemented and are the ideal platform for future Planning and Evaluation (P&E) and machine intelligent autonomy.

Conclusion / Future

This project will continue to advance the concepts of Autonomy and Perception for MCM using a heterogeneous combination of legacy and next-generation systems. Modern techniques for Deep Learning and ATR will be woven into updated doctrine for the Planning and Evaluation of MCM operations while the deliverables from other novel technologies such as the Low Frequency SAS project will also be applied.

21" AUV Black Collaborative Autonomy Testbed (BlackCAT)

High Resolution LF Synthetic Aperture Sonar

Mr. Reginald Hollett

Cooperation: The project delivers regular newsletters to subscribed members of the HRLFSAS Scientific Interest Group (SIG) which comprises governmental laboratories from the USA, UK, France, Netherlands, Belgium, Germany and Italy.

Background

Conventional high frequency acoustic systems offering high resolution images have been employed in mine-hunting operations for detection and classification of proud sea-bottom targets. However, the distinction between potentially life-threatening objects and clutter can be unsolvable in complex environments or for buried targets. Low frequencies offer the possibility of obtaining internal structural information from the target or penetration of the sound waves into the seabed, but suffers from poor spatial resolution. This project seeks to combine the benefits of low frequency propagation and synthetic aperture sonar (SAS) techniques to offer a high-resolution low frequency system.

Objectives

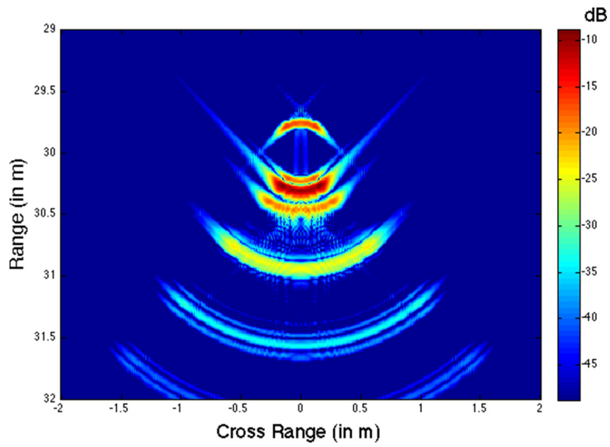
The project goals are to build a prototype low frequency wideband array for the detection and classification of mines in complex environments and/or buried targets, and to develop the processing and automatic target recognition (ATR) techniques that will enable the exploitation of the new sensor data. In particular, a complete understanding of the acoustic phenomena has to be achieved in order to provide standardised guidance to Nations on system optimisation and to operators for concepts of operations.

Achievements

A 2D transmit array was built with individual calibrated transducer elements. Additionally, a data set was collected on the CMRE rail where a set of known target types was imaged, providing the first experimental evidence of the potential applications of the system. Finally, the SIG workshop, held at CMRE 25 October, 2017, provided an opportunity for Nations to gain access to the details of the project and influence the way ahead.

Exploitation and impact

The project is a platform for Nations to observe and obtain knowledge of LFSAS including quantitative information on the optimal frequencies for operational effect. CMRE's work de-risks this new technology for Nations, which may not have the resources to develop it on their own. Furthermore, whilst operators can easily comprehend quasi-optical high frequency sonar images, a new approach will be required to analyse low frequency acoustic responses and images. CMRE is developing automated processing techniques to support operators and translate complex data into actionable information.



Simulated high resolution low frequency synthetic aperture sonar image

Conclusion / Future

The project continues in 2018 with the development of a larger 2D transmit array and the collection of additional data. Of particular interest is the optimisation of waveforms for the excitation of target resonances.

new BELgian MCM capability

Mr. Christopher Strode

Cooperation: This project is being delivered under direction, guidance and sponsorship of the Ministry of Defence of Belgium

Background

The BEL Navy required an analysis of the benefit of autonomous systems for minehunting operations and a comparison with legacy Mine Countermeasure Vessels (MCMVs). The vehicle was to be a two-week trial off the Belgian coast including an industry demonstration. A total of eight industrial entities demonstrated a wide range of systems, including autonomous underwater vehicles (AUVs) and unmanned surface vessels (USVs) employing both sidescan (SSS) and synthetic aperture sonars (SAS).

Objectives

CMRE was contracted by the BEL Navy to provide independent analysis of the performance of a number of minehunting systems, both traditional and autonomous, the latter demonstrated by industry participants. To this end, all participants carried out a series of trials in known exercise minefields, with the results provided to CMRE.

Achievements

Multiple metrics were employed to facilitate a detailed performance assessment of unmanned platforms against that of the legacy assets. These included the percentage clearance together with mission and analysis time, false alarm density and standoff ranges. Individual results and detailed analyses were provided to the respective industry suppliers, while a full report of the performance of all participants, and a comparison of different systems, was provided to the BEL Navy.

Exploitation and impact

The resulting report and analysis will be used by the Belgian Navy for the future procurement of unmanned MCM systems. The work demonstrated the Centre's ability to act as an independent assessor of military systems for a NATO Navy.

Conclusion / Future

The final report was delivered to the Belgian Navy and provided valuable insight towards the future procurement of an autonomous MCM capability.

Cubist-Inspired Deep Learning with Sonar for UXO Detection and Classification

Dr David Williams

Cooperation: This project is being delivered in cooperation with, and sponsored by, the US Department of Defense (Strategic Environmental Research and Development Programme)

Background

A legacy of military activities is the contamination of aquatic environments with munitions. In the United States, this applies potentially to more than 400 underwater sites, spanning more than 10 million acres. The presence of these munitions is a serious threat to both humans and the environment, so remediation is necessary. However, the return of these contaminated waters to public use is contingent upon the analysis and assessment of wide-area and detailed underwater surveys. Therefore, the US Department of Defense (DoD) has an express need for the development of technologies that will enable the detection and classification, at high probability, of military munitions found at underwater sites.

Objectives

The objective was the development of a framework for detection and classification of unexploded ordnance (UXO), by exploiting synthetic aperture sonar (SAS) data. The new algorithms were to be based on deep-learning techniques, specifically deep convolutional neural networks (CNNs), to enable higher probabilities of detection and classification, at much lower false alarm rates, than is possible with existing approaches. The application of these machine-learning algorithms to sonar data collected at potentially contaminated sites can guide remediation efforts to effect savings. Specifically, because fewer resources will be spent investigating harmless clutter, the cost of remediation should decrease substantially.

Achievements

The project addressed the need for robust detection and classification approaches for underwater UXO. A deep-learning framework was developed that, as a by-product, also automatically uncovers valuable classification features (via the learned CNN filters). The result of this work also has the potential to form a foundation for follow-on efforts that would seek to unify high-frequency and low-frequency sonar-data-based classification approaches.

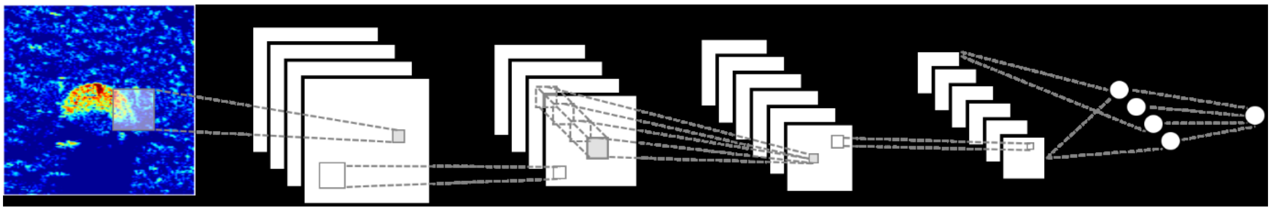
Exploitation and impact

This research laid the foundation for a more extensive and more ambitious follow-on project. The vision for the follow-on project is to create a single unifying framework for UXO classification that can simultaneously exploit HF sonar data, LF sonar data, environmental information, sensor characteristics, and other auxiliary information. The approach would build on the success of this seed project to construct multi-representation CNNs with greater sophistication that draw from more numerous information sources. The envisioned classifier would also be viable for transition to, and exploitation within, the MCM community with minimal modifications.

Conclusion / Future

This goal of unification is important because data collection is expensive, and there is a relative scarcity of UXO data (compared to computer vision applications where millions of examples are available for each class). In summary, the follow-on research has the potential to unify the UXO and

MCM communities, disparate sonar systems, and various research efforts, to achieve robust classification performance significantly beyond that which is achievable with present technology. Addressing the tasks outlined for the proposed project would initiate the march toward this grand vision.



Schematic of a basic CNN architecture consisting of an input image (shown here as a SAS magnitude mugshot), a convolutional layer with 4 filters, a pooling layer, a convolutional layer with 6 filters, another pooling layer, a fully-connected layer, and the final class probability output

Imaging SAS Performance Estimation

Dr David Williams

Cooperation: This project is being delivered in cooperation with, and sponsored by, the US Office of Naval Research

Background

At present, there is no complete method for quantitatively estimating overall acoustic detection and classification performance of minehunting systems. Their ability to separate target signatures from the surrounding environment varies with the quality of processed sensor output, which can be degraded for several reasons, including uncompensated motion, hardware malfunction, multipath, environment difficulties, target characteristics, image formation processing, and any subsequent post-processing. In addition, the automatic target recognition (ATR) method being used may have an impact on performance–an estimate of the bounds on detection and classification of a specified target type for a particular acoustic system. A framework for performance estimation and prediction would allow decision-making that could maximize the probability of detection and classification.

Objectives

The overall goal is to establish the framework for linking the environment, sonar system, and signal processing to ATR detection and classification performance, working with two fundamental metrics, quality and complexity, as they are supported by the consensus of the MCM research community. These metrics describe respectively the fidelity of sensor data and the environmental effects on ATR performance. To achieve this, data quality and complexity will be related to changes in ATR feature vector distributions and ultimately to performance via a loss in target/environment separability.

Achievements

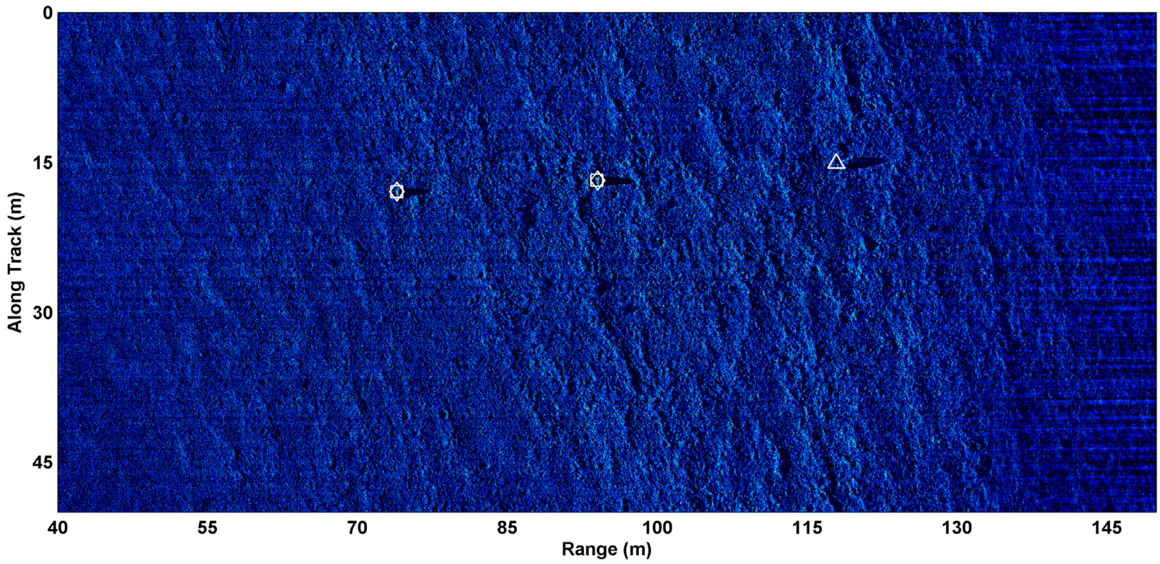
In 2017, the majority of the effort was devoted to ATR. A new detection algorithm, inspired heavily by the integral-image-based approach, though with considerable distinct differences, was developed. This new so-called Mondrian detection algorithm was developed for object detection in high-frequency (HF) SAS imagery. If a second low-frequency (LF) band image is available, the algorithm can exploit the additional information seamlessly via an auxiliary prescreener test, filling an important capability gap. A prescreener component limits the number of potential alarms with the main module searching for areas that pass a subset of pixel-intensity tests. A new set of reliable classification features has also been developed. The framework is uncomplicated intentionally to facilitate performance estimation, to avoid requiring dedicated training data, and to permit delayed real-time detection at sea on an autonomous underwater vehicle (AUV). Preliminary investigations into metrics for SAS image quality and complexity were initiated, with image quality development examining the use of mean-squared-error between full-resolution SAS imagery and smoothed versions. This will continue as planned in 2018. The focus will transition towards providing feedback, in the context of ATR, to the other team partners on the metrics they develop.

Exploitation and impact

The development of a performance estimation algorithm will support the Navy's use of ATR for minehunting systems. One perceived shortcoming is a lack of "self-awareness" to alert the users when the ATR is having difficulty making definitive classifications. A robust performance estimation tool will provide the users with an assessment of the reliability of ATR and, potentially, an evaluation of the number of targets remaining in an operational area on completion of a task. This type of information can be used to improve the effectiveness of the sensor through mission planning.

Conclusion / Future

The successful execution of the programme will be demonstrated at the end of 2018 in blind testing of the algorithms developed. This will serve as the first formal evaluation of the effectiveness of the proposed solution. The follow-on effort will include field demonstrations that will serve as an evaluation of the tool in an operationally relevant environment. The format of this evaluation will be developed and specified during the execution of the program. The performance estimation tool developed under the Base Effort will be matured in 2019-2020 to provide the Navy with a robust capability. At the same time, there may be one or more technology demonstrations where MCM SAS data will be collected and the performance estimation tool exercised.



Detections generated by the Mondrian detector for a MUSCLE SAS image with shell-covered seafloor. All three alarms are true targets

Maritime Intelligence, Surveillance, and Reconnaissance

Maritime Autonomous Networks and Smart Sensing for Secure Battlespace Characterisation

Dr Emanuel Coelho

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

Battlespace characterization requires the observation, analysis, prediction and mapping of environments, both on the surface and underwater. While there are solutions for NATO Military Oceanography and Rapid Environmental Assessment for open ocean and non-contested areas, there are no standard solutions for integrated, stealthy and secure characterisation of high risk domains. Solutions must include the ability to monitor the marine environment by tasking discreet sensors adaptively, while securely integrating, interpreting and exploiting the collected data for the operational advantage. ACT's Maritime Programme addresses these challenges with the goal of improving operations through a greater understanding of the ocean battlespace environment.

Objectives

1. Advance development of unmanned capabilities for surveillance and reconnaissance of natural environments and for Indication and Warning of signals of interest.
2. Advance new solutions for METOC for Battlespace Awareness in Anti-Access/Area Denial (A2/AD) zones, by turning environmental data into actionable information.
3. Integrate and leverage joint coalition environmental intelligence through the development of capabilities to facilitate the effective, efficient, and secure sharing of information and knowledge across all domains.
4. Investigate real-time data bases and evaluate the sustainability of persistent ASW and ISR missions in extreme ocean-acoustic environments.
5. Field tests, validation, operational integration and interoperability of unmanned technology for Battlespace Characterization.

Achievements

High-Latitude activities: Northern Recognized Environmental Picture 2017 (NREP17)

A unique set of scientific maritime expeditions off the coast of Iceland and Norway, at the margins of the Arctic Ocean revealed significant changes in the underwater environment that could have an impact on underwater surveillance and anti-submarine warfare (ASW) operations.

Enabling Maritime ISR using Robotic Networks

In CWIX17, information from live assets fed Command and Control (C2) and decision support systems to provide live glider C2 to final users. This contributed to the

NATO concepts Recognized Environmental and Maritime Pictures, and the Common Operational Picture (COP). CMRE's work demonstrated the operational relevance of the environmental information that was gathered and disseminated, and exposed new maritime ISR assets and products to NATO and the nations.

High-North Ocean-Acoustic Predictions Assimilating real-time Ocean Glider Data

Real time environmental characterization during the NREP17 trial was achieved with nowcasts and forecasts, fusing CMRE and other observation data through an Ocean Observing and Prediction System (OOPS). Data collected from NRV ALLIANCE, such as water column temperature and sound speed profiles, and from the fleet of gliders was transmitted to CMRE, quality checked in real-time, and combined with other data obtained from remote sensing satellites.

Long-Term Glider Missions for Environmental Characterization (LOGMEC17)

The LOGMEC17 sea trial was a study of the variability and predictability of the acoustic and oceanographic environment in the Ligurian Sea with 15 partners. Preliminary data analysis has shown very interesting small scale structures impacting the sound propagation.

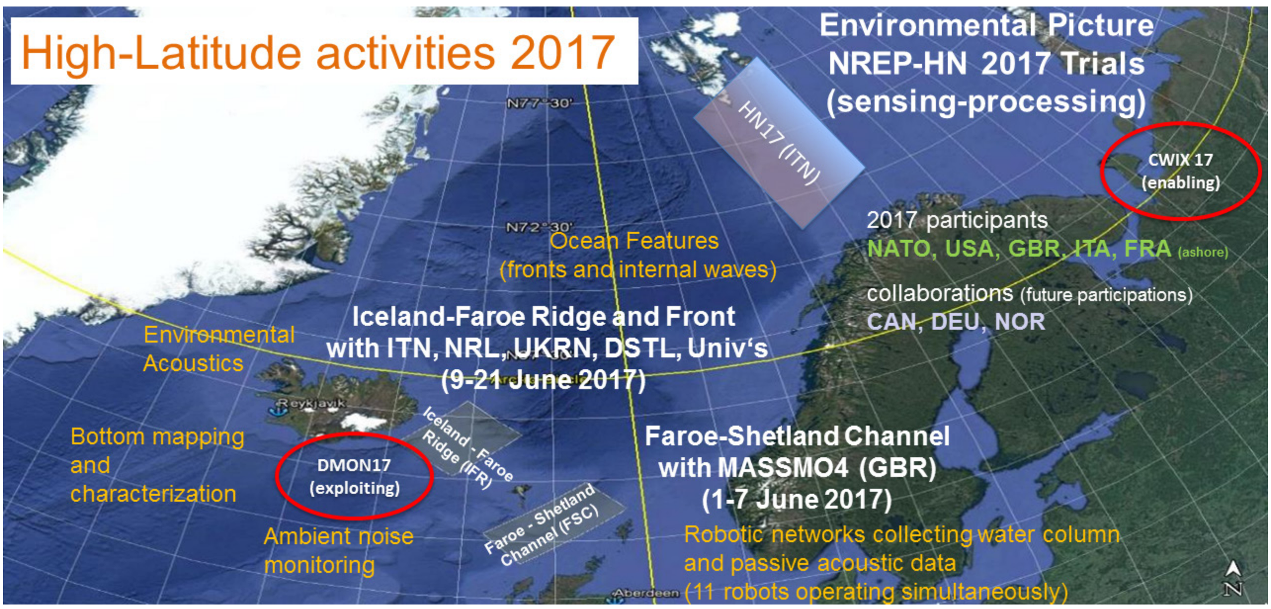
Exploitation and impact

In NREP17 a fleet of coalition Maritime Autonomous Systems (MUS) collected a large METOC dataset, enabling the investigation of the assimilation of data into ocean models and evaluation of forecasting skills. Participation in an Italian Navy (ITN) sea trial, the first deployment of CMRE gliders north of the Arctic Circle, facilitated better assessment of battery capacities and limitations in cold waters. Participation in CWIX17 exposed the operational community to the capabilities of underwater gliders and of remote C2 of gliders operations at sea.

Conclusion / Future

The following activities are foreseen for the future:

- Continued emphasis on high latitudes (Greenland Sea, Fram Strait, Svalbard):
- Large glider fleet operations and C2 integration;
- Simulated glider data into ocean prediction models to improve sound speed forecasts.



Schematic of High-Latitude activities, 2017

Sensing and Predicting Underwater Noise using Robotic Platforms and Forecast Models for Maritime ISR

Dr Emanuel Coelho

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

Operationally relevant characterization of the underwater battlespace requires accurate information on acoustic ambient noise and the ability to predict it. Ambient noise is a key parameter needed to estimate the performance of underwater sensors and to predict detection and counter-detection ranges. In this project, CMRE's goal is to demonstrate the sensing and prediction of acoustic ambient noise, and to make the information available to performance prediction models in an operational setting.

Objectives

1. Improve sensor and network capabilities for hydrophone/array-equipped underwater gliders monitoring the ambient noise environment.
2. Develop signal-processing for hydrophone/array-equipped underwater gliders for detection and classification of signals of interest.
3. Improve and evaluate capabilities for forecasting underwater acoustic noise by assimilating the data collected by underwater gliders into ocean-acoustic numerical prediction models.
4. Access new acoustic remote sensing modalities and techniques for charactering seabed geoacoustic properties.

Achievements

Wide-angle bottom loss measurement using hydrophone-equipped underwater glider

CMRE demonstrated the measurement of wide-angle bottom loss, an important acoustic parameter for predicting acoustic system performance, by exploiting ambient noise measurements from using hydrophone/array-equipped underwater gliders.

On the uncertainty of source localization using a fleet of three underwater gliders

A fleet of three gliders was used to demonstrate the detection of signals of interest and the automatic reporting of data back to the control centre at CMRE. The demonstrated capability has significant tactical applications.

Acoustic propagation characteristics in the High North

An acoustic experiment at high latitudes aiming to understand the impact of the water column environment on long range acoustic propagation identified how the Iceland Faeroe Front influences long range acoustic propagation.

Underwater ambient noise modelling capability development

A framework to facilitate interoperable modeling of the ocean physical environment and the underwater ambient noise field was created.

Information Exploitation – DMON17 Environmental Characterization Experimentation

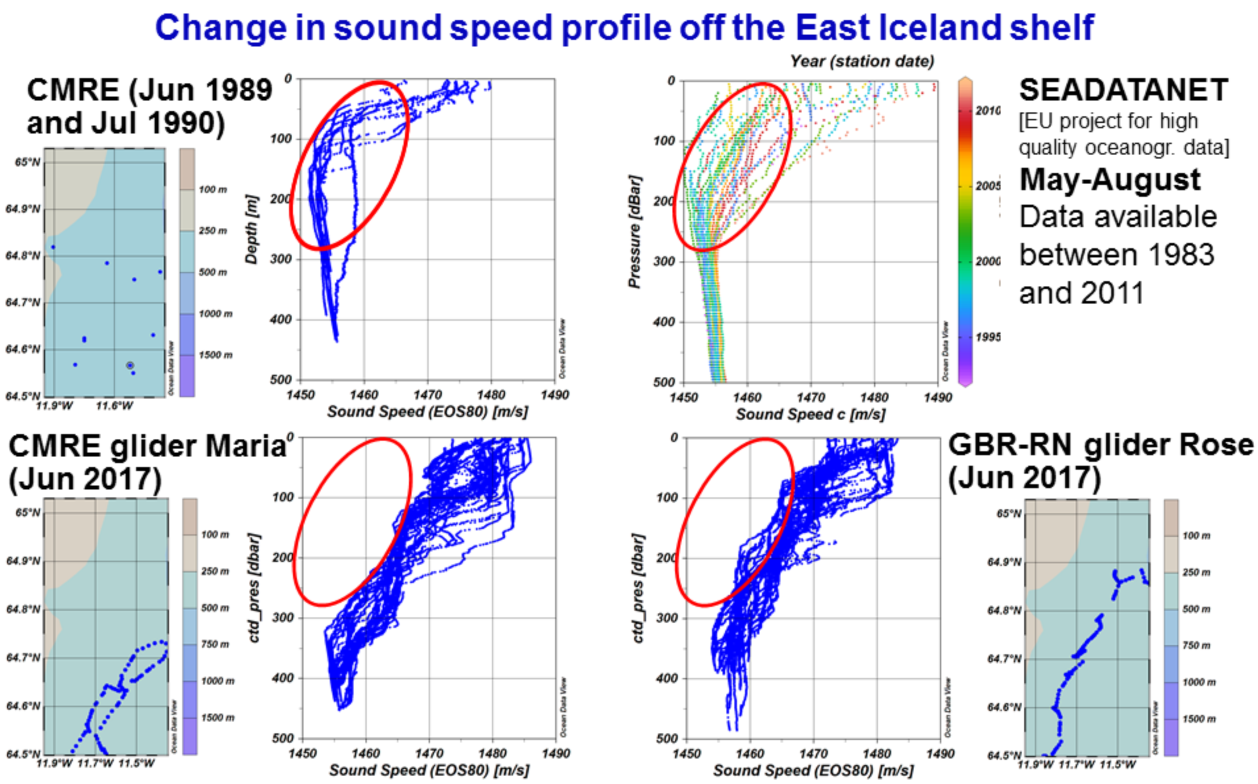
During NATO Exercise Dynamic Mongoose 2017, CMRE demonstrated the operation of ship-based systems for ocean floor and water column mapping, autonomous glider networks and high resolution numerical simulations and data assimilation tools to characterize and predict the local underwater "weather". The tools were successfully demonstrated in an operational context.

Exploitation and impact

In NREP17 a fleet of coalition MUS collected a large METOC dataset, enabling the investigation of changes in ocean properties, the assimilation of ocean models and the evaluation of forecasting skills. Participation in an ITA sea trial, the first deployment of CMRE gliders north of the Arctic Circle, facilitated a better assessment of battery capacities and limitations in cold waters. Participation in CWIX exposed the operational community to the capabilities of underwater gliders and allowed experience of remote command and control (C2) of gliders at sea.

Conclusion / Future

Future work includes in situ data assimilation into ocean acoustic models; ambient noise characterisation and prediction, leveraging improved glider acoustic sensing capabilities. Also foreseen is high spatial resolution modelling of ocean frontal systems and comparison to LOGMEC data to better understand the underwater acoustic environment in high-dynamic ocean conditions.



Example of the drastic change in sound speed profiles (SSP) observed on the Icelandic Shelf. Top panels show the SSP derived from observations made by CMRE (summer 1989 and 1990) and SEADATANET project (1983 - 2011). SSPs observed during the NREP sea trial are shown in the bottom panels

Glider with Acoustic Payloads for Seabed Characterisation

Dr Yong-Min Jiang, Mr. Bartolome Garau Pujol, Mr. Richard Stoner, Mr. Luigi Troiano and Dr Daniele Cecchi

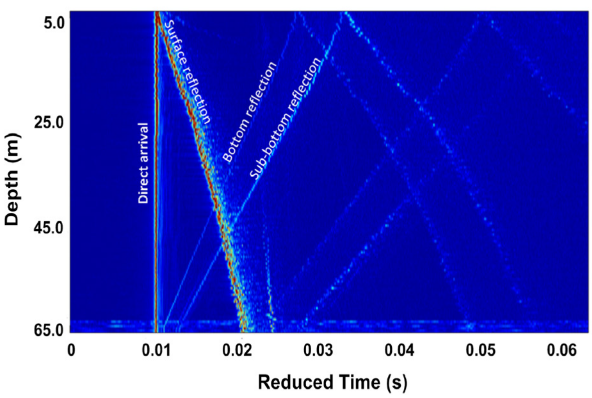
Cooperation: This project is being delivered in cooperation with, and sponsored by, the US Office of Naval Research

Background

Seabed geoacoustic properties (SGPs) have a profound impact on sonar performance in littoral regions. Conventional techniques for determination of SGP, such as taking geophysical cores or remote sensing using acoustic sources and receivers, often involve at least one ship, hence are time consuming and costly. CMRE has developed a new seabed characterization technique based on the use of underwater gliders equipped with acoustic payloads. This rapid and inexpensive technique supports the future NATO capabilities of battlespace characterization (BC) and battlespace preparation (BP) in denied or hostile littoral areas.

Objectives

The objective of the project was to prove the concept of using underwater gliders with acoustic payloads to passively characterize SGPs, specifically to measure wide angle bottom loss (or bottom reflection coefficient) as a function of grazing angle and frequency.



Matched filtered results showing the direct, bottom reflected and surface reflected arrivals at the glider

Achievements

Two CMRE underwater gliders with passive acoustic payloads developed at CMRE were used during the 'Seabed Characterization Experiments 2017 (SBCEX'17). The SBCEX'17 trial was sponsored by the US Office of Naval Research (ONR) and ONR Global. CMRE's experiment took place 6-19 March, 2017 at the "Mud Patch", which is located 110 km south of Cape Cod, Mass, USA. A broadband, wide angle bottom loss measurement technique, which was developed for the gliders, was successfully demonstrated for the first time during the trial. The grazing angle range of the bottom loss, that is critical for determining different sea floor types, was obtained. CMRE continues to work closely with the partners of SBCEX'17 comprising eleven US and four other research organizations. Post-trial work with the partners includes further work to estimate seabed geoacoustic properties from the data obtained, quantifying uncertainty of the estimates, and then to benchmark CMRE's new approach against other seabed characterization techniques.

Exploitation and impact

CMRE is one of the front-runners in transforming conventional sea floor characterization techniques to underwater gliders. This work will enable further development of the technique. By using fleets of gliders with active/passive acoustic capabilities, it is expected to be possible make BP/BC missions in denied or hostile littoral areas possible in a cost effective way.

Conclusion / Future

The concept of characterizing the seabed by measuring acoustic reflection coefficients at the sea bottom using hydrophone-equipped gliders has been successfully demonstrated at sea. The next step will be to fully exploit the data obtained during the trial by estimating SGP over a wide range of frequencies and to set requirements for future developments.

Data Knowledge & Operational Effectiveness

Data Knowledge and Operational Effectiveness

Mr. Johnathan Locke, Dr Paolo Braca, Dr Anne-Laure Jousselme

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

Situational awareness of surface maritime traffic, including the commercial vessel "White Picture," is complicated by a lack of sensor coverage away from coastal areas, reliance on the voluntary transponder-based Automated Identification System (AIS), requirement for both international and inter-agency information sharing, and the enormous challenge of identifying vessel intent. Research in this project leverages previous work in the areas of multi-sensor data fusion, the extraction of maritime traffic patterns from historical data, reasoning under uncertainty with partially reliable sources, and gaming approaches to further enhance the state-of-the-art in addressing the challenges for information management in the maritime domain. The 2017 project includes Exploiting Information Variety and Exploiting Information Volume.

Objectives

The objective of the Data Knowledge and Operational Effectiveness project is to provide speed and accuracy to information processing techniques enabling Maritime Information Superiority. This is done through the development of focused research products which are then integrated into a testbed environment able to interoperate with networked systems, including military C2 systems. Research products are evaluated by the NATO Shipping Centre, MARCOM, to provide feedback and assessment of operational utility.

Achievements

1 The Vessel Prediction Layer is developing methods to improve the long-term prediction of the behaviour of vessels at sea. Predicting vessel location and movement informs the warfighter of what to expect, facilitates an intercept for boarding, and influences acoustic planning and operations based on prediction of underwater acoustic conditions.

2 The MPOLIS Port Product Demonstrator characterises the maritime Pattern-of-Life (PoL) in a way that is relevant to defence and security.

3 The work on Scalable Multi-sensor Data Fusion seeks to provide scalability for many of the algorithms or that are applied in the other products.

4 Information Processing Architecture Development considers the placement and management of sensors in MSA applications and reports the efficient management of multiple sensor platforms searching for vessels of interest.

5 Uncertainty Characterization for Human-Machine Hybrid Decision via a Risk Game Methodology formalises uncertainty representation, defines measures of inconsistency and implements a gaming methodology for experts' knowledge elicitation.

6 A Table Top eXercise (TTX) gathered experts from the operational community across NATO nations to address MSA issues, related to the common

understanding of the MSA concept, and uncertainty or source reliability handling.

Exploitation and impact

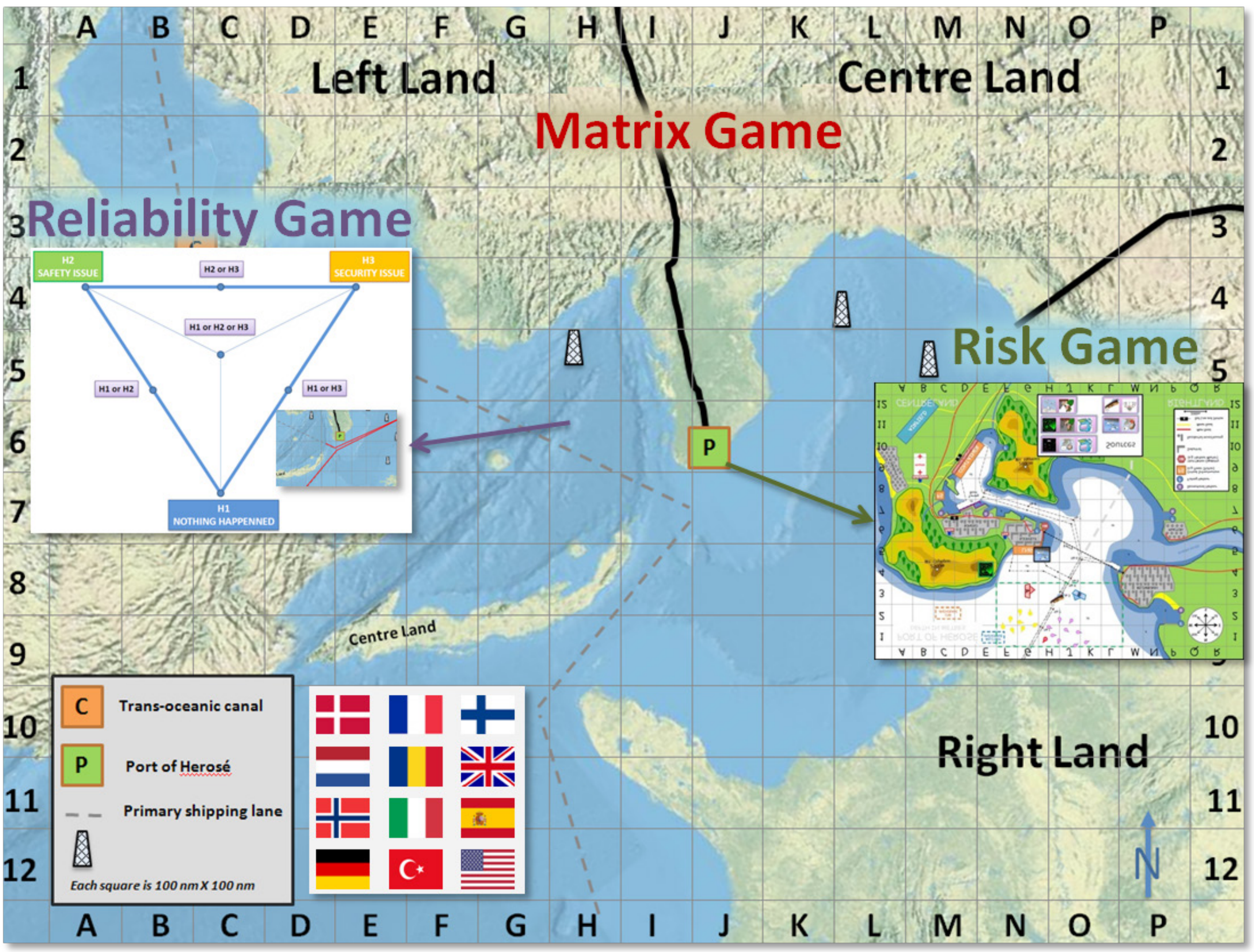
The solutions address specific Maritime Situational Indicators (MSIs) of the MARCOM MSA Direction & Guidance, such as vessels proceeding with course and speed inconsistent with reported next/last port of call, and vessels suspected of transmitting false AIS data. The adaptive multi-sensor-multi-target algorithm allows continuous estimation of several unknown parameters, which translates into a reduction of the probability of missing a vessel of interest. Many maritime surveillance and situational awareness applications can benefit from this capability.

Conclusion / Future

We demonstrated the ability to capture and process different kinds of information about shipping and measure possible conflicts between sources as an indicator of suspicious behaviour. The proposed framework can be instantiated to solve other problems involving diverse sources of information.

An exit survey judged the TTX to have been a success and a useful contribution to the wider understanding of MSA within the NATO operational community. CMRE's new Reliability Game was validated as an efficient means to gather data.

The belief propagation (BP) message-passing scheme can be used to develop a Bayesian multi-sensor/multi-target tracking algorithm that can adapt to unknown model parameters.



Game boards of the Table Top eXercise (TTX) on Maritime Situation Awareness, held at CMRE in May 2017: The Matrix Game focused on MSA, the Risk Game focused on information quality, and the Reliability Game focused on source quality

Pattern of Life model parameterization for exploitation in Command and Control Systems

Mr Leonardo M. Millefiori, Dr Raffaele Grasso, Dr Paolo Braca

Cooperation: This project is being delivered in cooperation with Defence Research & Development Canada

Background

Defence R&D Canada, the research agency of the Canadian Department of National Defence, has a requirement to analyse and manage sparse data.

Objectives

The objective was to integrate new algorithms into national and NATO tools, thereby extending the state-of the-art for exploitation of sparse data. The algorithms include existing data fusion, machine learning, and prediction techniques. Initially, the activity focused on the extension of the CMRE Traffic Route Extraction and Anomaly Detection (TREAD) model. The activity led to the formulation of probabilistic techniques to extract recurrent ship behaviours in the form of a network traffic graph, and exploit them for track correlation and prediction.

Achievements

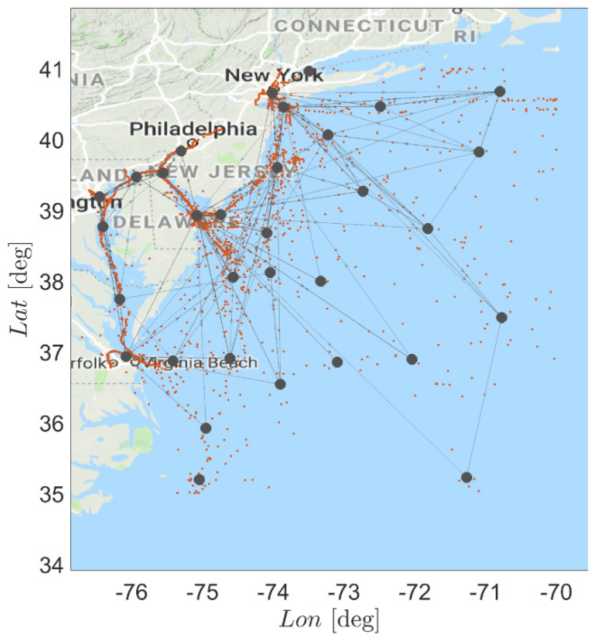
Algorithms based on kinematic modelling of vessel movement through mean-reverting stochastic processes were used to generate patterns of life (PoLs). Specifically, a parametric change detector and several clustering techniques were developed and tested on real data to detect recurrent ship manoeuvring points. In addition, strategies to infer the network graph topology from ship waypoints have been developed, which rely on hidden Markov models for the representation of ship motion across the graph. Finally, techniques to associate a live track to one edge (or vertex) of the traffic network graph have been formalized, relying on the underlying probabilistic model. An enhanced vessel location prediction algorithm combines all these elements to produce accurate and contextually-informed predictions.

Exploitation and impact

Novel techniques for vessel prediction based either on historical routes or other context-enhanced position forecasting, can be introduced in a future maritime command and control (C2) system.

Conclusion / Future

This project laid the theoretical foundations for the development of knowledge discovery techniques in a probabilistic framework. The traffic model fitting procedure and the association algorithm were tested qualitatively using real AIS datasets, with promising results. Future work will focus on the definition and implementation of metrics for the quantitative evaluation of the performance of the association algorithm.



Traffic graph model resulting from the analysis of AIS data provided by DRDC

Engineering

Persistent Autonomous Reconfigurable Capability

Robert Been, Gianfranco Arcieri, Francesco Baralli, Alberto Grati, Stefano Fioravanti, Alberto Tremori, Arnau Carrera, Pilar Caamaño

Cooperation: This project is being delivered under direction, guidance and sponsorship of NATO's Allied Command Transformation

Background

CMRE has been actively involved in maritime unmanned systems (MUS) S&T for over fifteen years. The project Persistent Autonomous Reconfigurable Capability (PARC) was started in 2014 to assist NATO in preparing for the future in this domain. The project supports ACT's Autonomous Security Networks Programme.

Objectives

PARC focuses on increasing MUS capabilities, scalability, interoperability and persistence whilst addressing standardisation and information assurance. The technical approach builds on the experience that CMRE has accumulated in the last two decades with regard to the specification, procurement, modification, design, prototyping and fielding of MUS.

Achievements

1. Modelling and Simulation federates were developed. The Verification and Validation (V&V) of each federate was completed and a preliminary integration test was run successfully.
2. In interoperability and standardisation, PARC contributed to NATO's Multi-Domain Control Station (MDCS) working group (WG), scoping the work for a STANAG (4817) in 2018. A technical activity proposal (TAP) was prepared on 'security challenges for multi-domain autonomous and unmanned C4ISR systems'.
3. Milestones were met in architecture design and the implementation of a service-oriented architecture software payload for a MUS and the Autonomous Naval Mine Countermeasure (ANMCM) payload tested at sea.
4. Improvements were made to the hardware and software of the Wireless Power Transfer (WPT) module and fast underwater data link in an eFolaga AUV and the docking station. A long duration mission for a 'port protection' scenario was conducted.

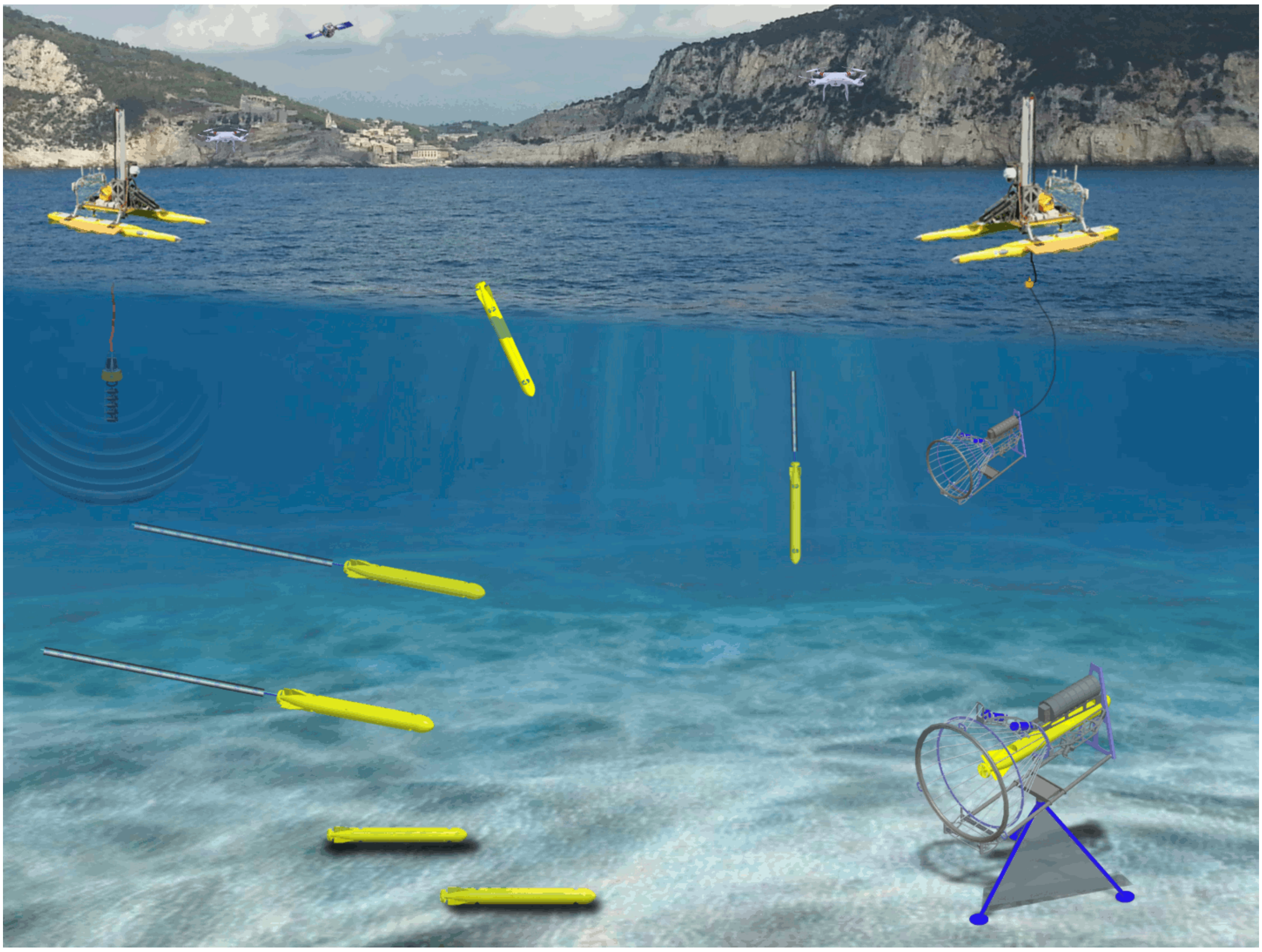
Exploitation and impact

The project supports STO Panel activities on Autonomy in Communications-Limited Environments, Security Challenges for Multi-Domain Autonomous and Unmanned C4ISR Systems, Autonomy from a System Perspective, and Cyber Security Challenges of Autonomous Multi-Domain Vehicles. Project staff participated in the

yearly symposium of the Joint Industry Project on Launch and Recovery of Unmanned Systems (JIP LAURA).
Several Nations have expressed interest in CMRE's work on the persistence of MUS with the potential for future collaboration. Exploitation within the European Union (EDA, H2020) is also being explored.
The M&S capability was demonstrated at the Inter-service/Industry Training, Simulation, and Education Conference (I/ITSEC) at Orlando, Florida in Nov. 2017. Further demonstrations will be performed at Exercise VIKING 2018 based in Sweden distributed across sites in 50 countries.

Conclusion / Future

The Multi-Domain Control System (MDCS) working group, which CMRE has been part since 2012, aims to establish a STANAG (number 4817) in 2018. CMRE has been a successful contributor to the team, offering domain expertise, software architects, cyber knowledge, hands-on experience and operational experimentation input.
Bringing together the robotics, M&S and C3 communities, has resulted in the successful operation of hardware and software in the loop, C3 functionality and distributed simulation capabilities. This, with the adoption and implementation of standards, specifically the High Level Architecture (HLA) and Service Oriented Architecture paradigms, will allow further S&T activities in support of NATO and Nations.
The feasibility of a docking station for AUVs, providing navigation assistance to homing, contactless battery recharging, and a high-speed underwater data link, was demonstrated. The concept, designed with a high degree of scalability and interoperability, was showcased during a long duration mission, and has proven to be highly successful.



Inductive recharging unit for AUVs

Towed Array for the Italian Navy

Mr. Rod Dymond, Mr. Gordon Murray, Mr. Luigi Troiano

Cooperation: This project is being delivered in cooperation with, and sponsored by Leonardo Defence Systems for the Ministry of Defence of Italy

Background

CMRE's multi-decade experience in designing, building and operating towed hydrophone arrays is well recognised internationally and has resulted in a number of contracts for the design and realisation of arrays to customer specifications. The latest such contract was awarded to CMRE by Leonardo Defence Systems (LDS), one of the world's top ten defence companies.

Objectives

Design and build a military-grade towed array, to the customer's acoustic and mechanical specifications. Design and build a purpose-built hosing/dehosing system. Technology transfer to the customer via on-site training sessions during the construction phase.

Achievements

The project utilised CMRE's engineering facilities, including acoustic calibration, tensile test bench, pressure chamber, moulding and machine shop facilities and the off-site array construction building in Valdilocchi. Key stages in the design process included:

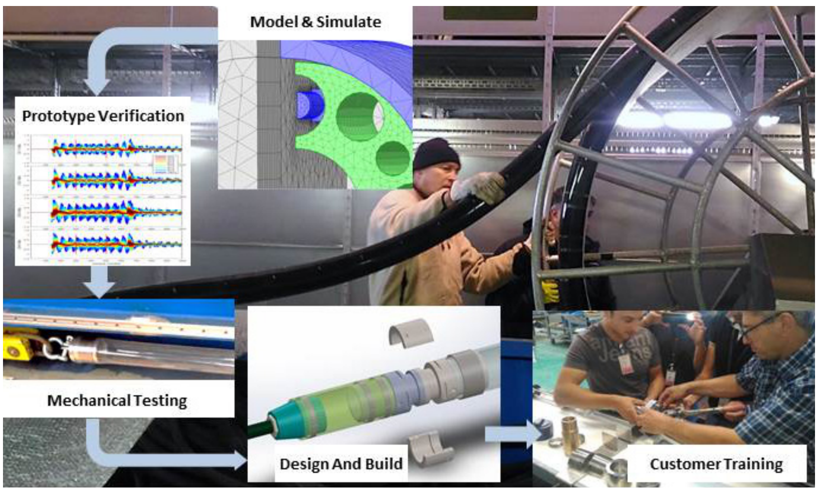
- modelling of the acoustic scattering within the hose/spacer/oil assembly and the resulting frequency and spatial response of the hydrophones using finite element modelling (FEM) software
- verification of the modelled results using a prototype array module in the acoustic test-tank
- design of a mechanical hose termination and subsequent dynamic tension testing to full static force, with superimposed vibrations
- building a test module to evaluate problems associated with winding/unwinding operations on the winch drum
- close cooperation with the customer throughout the design and realisation stages, particularly for the integration of customer-supplied electronics and coordination of the training sessions.

Exploitation and impact

To satisfy the challenging military specifications, design and development of a number of new components and techniques was required in the fields of mechanical, electrical and acoustical engineering. This has enriched CMRE's knowledge and expertise in the field.

Conclusion / Future

The project came to a successful conclusion with the delivery of the towed array in December 2017. Since delivery, LDS has requested a quotation from CMRE for the design and realisation of a related system.



Main photo: winding the array onto a drum, ready for delivery Insets: show some of the key phases in the design and realisation of the LDS array: FEM simulation; acoustic prototype evaluation; tension and vibration testing; mechanical design and customer training.

European Commission

Various Projects

SUNRISE:
Mr. Joao Alves, Dr Roberto Petroccia, Dr Costas Pelekanakis, and Dr Giovanni Zappa

ROCK-EU2: Dr Gabriele Ferri

RANGER: Dr Paolo Braca

DATACRON: Dr Anne-Laure Jousselme, Dr Elena Camossi

MARISA: Dr Anne-Laure Jousselme, Ms Francesca de Rosa

CAMELOT: Dr Stefano Fioravanti

ROBORDER: Dr Alberto Tremori

Background

According to the Warsaw Summit Joint Declaration by the European Commission (EC) and NATO 2016: "We believe that the time has come to give new impetus and new substance to the NATO-EU strategic partnership… we believe there is an urgent need to broaden and adapt our operational cooperation including at sea, and on migration, through increased sharing of maritime situational awareness as well as better coordination and mutual reinforcement of our activities in the Mediterranean and elsewhere." Accordingly, following submission to the EC in the 2014-2016 timeframe, CMRE participated in several EC projects in 2017.

Objectives

SUNRISE: Develop a federation of underwater testing infrastructures for novel technologies for ocean monitoring.

ROCK-EU2: Provide networking, education and outreach, for the European robotics community through the organization of robotics competitions.

RANGER: Combine innovative radar technologies with novel solutions for detection and tracking.

DATACRON (Big Data Analytics for Time Critical Mobility Forecasting): Develop novel methodology and architecture for big data analytics, prediction and visual analytics.

MARISA (Maritime Integrated Surveillance Awareness): Provide a toolkit to fuse data from heterogeneous sources to improve information exchange and situational awareness.

CAMELOT (C2 Advanced Multi-Domain Environment and Live Observation Technologies): Develop modules for a modular, scalable command and control station for surveillance.

ROBORDER (Autonomous Swarm of Heterogeneous Robots for Border Surveillance under Extreme Conditions): Develop an autonomous surveillance system with multimodal sensors in an interoperable network.

Achievements

SUNRISE: Underwater systems technology, seagoing operations and system integration. Definition of software-defined acoustic modem and communications. Integration and testbed operation.

ROCK-EU2: Organised a large scale air, land and sea competition, the second multi-domain multi-robot competition in the world.

RANGER: Demonstrated accurate, long distance detection and identification of small boats, to improve response and intervention.

DATACRON: Demonstrated trajectory mining and route extraction, and prediction algorithms for the maritime domain; design and implementation of the maritime use case; design of experiments and evaluation of the prototype.
MARISA: Developed a multisource dynamic behavioural analysis service which takes into account source quality to improve situation assessment under uncertainty. Developed methods to improve context extraction in the maritime domain and exploitation for vessel kinematic prediction.
CAMELOT: Developed a simultaneous localization device for multiple vehicles. Spiral wave-front beacon hardware and software design. Signal processing software for estimation of direction and time of arrival. Integration into JANUS and CAMELOT interoperability layer.
ROBORDER: Definition and setup of pilot cases. End-user evaluation plans and methodology by demonstrations and interoperable modelling and simulation, both hardware-in-the-loop and software-in-the-loop.

Exploitation and impact

The Centre continues to be successful with Horizon 2020 proposals when measured against other research institutions. The Centre's involvement with EC Consortia has strengthened its network within the European research community and facilitates involvement in other EU-funded initiatives. However, the return on investment has been moderate with the volume of work unlikely ever to match that sponsored by NATO. Plans are being made to transition to a more strategic relationship to place the Centre at the core of a major EC programme. The Preparatory Action initiative presents such a new opportunity. There is also the prospect of brokering a joint EC-EDA relationship that would open up opportunities to participate in European defence initiatives organised by these bodies.

Conclusion / Future

CMRE engagement with the EC offers considerable potential for funding for CMRE to do work in the defence and security domains. However, the overhead required to compete for many relatively small EC projects diminishes their benefit to the Centre and also poses challenges for the long-term strategic direction of CMRE. The Centre secured a place in the European Commission's (EC) Maritime Demonstrator (MD)/Ocean2020 project but the current procedures for authorisation within NATO are stifling progress.

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