SCIENCE AND TECHNOLOGY ORGANIZATION
CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

Conference Proceedings **CMRE-CP-2019-003**

Conference proceedings of the Sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)

Raúl Vicen-Bueno, Ines Borrione and Stefan Wittwer

April 2020

About CMRE

The Centre for Maritime Research and Experimentation (CMRE) is a world-class NATO scientific research and experimentation facility located in La Spezia, Italy.

The CMRE was established by the North Atlantic Council on 1 July 2012 as part of the NATO Science & Technology Organization. The CMRE and its predecessors have served NATO for over 50 years as the SACLANT Anti-Submarine Warfare Centre, SACLANT Undersea Research Centre, NATO Undersea Research Centre (NURC) and now as part of the Science & Technology Organization.

CMRE conducts state-of-the-art scientific research and experimentation ranging from concept development to prototype demonstration in an operational environment and has produced leaders in ocean science, modelling and simulation, acoustics and other disciplines, as well as producing critical results and understanding that have been built into the operational concepts of NATO and the nations.

CMRE conducts hands-on scientific and engineering research for the direct benefit of its NATO Customers. It operates two research vessels that enable science and technology solutions to be explored and exploited at sea. The largest of these vessels, the NRV Alliance, is a global class vessel that is acoustically extremely quiet.

CMRE is a leading example of enabling nations to work more effectively and efficiently together by prioritizing national needs, focusing on research and technology challenges, both in and out of the maritime environment, through the collective Power of its world-class scientists, engineers, and specialized laboratories in collaboration with the many partners in and out of the scientific domain.

CMRE-CP-2019-003

Conference proceedings of the Sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)

Raúl Vicen-Bueno, Ines Borrione
and Stefan Wittwer

This document, which describes work performed under the Project SAC000906 (EKOE 1 - *Maritime Autonomous Networks and Smart Sensing for Stealth and Secure Battlespace Characterization*) of the NATO STO CMRE Programme of Work sponsored by NATO Allied Command Transformation (ACT) / Innovation Branch, has been approved by the CMRE Director.

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Conference proceedings of the Sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)

Raúl Vicen-Bueno, Ines Borrione and Stefan Wittwer

Executive Summary: NATO STO Centre for Maritime Research and Experimentation (CMRE) organized the sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT) under the sponsorship of the NATO Allied Command Transformation, Innovation Branch. The workshop took place at CMRE, La Spezia, Italy, from the 12-14 November 2019.

The WMAUGT is a continuous effort of the Environmental Knowledge and Operational Effectiveness/Maritime Intelligence Surveillance and Reconnaissance programme at CMRE to bring together the military, industrial and research/academic communities to discuss the requirements of underwater glider technology for military applications (e.g., MISR or Anti-Submarine Warfare missions); to define future research and development challenges for underwater glider technology; and to provide a forum for the military communities of NATO and NATO Nations to express their interests in research and experimentation on this technology.

More than 40 participants, affiliated with 10 NATO Nations, 5 NATO Bodies and 20 different institutions, organizations and companies, attended the 6WMAUGT. This level of participation, especially when compared to the attendance of previous workshops, denotes a continuous interest of the NATO Nations, their industries and research institutions in using underwater glider technology to not only explore and characterize the maritime domain, but also to understand the potential of this technology in military applications.

In total, 20 abstracts were submitted for oral presentations, among which two were keynote speeches from NATO Headquarters and NATO Supreme Allied Headquarter Europe/Allied Command Operations. Relevant workshop outcomes were collected and discussed during the final plenary session, which was organized to collect military requirements, recommendations, issues/ challenges and future research topics for underwater glider technology from all participants. Many new topics, such as the integration of unmanned underwater gliders with other maritime unmanned systems, the integration of new sensing capabilities and the extension of their applicability to other missions/operations, were thoroughly discussed by the participants.

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Conference proceedings of the Sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)

Raúl Vicen-Bueno, Ines Borrione and Stefan Wittwer

Abstract: Under the sponsorship of the Innovation Branch at NATO Allied Command Transformation, NATO STO Centre for Maritime Research and Experimentation (CMRE) organized the sixth *Workshop on Military Applications of Underwater Glider Technology* (6WMAUGT). The workshop was held for NATO and NATO Nations from 12-14 November 2019 at CMRE facilities in La Spezia Italy.

The 6WMAUGT joined more than 40 participants. The 2019 event resulted in a significant increase in the number of military attendees, denoting the great interest NATO and NATO Nations have in underwater glider technology and its applications for military purposes. Overall, participants represented 10 NATO Nations (BEL, CAN, DEU, ESP, FRA, GBR, GRC, ITA, ROU and USA); five NATO Bodies (NATO HQ, SHAPE/ACO, MARCOM, DACCC and CMRE); and 20 different institutions, organizations, and companies.

The conference proceedings provide the agenda, list of participants and the abstracts of the presentations given during the 6WMAUGT.

Keywords: WMAUGT; Conference; Proceedings; Military; Applications; Underwater; Gliders; Maritime Unmanned Systems; MUS; Recognized Environmental Picture; REP; Rapid Environmental Assessment; REA; Environment; Characterization; RMP; NATO; Command and Control; C2; Intelligence; Surveillance; Reconnaissance; ISR; Maritime ISR; MISR; Tasking; Collection; Processing; Exploitation; Dissemination; TCPED; Interoperability; Research; Development; R&D; Experimentation

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6WMAUGT: exploring underwater glider technology and its use for NATO and NATO Nations

1.1 Sponsorship: ACT/ACT Innovation Branch

The sixth *Workshop on Military Applications of Underwater Glider Technology* (6WMAUGT) has been completely sponsored by the NATO Allied Command Transformation (ACT), Innovation Branch. The NATO STO Centre for Maritime Research and Experimentation (CMRE), the authors of this conference proceedings report and the participants thank both ACT as well as the ACT Innovation Branch for sponsoring and supporting this workshop that allows military, research, academic and industrial personnel from the 29 NATO Nations to meet and discuss about developments in underwater glider technology and its applicability in the military and civilian fields.

1.2 History of the WMAUGT

Among others, Unmanned Underwater Gliders (UUGs) have two main abilities. First, UUGs can undertake cost-effective and sustained surveillance of hostile regions, carrying a variety of sensors into areas where it may not be safe or secure for manned platforms. Secondly, they can complement Underwater Intelligence, Surveillance and Reconnaissance (UISR) missions conducted by submarines and/or other manned platforms [1]. These two abilities have raised significant interest in the military community towards this technology, making UUGs an indispensable tool for future deployments. Therefore, organizing a workshop where military personnel, UUG manufacturers, scientists and UUG operators/technicians can meet, explore and discuss the advantages of using UUGs in naval warfare is beneficial for all. This workshop also serves to identify the issues that need to be resolved to convert gliders into tactical tools. In order to address this need, the first WMAUGT was organized in October 2013 [2]. Since then, the WMAUGT has taken place almost annually in order to respond to the increasing interest demonstrated by NATO and NATO Nations, as clearly evidenced by an increasing number of participants from the military community. More information on the past workshops can be found at the following URLs and/or related conference proceedings/reports:

5WMAUGT, 13-15 November 2018, NATO STO CMRE [3]:
www.cmre.nato.int/6wmaugt-home/former-events/wmaugt-2018

4WMAUGT, 4-6 October 2017, NATO STO CMRE:
www.cmre.nato.int/5wmaugt-home/former-events/wmaugt-2017

3WMAUGT, 4-6 October 2016, NATO STO CMRE [4]:
www.cmre.nato.int/5wmaugt-home/former-events/wmaugt-2016

2WMAUGT, 7-9 October 2014, NATO STO CMRE [5]:
www.cmre.nato.int/5wmaugt-home/former-events/wmaugt-2014

1WMAUGT, 8-10 October 2013 [2]:
http://geos3.cmre.nato.int/portal/web/gliderworkshop13/home

1.3 6WMAUGT: when, where and the official website

The 6WMAUGT took place at CMRE facilities on 12-14 November 2019. The official logo of the 6WMAUGT is shown in Figure 1.

Figure 1: Official logo of the 6WMAUGT.

The official website of the 6WMAUGT (as of 12 December 2019) is:

www.cmre.nato.int/6wmaugt-home

A screenshot of the homepage of the official 6WMAUGT website as of 12 December 2019, is depicted in Figure 2.

Figure 2: Screenshot of the Home of the 6WMAUGT website, as of 12 December 2019.

The call for abstracts created to disseminate and populate 6WMAUGT is shown in Figure 3.

North Atlantic Treaty Organization
Science and Technology Organization
Center for Maritime Research and Experimentation

CFA - Call for Abstracts and Participation

6WMAUGT

Sixth Workshop on Military Applications of Underwater Glider Technology

12 – 14 November 2019

NATO STO CMRE, La Spezia, Italy

Find the description, abstract submission and registration information at:

www.cmre.nato.int/6wmaugt

Abstract submission is open. **Submission deadline: 13 October 2019.**

The aim of the 6WMAUGT is to provide an opportunity for the personnel from the scientific, academic, industrial and military communities to present and discuss the state-of-art developments in underwater glider technology, and the relevant military and civilian applications it offers and could offer in the future. Topics (not limited to) to be explored among the participants are:

- Integration in naval operations
- Exploitation in Rapid Environmental Assessment (REA) activities
- Exploitation in Maritime Intelligence, Surveillance and Reconnaissance (MISR) activities
- Novel payloads and capabilities
- Passive acoustic capabilities
- TCPED interoperability: Interoperable ways for Tasking gliders and Collecting, Processing, Exploiting and Disseminating data/information
- Sustained monitoring, characterization and surveillance of marine regions
- Operations in remote and high-risk environments (e.g. high latitudes, A2/AD - Anti-Access/Area-Denial)
- Interconnected fleets/networks
- Risks and legal aspects

Attendance is limited to the nationals of the 29 member countries of NATO. The meeting will be held at NATO UNCLASSIFIED security level. Participation will be confirmed once an abstract and/or a summary of intent has been submitted and accepted.

Organizing committee (NATO STO CMRE):

Dr. Raul VICEN	Raul.Vicen@cmre.nato.int
Dr. Ines BORRIONE	Ines.Borrione@cmre.nato.int
Cdr. DEU-N Stefan WITTWER	Stefan.Wittwer@cmre.nato.int

Figure 3: 6WMAUGT Call for Abstracts.

1.4 Workshop overview

UUGs have been recognized to have great potential for assisting different kinds of underwater and maritime missions [6] [7] [8]. Among others, UUGs have demonstrated their value in counter A2/AD (anti-access/area denial) activities, persistent environmental survey (e.g., under ice), and Maritime Intelligence, Surveillance and Reconnaissance (MISR) missions [1] [9]. This is due to their cost-effectiveness, heterogeneity in payloads, low power consumption, long endurance (up to several months), and stealth properties (low detectability). It has also been well perceived that MISR should be based on coordinated networking configurations so that the data from different assets can be fused to obtain sensitive information.

The Declaration of Intent for the Maritime Unmanned Systems (MUS) Initiative in 2018 [10] states the need and importance of future explorations of these kind of vehicles/platforms.

Following five successful workshops in 2013, 2014, 2016, 2017 and 2018, the 6WMAUGT was hosted again at the CMRE in La Spezia, Italy from Tuesday 12 to Thursday 14 November 2019. The first half of the workshop was dedicated to presentations, discussions and analysis of work done in previous years. The second half was dedicated to summarizing the outcomes of the workshop and to discussing prospective collaborations among participants and future research topics.

1.5 Objectives and topics

The aim of the 6WMAUGT was to provide an opportunity for the personnel from the scientific, academic, industrial and military communities to present and discuss state-of-art developments in UUG technology as well as the relevant military and civilian applications it offers and could offer in the future.

The event was designed for military and civilian personnel who seek to extend their expertise on new robotic technology for MISR and environmental characterization. It was also designed for scientists and engineers who are interested in how this technology can address challenges in current and future naval warfare.

Topics initially planned to be explored, but not limited to, in the 6WMAUGT were:

1. Integration in naval operations
2. Exploitation in Rapid Environmental Assessment (REA) activities
3. MISR activities
4. Novel payloads and capabilities
5. Passive acoustic capabilities
6. Interoperability of Tasking gliders and Collecting, Processing, Exploiting and Disseminating (TCPED) data/information

7. Sustained monitoring, characterization and surveillance of marine regions
8. Operations in remote and high-risk environments (e.g., high latitudes, A2/AD)
9. Interconnected fleets/networks
10. Risks and legal aspects

1.6 Expected outcomes

The following outcomes from the 6WMAUGT were initially planned:

1. Analysis of progress from the 2018 workshop from participants of the scientific, industrial, academic and military communities.
2. Summary of current and future applications of underwater gliders in the EKOE (Environmental Knowledge and Operational Effectiveness) and MISR domains, as well as in other applications or domains (based on NATO priorities).
3. Status of where this technology is being directed in the future, including new developments (e.g., under ice exploration, very deep-water exploration).
4. Definition of military requirements for underwater glider technology from the perspective of the military personnel participating in the workshop.

1.7 Engagement process

Participants from the military, government, research, academia and industry communities were welcomed to the 6WMAUGT on the condition that one of following two participation options were followed:

- Attend and contribute: Submit a short abstract (no more than 200 words), give a short presentation (10 minutes) about one of the stated objectives/topics of the conference, and provide a summary of intent for participation (background and expected outcome).
- Only attend: Provide a summary of intent for participation (background and expected outcome).

Abstracts were planned to appear online on the 6WMAUGT website as a part of the 6WMAUGT proceedings.

Attendance was limited to the nationals of the 29 member countries of NATO.

2 6WMAUGT: agenda and participants

This chapter provides the agenda of the workshop (see Section 2.1). This agenda provides the titles of the briefs/presentations per date and session, the speakers and the institution/organization, and represented Nation. The 6WMAUGT was divided into five sessions:

1. Administrative Remarks and NATO STO CMRE
2. Military Requirements for UUGs
3. Applications of UUGs
4. Industrial and Technological Developments
5. Outcomes and Future Research Challenges

This chapter also provides the list of participants (see Section 2.2) in more detail, where full names, institutions/organizations/companies and nationalities are given. It includes speakers and non-speakers (attendees).

Section 2.3 provides a summary of the participating NATO Bodies and NATO Nations. Section 2.4 provides a summary of the participating institutions and organizations.

2.1 Agenda

6th Workshop on Military Applications of Underwater Glider Technology (6WMAUGT) - AGENDA

6WMAUGT

Sixth Workshop on Military Applications of Underwater Glider Technology

12 – 14 November 2019

NATO STO CMRE (Centre for Maritime Research and Experimentation), La Spezia, Italy

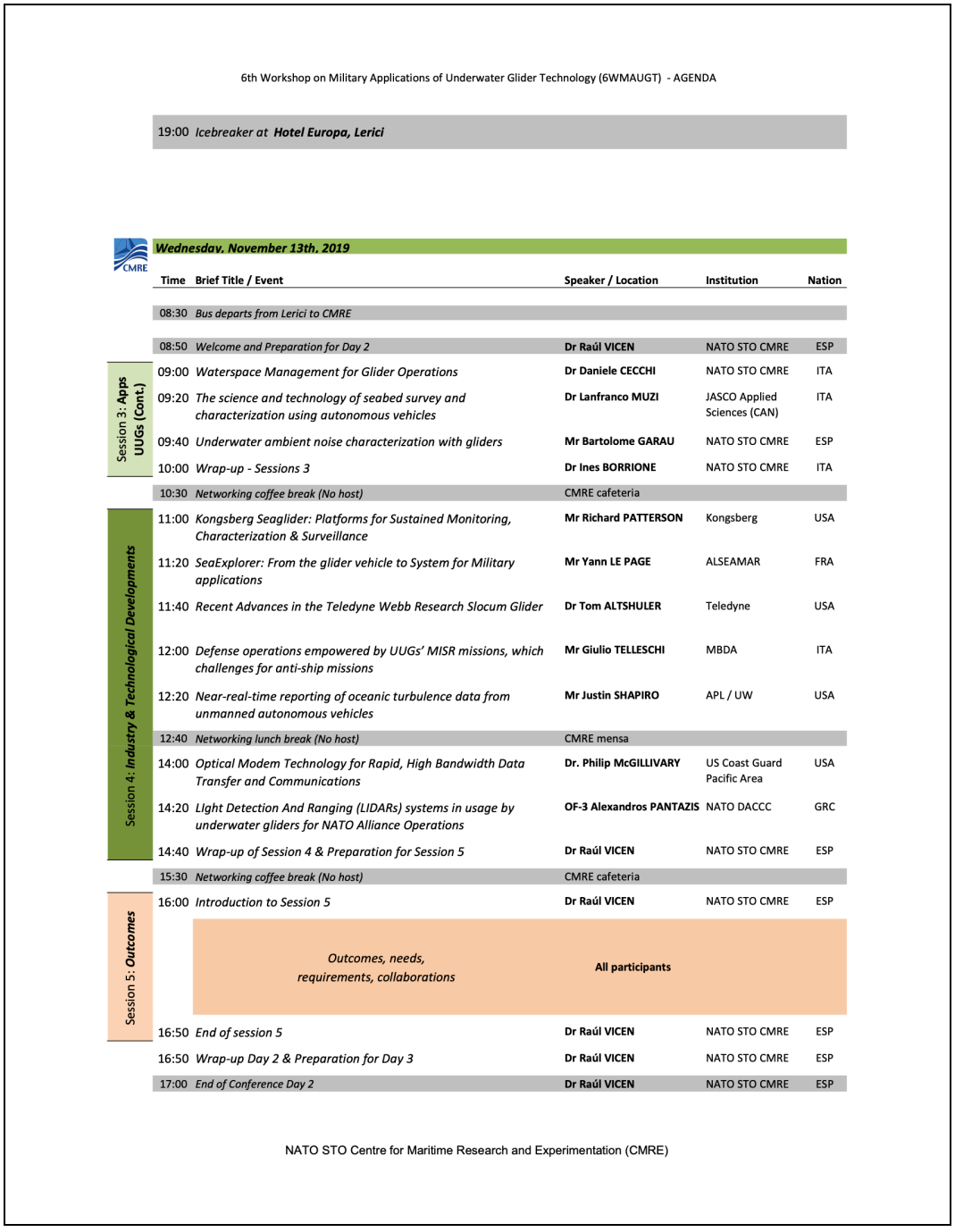
Agenda
Version 1.2
12-Nov-19

Tuesday, November 12th, 2019

	Time	Brief Title / Event	Speaker / Location	Institution	Nation
	08:30	*Bus departs from Lerici to CMRE*			
	08:45	*Registration / Check-in*	**Mrs Ilaria SAUDELLA**	NATO STO CMRE	ITA
Session 1: **Admin & *CMRE***	09:00	*Introduction and Agenda, 6WMAUGT Organizers*	**Dr Raúl VICEN** **Dr Ines BORRIONE** **Cdr Stefan WITTWER**	NATO STO CMRE NATO STO CMRE NATO STO CMRE	ESP ITA DEU
	09:15	*Administrative & Security Remarks, 6WMAUGT Assistant*	**Mrs Ilaria SAUDELLA**	NATO STO CMRE	ITA
	09:30	*Institutional Welcome, CMRE Director*	**Dr Catherine WARNER**	NATO STO CMRE	USA
	09:45	*Self-introduction of Participants*	**All participants**	-	-
	10:00	*CMRE at a Glance, Head Research Department*	**Dr Sandro CARNIEL**	NATO STO CMRE	ITA
	10:15	*Workshop Execution, 6WMAUGT Chair*	**Dr Raul VICEN**	NATO STO CMRE	ESP
	10:30	*Networking coffee break (No host)*	CMRE cafeteria		
Session 2: ***Military Requirements***	11:00	Keynote Speech: ***Update on NATO's Maritime Unmanned Systems Initiative (MUSI)***	**Cdr Ian DANBURY**	NATO HQ IS	GBR
	11:30	Keynote Speech: ***Rapid Environmental Assessment (REA) and the Recognised Environmental Picture (REP) in NATO***	**LtCdr Neil SCOTT**	NATO ACO / SHAPE	GBR
	12:00	*US Navy Glider Operations Center Update*	**Dr Andrea MASK**	NAVO	USA
	12:20	*Wrap-up - Sessions 2*	**Cdr Stefan WITTWER & Dr Raúl VICEN**	NATO STO CMRE	DEU & ESP
	12:40	***Picture of participants*** *(Main Gate/Entrance CMRE building)*	**All participants**		
	13:00	*Networking lunch break (No host)*	CMRE mensa		
Session 3: ***Applications of UUGs***	14:00	*Acoustic Glider: Thoughts and Insight*	**Dr Walter ZIMMER & Dr Jan SLIWKA**	NATO STO CMRE	DEU
	14:30	*Lessons Learned from recent Observer-Glider deployments in the Gulf of St Lawrence*	**LT(N) (Ret) John MOLONEY**	JASCO Applied Sciences	CAN
	14:50	*Passive Acoustic Signal Processing with a 3D Acoustic Vector Sensor Hosted on a Buoyancy Glider*	**Dr Pietro STINCO**	NATO STO CMRE	ITA
	15:10	*Oceanic soundscape observed from gliders: applications and challenges*	**Mr Pierre CAUCHY**	UEA – University East Anglia (GBR)	FRA
	15:30	*Networking coffee break (No host)*	CMRE cafeteria		
	16:00	*Operating gliders and other autonomous underwater assets at high latitudes during the NARVAL19 sea trial*	**Dr Pierre-Marie POULAIN**	NATO STO CMRE	BEL
	16:20	*Glider applications for REA and MISR: examples from NATO STO CMRE past experiments*	**Dr Ines BORRIONE**	NATO STO CMRE	ITA
	16:40	*Wrap-up of Day 1 & Preparation for Day 2*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
	17:00	*End of Conference Day 1*			
	17:15	*Bus departs from CMRE to Lerici*			

NATO STO Centre for Maritime Research and Experimentation (CMRE)

Figure 4: 6WMAUGT agenda, page 1 of 3.



6th Workshop on Military Applications of Underwater Glider Technology (6WMAUGT) - AGENDA

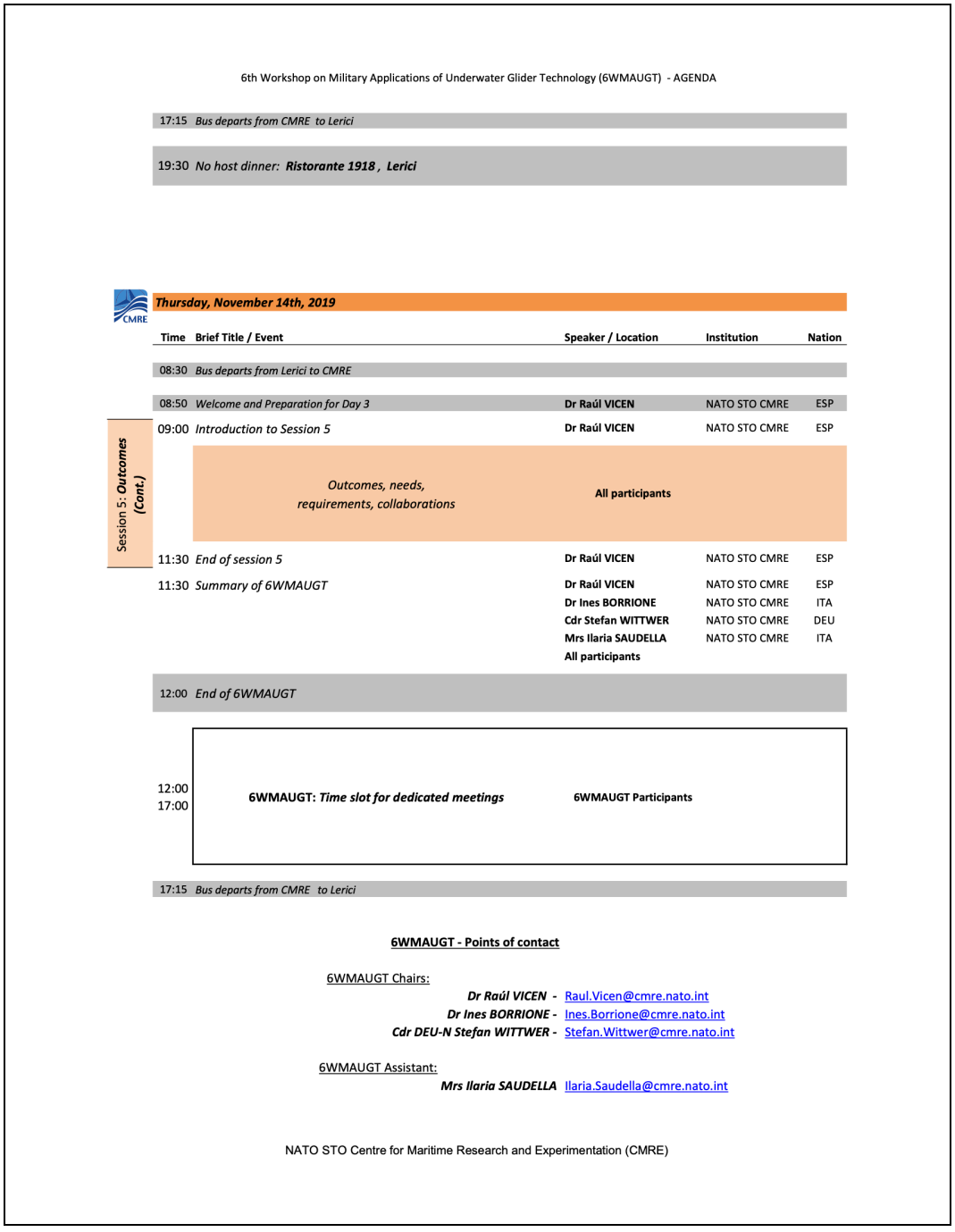
19:00 *Icebreaker at* ***Hotel Europa, Lerici***

Wednesday, November 13th, 2019

	Time	Brief Title / Event	Speaker / Location	Institution	Nation
	08:30	*Bus departs from Lerici to CMRE*			
	08:50	*Welcome and Preparation for Day 2*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
Session 3: **Apps UUGs (Cont.)**	09:00	*Waterspace Management for Glider Operations*	**Dr Daniele CECCHI**	NATO STO CMRE	ITA
	09:20	*The science and technology of seabed survey and characterization using autonomous vehicles*	**Dr Lanfranco MUZI**	JASCO Applied Sciences (CAN)	ITA
	09:40	*Underwater ambient noise characterization with gliders*	**Mr Bartolome GARAU**	NATO STO CMRE	ESP
	10:00	*Wrap-up - Sessions 3*	**Dr Ines BORRIONE**	NATO STO CMRE	ITA
	10:30	*Networking coffee break (No host)*	CMRE cafeteria		
Session 4: ***Industry & Technological Developments***	11:00	*Kongsberg Seaglider: Platforms for Sustained Monitoring, Characterization & Surveillance*	**Mr Richard PATTERSON**	Kongsberg	USA
	11:20	*SeaExplorer: From the glider vehicle to System for Military applications*	**Mr Yann LE PAGE**	ALSEAMAR	FRA
	11:40	*Recent Advances in the Teledyne Webb Research Slocum Glider*	**Dr Tom ALTSHULER**	Teledyne	USA
	12:00	*Defense operations empowered by UUGs' MISR missions, which challenges for anti-ship missions*	**Mr Giulio TELLESCHI**	MBDA	ITA
	12:20	*Near-real-time reporting of oceanic turbulence data from unmanned autonomous vehicles*	**Mr Justin SHAPIRO**	APL / UW	USA
	12:40	*Networking lunch break (No host)*	CMRE mensa		
	14:00	*Optical Modem Technology for Rapid, High Bandwidth Data Transfer and Communications*	**Dr. Philip McGILLIVARY**	US Coast Guard Pacific Area	USA
	14:20	*LIght Detection And Ranging (LIDARs) systems in usage by underwater gliders for NATO Alliance Operations*	**OF-3 Alexandros PANTAZIS**	NATO DACCC	GRC
	14:40	*Wrap-up of Session 4 & Preparation for Session 5*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
	15:30	*Networking coffee break (No host)*	CMRE cafeteria		
Session 5: ***Outcomes***	16:00	*Introduction to Session 5*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
		Outcomes, needs, requirements, collaborations	**All participants**		
	16:50	*End of session 5*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
	16:50	*Wrap-up Day 2 & Preparation for Day 3*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
	17:00	*End of Conference Day 2*	**Dr Raúl VICEN**	NATO STO CMRE	ESP

NATO STO Centre for Maritime Research and Experimentation (CMRE)

Figure 5: 6WMAUGT agenda, page 2 of 3.



6th Workshop on Military Applications of Underwater Glider Technology (6WMAUGT) - AGENDA

17:15 *Bus departs from CMRE to Lerici*

19:30 *No host dinner:* ***Ristorante 1918 , Lerici***

Thursday, November 14th, 2019

Time	Brief Title / Event	Speaker / Location	Institution	Nation
08:30	*Bus departs from Lerici to CMRE*			
08:50	*Welcome and Preparation for Day 3*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
09:00	*Introduction to Session 5*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
Session 5: ***Outcomes (Cont.)***	*Outcomes, needs, requirements, collaborations*	**All participants**		
11:30	*End of session 5*	**Dr Raúl VICEN**	NATO STO CMRE	ESP
11:30	*Summary of 6WMAUGT*	**Dr Raúl VICEN** **Dr Ines BORRIONE** **Cdr Stefan WITTWER** **Mrs Ilaria SAUDELLA** **All participants**	NATO STO CMRE NATO STO CMRE NATO STO CMRE NATO STO CMRE	ESP ITA DEU ITA
12:00	*End of 6WMAUGT*			
12:00 17:00	**6WMAUGT:** ***Time slot for dedicated meetings***	**6WMAUGT Participants**		
17:15	*Bus departs from CMRE to Lerici*			

6WMAUGT - Points of contact

6WMAUGT Chairs:

Dr Raúl VICEN - Raul.Vicen@cmre.nato.int
Dr Ines BORRIONE - Ines.Borrione@cmre.nato.int
Cdr DEU-N Stefan WITTWER - Stefan.Wittwer@cmre.nato.int

6WMAUGT Assistant:

Mrs Ilaria SAUDELLA Ilaria.Saudella@cmre.nato.int

NATO STO Centre for Maritime Research and Experimentation (CMRE)

Figure 6: 6WMAUGT agenda, page 3 of 3.

2.2 Participants: CMRE and non-CMRE

Figure 7 summarizes the 42 military, research, academic and industrial personnel participating in the 6WMAUGT.

6WMAUGT

Sixth Workshop on Military Applications of Underwater Glider Technology

12 – 14 November 2019

NATO STO CMRE (*Centre for Maritime Research and Experimentation*), La Spezia, Italy

Participants

Version 1.2
12-Nov-19

	Title	Name	Lastname	Nationality	Institution
1	Dr.	Thomas	Altshuler	USA	Teledyne Marine
2	Dr.	Ines	Borrione	ITA	NATO STO CMRE
3	Dr.	Andreas	Caffaz	ITA	Graal Tech
4	Dr.	Sandro	Carniel	ITA	NATO STO CMRE
5	Mr.	Pierre	Cauchy	FRA	UEA
6	Dr.	Daniele	Cecchi	ITA	NATO STO CMRE
7	Maj.	Martin	Couet	CAN	CFINTCOM
8	Cpt. Eng.	Roxana	Damian	ROU	RCN within METRA
9	Cdr.	Ian	Danbury	GBR	NATO HQ
10	Cdr.	Paolo	Dei	ITA	MARCOM
11	Mr	Simone	Di Giacomo	ITA	kongsberg
12	Dr.	Andrew	Flinn	GBR	MOD
13	Dr.	Andreas	Funk	DEU	WTD71
14	Mr.	Bartolome	Garau	ESP	NATO STO CMRE
15	Mr.	Jean-Philippe	Goudeau	FRA	THALES DMS – UWS
16	Mr.	James	King	GBR	Marine Tech Systems Ltd
17	Lt. Cdr.	Simone	La Riviera	ITA	Italian Navy
18	Mr.	François-Xavier	Launay	FRA	THALES DMS – UWS
19	Mr.	Yann	LePage	FRA	ALSEAMAR
20	Dr.	Andrea	Mask	USA	NAVOCEANO
21	Dr.	Phil	McGillivary	USA	US Coast Guard Pacific Area
22	IETA	Adelaide	Missault	FRA	DFG
23	Mr.	John	Moloney	CAN	JASCO Applied Sciences
24	Dr.	Lanfranco	Muzi	ITA	JASCO Applied Sciences
25	OF-3	Alexandros	Pantazis	GRC	NATO DACCC
26	Mr.	Richard	Patterson	USA	Kongsberg Underwater Technology, Inc.
27	Mrs.	Gwénaëlle	Petit	FRA	DGA Naval Systems
28	Dr.	Pierre-Marie	Poulain	BEL	NATO STO CMRE
29	Cpt. Eng.	Giuseppe	Rizzi	ITA	Italian Navy
30	Snd Lt. Eng.	Alexandru	Savastre	ROU	RCN within METRA
31	Lt. Cdr.	James	Schnadhorst	GBR	NATO MARCOM
32	Lt. Cdr.	Neil	Scott	GBR	NATO SHAPE
33	Mr.	Justin	Shapiro	USA	Applied Physics Lab., Univ. Washington
34	Dr.	Jan	Sliwka	POL	NATO STO CMRE
35	Mr	John	Statsny	USA	ONR
36	Dr.	Pietro	Stinco	ITA	NATO STO CMRE
37	Dr.	Raul	Vicen	ESP	NATO STO CMRE
38	Dr.	Cyrille	Vuilmet	FRA	DGA Naval Systems
39	Dr.	Catherine	Warner	USA	NATO STO CMRE
40	Cdr.	Stefan	Wittwer	DEU	NATO STO CMRE
41	Dr.	Fabian	Wolk	CAN	Rockland Scientific
42	Dr.	Walter	Zimmer	DEU	NATO STO CMRE

Figure 7: 6WMAUGT CMRE and non-CMRE participants.

2.3 Participating NATO Bodies and NATO Nations

The following is a list of NATO Bodies and NATO Nations participating in the 6WMAUGT:

5 NATO Bodies:

- NATO SHAPE/ACO – Supreme Headquarters Allied Powers Europe / Allied Command Operations
- NATO MARCOM – Allied Maritime Command (Northwood)
- NATO HQ – Headquarters
- NATO DACCC – Deployable Air Command and Control Centre
- NATO STO CMRE – Science and Technology Organization-Centre for Maritime Research and Experimentation

10 NATO nations (in alphabetical order by abbreviation):

- BEL – Belgium
- CAN – Canada
- DEU – Germany
- ESP – Spain
- FRA – France
- GBR – Great Britain
- GRC – Greece
- ITA – Italy
- ROU – Romania
- USA – United States of America

2.4 Participating institutions and organizations

The names, hosting countries and official websites of the 14 military/defence institutions and organizations, two universities and research centres, and eight industrial entities participating in the 6WMAUGT are given below.

Military / Defence Organizations and Institutions

CAN – Canadian Forces Intelligence Command (CFINCOM)
www.canada.ca/en/department-national-defence/corporate/organizational-structure/canadian-forces-intelligence-command.html

DEU – Wehrtechnische Dienststelle für Schiffe und Marinewaffen, Maritime Technologie und Forschung (WTD 71)
www.baainbw.de

FRA – Direction Générale de l'Armement - French MoD Procurement Agency (DGA)
www.defense.gouv.fr/dga

GBR – Ministry of Defence
www.gov.uk/government/organisations/ministry-of-defence

ITA – Italian Navy
www.marina.difesa.it/en

NATO – Supreme Headquarters Allied Powers Europe (SHAPE)/Allied Command Operations (ACO)
www.shape.nato.int

NATO – Allied Maritime Command (MARCOM)
www.mc.nato.int

NATO – Headquarters (HQ) –International Staff (IS)
www.nato.int

NATO – Deployable Air Command and Control Centre (DACCC)
Not available

NATO – STO Centre for Maritime Research and Experimentation (CMRE)
www.cmre.nato.int

ROU – Romanian Naval Forces
www.navy.ro/despre/istoric/istoric_index_en.php

USA – US Coast Guard Pacific Area
www.pacificarea.uscg.mil

USA – US Naval Oceanography Operations Command (NAVOCEANO)
www.metoc.navy.mil/navo/navo.html

USA – US Office of Naval Research Global (ONR Global)
www.onr.navy.mil/Science-Technology/ONR-Global.aspx

Universities and Research Centers

GBR – University of East Anglia
www.uea.ac.uk

USA – Applied Physics Laboratory (APL), University of Washington
www.apl.washington.edu

Industrial Organizations

CAN – Jasco Applied Sciences
www.jasco.com

CAN – Rockland Scientific
www.rocklandscientific.com

FRA – Alseamar Alcen
www.alseamar-alcen.com

FRA – Thales
www.thalesgroup.com/en

GBR - Marine Tech Systems Ltd
www.marinetechnet.com

ITA – Graal Tech
www.graaltech.com

USA – Kongsberg Underwater Technology
www.kongsberg.com

USA – Teledyne Marine
www.teledynemarine.com

3 6WMAUGT: sessions and abstracts

3.1 6WMAUGT sessions

Based on the topics and objectives of the 6WMAUGT, the workshop was split into five different sessions:

- Session 1 – Administrative Remarks and NATO STO CMRE
- Session 2 – Military Requirements for UUGs
- Session 3 – Applications of UUGs
- Session 4 – Industrial and Technological Developments
- Session 5 – Outcomes and Future Research Challenges

3.2 6WMAUGT abstracts

The abstracts indicated as "N/A" denote either the abstract was ultimately not submitted or the authors did not allow its publication in this conference proceedings report.

Available abstracts are provided in the following section sorted according to the sessions and following the 6WMAUGT agenda shown in Figures 4-6.

3.2.1 Session 1 – Administrative remarks and NATO STO CMRE

This session was dedicated to providing administrative remarks to participants, as well as to present the way the organizers wanted to execute the workshop. This session was also used to introduce the role of NATO STO CMRE within NATO and the main scientific research and experimental activities run by its different programmes.

3.2.2 Session 2 – Military requirements for UUGs

Keynote: **Update on NATO's Maritime Unmanned Systems Initiative (MUSI)**
Cdr GBR-N Ian DANBURY
NATO Maritime Unmanned Systems Innovation and Coordination Cell, NATO Headquarters (HQ)

The update will aim to inform workshop delegates of the progress of the NATO Maritime Unmanned Systems (MUS) initiative. It will recap on the background and rationale for the Initiative and the Declaration of intent, which was signed by the Nations. It will highlight the ambition, goals and objectives and the progress made against them to date, finally it will take a look at the future for the initiative and where we see the programme of work developing in the future.

Keynote: **Rapid Environmental Assessment (REA) and the Recognized Environmental Picture (REP) in NATO**
LtCdr Neil SCOTT
NATO Supreme Headquarters Allied Powers Europe (SHAPE) / Allied Command Operations (ACO)

The aim of the brief is to introduce both concepts to the audience and brief them on current practices and future direction of the concept.

US Navy Glider Operations Center Update
Dr Andrea MASK
Naval Oceanographic Office (NAVO), Stennis Space Center, MS, USA

The US Navy utilizes Slocum gliders to obtain oceanographic data collection required to support its global operational ocean modeling capability. Fleet requirements for environmental data is weighed against availability of gliders and deployers. This necessitates a feedback with other oceanographic information to determine if gliders are the best use of resources versus other data collection methods. Future goals and planned capabilities will also be discussed.

3.2.3 Session 3 – Applications of UUGs

Acoustic Glider: Thoughts and Insight
Dr. Walter M.X. ZIMMER, Jan SLIWKA, Bartolomé GARAU and Paolo ODDO
NATO STO Center for Maritime Research and Experimentation (CMRE)

This presentation addresses recent efforts at CMRE to develop a compact volumetric acoustic sensor (cVAS) to be implemented as scientific payload on SLOCUM gliders. The purpose of the cVAS is to estimate the three-dimensional sound intensity vector, which plays an important role in the characterization of the environmental soundscape and will be of importance for improved sonar performance prediction systems. Additionally, the cVAS may also be of use for detection and characterization of discrete acoustic sources, glider self-localization and emergency homing in ice-covered environments. Differing to accelerator based systems the cVAS uses discrete, closely-spaced hydrophones to estimate the directional sound intensity. Here, we discuss the design criteria of the cVAS, some preliminary results from recent at-sea deployments, discuss various implementation aspects and lay out future developments.

Lessons Learned from recent Observer-Glider deployments in the Gulf of St Lawrence
LT(N) (Ret) John MOLONEY, Briand M. GAUDET, Bruce MARTIN, Art COLE and Katie A. KOWARSKI
JASCO Applied Sciences, CAN

JASCO Applied Sciences (Canada) Ltd (JASCO) has been progressing the development and demonstration of JASCO's passive acoustic monitoring systems aboard Teledyne Slocums, Kongsberg's Seaglider and ALSEAMAR's SeaExplorer ocean gliders (Unmanned Underwater Vehicles).
In previous presentations at WMAUGTs' JASCO has described these PAM systems and some of the ongoing developments and trial deployments of this novel technology.

JASCO would like to now present some empirical results from the Sept-Oct 2018 Observer-Glider deployment in the Gulf of St. Lawrence, Atlantic Canada in search of endangered North Atlantic Right Whales. The focus of this presentation will be a comparison of the real-time results (i.e. automatic detector performance) with ground-truth information derived during trial post-analysis. Novel tools for navigating and visualizing PAM data from gliders will also be presented. The ongoing development and the beneficial capabilities of these novel PAM systems to will also be described.

Passive Acoustic Signal Processing with a 3D Acoustic Vector Sensor Hosted on a Buoyancy Glider

Dr Pietro STINCO, Alessandra TESEI, Richard DREO, Gabriele FERRI, Stefano BIAGINI, Michele MICHELI, Bartolome GARAU, Kevin D. LePAGE, Luigi TROIANO, Alberto GRATI and Piero GUERRINI
NATO STO Center for Maritime Research and Experimentation (CMRE)

This work deals with the detection and estimation of the direction of arrival of a noise source using an acoustic vector sensor hosted on a buoyancy Slocum glider. The sensor used is a 3D directional hydrophone capable of acquiring both the acoustic pressure and the components of the particle velocity vector. The paper presents experimental results with data collected at sea and describes the signal processing chain, including detection, direction of arrival and clustering. The vehicle is equipped with a modem and is supported by a USBL (ultra-short baseline) located on a mother ship or gateway to achieve the navigational accuracy required for correct target localization. The results discussed in this paper demonstrate two important achievements: that an underwater glider can produce accurate bearing estimates on a target and the feasibility of the integration of an acoustic modem and a USBL positioning system on a glider.

Oceanic soundscape observed from gliders: applications and challenges

Mr Pierre CAUCHY
University East Anglia, GBR

Unmanned underwater gliders are highly suitable for passive acoustic monitoring (PAM). They offer persistent presence at sea, they move silently through the water column, they collect sound velocity profiles, they are able to carry one or several hydrophones.

We deployed single hydrophone systems, self-contained or integrated to the glider, on Slocum and Seagliders performing oceanographic missions. We recorded underwater ambient noise during months-long missions to monitor the environment. Analysis of the oceanic soundscape allows us to measure surface wind speed, monitor marine life and detect human activities.

Going further, we now focus on rainfall rate, ice sounds and fish choruses. We investigate the challenges to calibrated sound level measurements from gliders, for application to source ranging and assessment of noise pollution.

Operating gliders and other autonomous underwater assets at high latitudes during the NARVAL19 sea trial

Dr Pierre-Marie POULAIN
NATO STO Center for Maritime Research and Experimentation (CMRE)

Underwater gliders equipped with oceanographic and acoustic sensors were operated in the areas southwest of Svalbard and western Barents Sea in September-October 2019 as part of the NARVAL19 sea trial. Oceanographic gliders provided, along with moored and profiling systems, an environmental characterization of the high-frequency dynamics on the Svalbard continental shelf and slope, including strong tidal currents and internal waves. Acoustics gliders were used in the vicinity of the Polar Front in the western Barents Sea to complement an array of moored sound sources and hydrophones, as well as a towed hydrophone array. The aim of this acoustic experiment was to study the sound propagation across the Polar Front, including not only fast meandering instability variability but also tidal and internal wave signals. Preliminary results of the NARVAL19 cruise are presented and issues on the operation of autonomous underwater platforms in cold and harsh environments are discussed.

Glider applications for REA and MISR: examples from NATO STO CMRE past experiments

Dr. Ines BORRIONE
NATO STO Center for Maritime Research and Experimentation (CMRE)

Taking examples from NATO STO CMRE's experience with the operation of gliders, this contribution aims at giving an overview of the different ways underwater gliders can be exploited for the purposes of supporting Rapid Environmental Assessment (REA) and Marine Intelligence Surveillance Reconnaissance operations (MISR).

Waterspace Management for Glider Operations

Dr Daniele CECCHI, Bartolomé GARAU, Giuliana PENNUCCI, Manlio ODDONE and Giampaolo CIMINO
NATO STO Center for Maritime Research and Experimentation (CMRE)

Water-space management for glider operations is an important topic considering the safety of the vehicles and navigation, as well as the integration of underwater gliders in the battlefield. The presentation will review the risks associated with gliders activities, past CMRE experience operating gliders during NATO exercises and will propose a water-space management framework that considers the risk of collision with ships. AIS data are used to assess present and future

collision risk, but the approach is valid for different sources of information in different scenarios.

The science and technology of seabed survey and characterization using autonomous vehicles

Dr Lanfranco MUZI
JASCO Applied Sciences, CAN

In littoral waters, seabed reflectivity and scattering properties are critical parameters in sonar performance prediction for both anti-submarine warfare and mine counter measures. Complex experimental setups and data analysis schemes can provide high-fidelity seabed properties, but rely on expensive equipment and logistic support, are limited to local measurements and are often not suited for covert operation. Databases exist containing bottom information, but these data are often not adequate for accurate performance prediction, particularly in shallow-water environments. Recent exercises have demonstrated that Autonomous Underwater Vehicles (AUVs) and gliders are viable platforms for the spatio-temporal characterization of water-column properties, surveying large areas of the ocean over long periods of time. This presentation shows that, with the addition of a powerful acoustic payload (a hydrophone array and a multi-channel data recording system), the capabilities of AUVs can be extended to the passive measurement of the seabed reflection coefficient and layering structure, by exploiting sea-surface natural ambient noise or a passing ship. These properties are critical for estimating the contribution of the bottom reflection loss to the total transmission loss. JASCO has expertise and hardware to support this type of payload on gliders, including the possibility of on-board data processing.

Underwater ambient noise characterization with gliders

Mr Bartolomé GARAU
NATO STO Center for Maritime Research and Experimentation (CMRE)

Underwater gliders are suitable platforms to perform underwater acoustic related activities, due to their robustness, endurance and quietness. The activity must take into account their limitations in terms of computational capabilities, power consumption and maneuverability. Nowadays, the acoustic datasets collected by gliders cannot be sent through current state of the art communication systems integrated into the platforms. The access to the full dataset requires waiting for the platform recovery at the end of its deployment. Acoustic derived products could be used in near real time by other applications, such as acoustic modelling, sonar performance or marine mammal risk mitigation. The time scales for such applications are shorter than the intended glider endurance. This presentation will provide an overview on the progress at CMRE regarding the development of

smart payloads for underwater gliders. These payloads perform the acquisition and on board processing, synthetizing and sending acoustic products through the limited bandwidth connection to the shore station, so they are ready to be used in near real time by other applications like the above mentioned. The implementation of ambient noise characterization will be described as an example of how gliders can provide to the community information about key environmental acoustic parameters in a useful manner.

3.2.4 Session 4 – Industrial and technological developments

Kongsberg Seaglider: Platforms for Sustained Monitoring, Characterization & Surveillance
Mr Richard PATTERSON
Kongsberg Underwater Technology, WA, USA

This presentation will give the attendees an update on the current state of the Kongsberg Seaglider product. Topics will include vehicle control system, sensor payloads and operator interface.

SeaExplorer: From the glider vehicle to System for Military applications
Mr Yann LE PAGE
Alseamar, FRA

Alseamar and partners have been developing two major component for the last 3 years allowing operational military use of the SeaExplorer Glider. Those two components are a secured server framework allowing remote piloting and data storage of fleets of gliders, and an ultra-low power, acoustic payload allowing low-noise recording of hydrophone arrays, as well as embedded detection, localization and classification using deep learning techniques. The web-based piloting interface will be demonstrated in order to show that piloting and supervision is now accessible for operational personnel, while it has been only accessible to software engineers before. A focus will be made on the use of fleets of gliders for REA and ASW operation using the system, from the interface to the fleet synchronization server on shore. Last, at-sea use of the novel acoustic payload will be shown.

Recent Advances in the Teledyne Webb Research Slocum Glider
Dr Thomas ALTSHULER
Teledyne Webb Research, USA

Over the last decade, the Teledyne Webb Research (TWR) Slocum glider has become a significant asset in multiple United States Navy programs including the Littoral Battlespace Sensing – Glider (LBS-G) program. During the period, TWR has delivered over 250 gliders for various defense applications. In order to meet the growing and broadening demands for persistent assets in the water column to satisfy defense missions, TWR continues to invest in expanding the Slocum glider capabilities through dedicated technology development and integration.

In this presentation, TWR will provides an overview of the latest Slocum glider advances and features. These advances include the introduction of a new STM32 processor to replace the Persistor that has been a mainstay in the existing Slocum gliders. TWR has developed both high and ultra-high displacement pumps. TWR is providing better ease of use for the operator with increased backseat driver autonomy.

Since the Slocum glider's primary role is to permit deployment of sensors for both scientific and defense mission. This presentation will present the latest sensor integrations including fast response thermistor probe, the Sequoia partial size distribution, mammal mitigation through acoustic monitoring, a mobile acoustic source, acoustic biomass imaging, and enhancement of acoustic communication for data exfiltration.

Defense operations empowered by UUGs' MISR missions, which challenges for anti-ship missions
Mr Giulio TELLESCHI
MBDA, ITA

Anti-ship missile missions are well-defined in terms of required information to succeed and to assess the mission. The adoption of UUGs in naval operations introduces a great potential both in data gathering (to assess and plan future missile missions) and stealth missions concepts. The challenge is to reach effective interoperability between UUGs and missiles, whilst those systems rely on different paradigms such as:

- Mission duration,
- Data transmission and power constraints,
- Human interaction,
- Data acquisition and accuracy, and
- Availability.

A key factor will be the data-link for NEC operations, impacting requirements on UUGs missions and concepts.

Near real-time reporting of oceanic turbulence data from unmanned autonomous vehicles

Mr Justin SHAPIRO
Applied Physics Laboratory/University of Washington, WA, USA

Unmanned Underwater Vehicles have emerged as platforms of choice for in situ turbulence measurements due to their stable flight characteristics, low hydrodynamic noise and the ability to continuously operate in harsh conditions that would prevent shipboard measurements. UUVs have been prevented from telemetering turbulence data while deployed due to the high sampling rate and the low bandwidth of satellite communication channels. We present a novel sensing and processing architecture that enables measurement, processing and telemetry of ocean turbulence onboard a Teledyne-Webb Research G2 Slocum Glider. This capability has been demonstrated in both coastal- and deep-ocean environments, where turbulence levels are modulated by a broad spectrum of naturally occurring forcing including the internal wave climate and surface forcing. Recently collected data from the Icelandic region of the North Atlantic will be presented. Several examples of turbulence signal interpretations relevant to contemporary naval applications will be discussed.

Optical Modem Technology for Rapid, High Bandwidth Data Transfer and Communications

Dr Philip McGILLIVARY
US Coast Guard Pacific Area, USA

Advanced sensor technologies on gliders now provide high data rates than previously possible. Gliders as ocean observing system components can either surface or interact with moorings to download data. New optical modems data rates greatly exceeding those of acoustic modems, so download of large amounts of data proceeds rapidly, and without acoustic interference found in many maritime environments. We review this technology, and how it can be used to communication from and between gliders, AUVs, moorings and unmanned aircraft.

LIght Detection And Ranging (LIDARs) systems in usage by underwater gliders for NATO Alliance Operations

OF-3 Alexandros PANTAZIS
NATO Deployable Air Command and Control Centre (DACCC)

LIght Detection And Ranging (LIDARs) are cutting edge technological devices and are widely used in atmospheric science, in order to examine the optical and chemical properties of the present atmosphere, in mapping and topography and nowadays their participation in autonomous driving and in the benefit of shipping for autonomous navigation is evolving. In this work a presentation is been made on how LIDARs can be used in detection and self-protection against, submarines, Maritime Unmanned Systems (MUSs), mines, bottom returns and oil - spill - wrecks detection and characterization. The scope of this work is to present the multiple usages that LIDARs can commit in underwater gliders.

Existing subsea LIDAR operating systems, are usually designed for deep water environments to serve the oil and gas mining industries, so applied knowledge already exists. Developing a LIDAR system by NATO alliance that integrates directly into an existing platform (e.g., underwater glider), will allow it to fit optimally within the confines of an existing space and make use of synergies relating to navigation sensors, computational power and storage. This will help the alliance to commit safer marine operations, mine - MUS detection and avoidance, as well as exploitation in REA and in MISR activities. LIDARs can also be found useful in sustained monitoring, contributing the most to characterization and surveillance of marine regions with high precision and cover for operations in remote and high-risk environments.

3.2.5 Session 5 – Outcomes and future research challenges

During this session, several outcomes were collected in terms of:

- Military requirements
- Issues/challenges
- Recommendations
- Future research topics

These outcomes can be found in the NATO UNCLASSIFIED CMRE Memorandum Report titled *Outcomes and future research Challenges of underwater glider technology from the sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)* [11].

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Title

Conference proceedings of the Sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT)

Abstract

Under the sponsorship of the Innovation Branch at NATO Allied Command Transformation, NATO STO Centre for Maritime Research and Experimentation (CMRE) organized the sixth Workshop on Military Applications of Underwater Glider Technology (6WMAUGT). The workshop was held for NATO and NATO Nations from 12-14 November 2019 at CMRE facilities in La Spezia Italy.

The 6WMAUGT joined more than 40 participants. The 2019 event resulted in a significant increase in the number of military attendees, denoting the great interest NATO and NATO Nations have in underwater glider technology and its applications for military purposes. Overall, participants represented 10 NATO Nations (BEL, CAN, DEU, ESP, FRA, GBR, GRC, ITA, ROU and USA); five NATO Bodies (NATO HQ, SHAPE/ACO, MARCOM, DACCC and CMRE); and 20 different institutions, organizations, and companies.

The conference proceedings provide the agenda, list of participants and the abstracts of the presentations given during the 6WMAUGT.

Keywords

WMAUGT; Conference; Proceedings; Military; Applications; Underwater; Gliders; Maritime Unmanned Systems; MUS; Recognized Environmental Picture; REP; Rapid Environmental Assessment; REA; Environment; Characterization; RMP; NATO; Command and Control; C2; Intelligence; Surveillance; Reconnaissance; ISR; Maritime ISR; MISR; Tasking; Collection; Processing; Exploitation; Dissemination; TCPED; Interoperability; Research; Development; R&D; Experimentation

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