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A Paradigm Shift for Interoperable Submarine Rescue Operations: The Usage of JANUS During the Dynamic Monarch 2017 Exercise

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***Abstract*—The NATO Centre for Maritime Research and Experimentation (CMRE) participated for the first time in the Dynamic Monarch submarine rescue exercise, bringing to the operational players a new interoperable digital underwater acoustic communications capability introduced by JANUS. Currently, communications during rescue operations are performed solely with the analogue underwater telephone and the usage of the phonetic codes (*alpha* to *zulu*). This has the clear problem of needing an operator (that may be required for other equally critical tasks) to handle the communications on the submarine side. Stress and phonetic biases may also play a role in the success of the underwater telephone communications. Interoperable digital underwater communication may undoubtedly render submarine escape and rescue more effective, but above all it may introduce a whole new way of conducting operations. Digital underwater communications can, in fact, enable machine-to-machine interaction (not viable with analogue underwater telephone) and open the way for the introduction of networked underwater unmanned systems. This paper provides an overview of the activities that led to the participation of CMRE in the submarine rescue exercise Dynamic Monarch 2017. We present the key conclusions taken throughout the process that started in 2016 and culminated with the participation in the exercise, in September 2017.**

I. Introduction

After 10 years of development by CMRE and partners, with support from the NATO Allied Command Transformation (ACT), the first ever standard for digital underwater communications was established in March 2017. It is called JANUS [1], [2] and is known in formal terms as STANAG 4748. JANUS is open and free for use by military and civilian operators. Its technical specification is available without security markings from the NATO standardisation Office (NSO) and example implementations coded in C and Matlab languages are available in the JANUS wiki website [3]. This free and open nature of JANUS makes it ideal to be used in support of distressed/disabled submarine (DISSUB) operations where interoperability and availability may literally be a matter of life and death. The current submarine rescue manual [4] establishes that communications during DISSUB operations are performed with the analogue underwater telephone (UT) and the usage of the phonetic codes ***Alpha*** to ***Zulu***. The analogue UT is a very simple standard. It specifies the modulation of voice by upper single side band with 2.7 kHz of analogue bandwidth. This is approximately the same bandwidth offered by a regular telephone and is sufficient to convey speech. It was standardised in STANAG 1074 for NATO and cooperating navies. Meanwhile, the specification of UT was transferred into STANAG 1475 [5] as submarine rescue equipment. One obvious problem with the UT is that it requires an operator (that may be needed for other equally critical tasks) to handle the communications on the submarine side. Human factors such as stress and language phonetic biases may also play a role in the success of the analogue communications. As shown in [6] such operator-dependent factors affect the ability to properly decode analogue UT transmissions. For these reasons, the prospect of employing digital underwater communications for submarine rescue operations is particularly attractive. The use of JANUS for rescue communications enables the removal of the operator from the communications process. It makes automation of critical data transmission possible while removing the confounding human factors. JANUS could therefore be used to replace (or used in combination with) analogue underwater telephone systems to increase the robustness, efficiency and reliability in delivering critical information in DISSUB operations. The organisation of the paper follows the chronological sequence of activities as described below. Section II describes the JANUS experimental activities for DISSUB scenarios conducted during the REP16-

ATLANTIC (REP16) and REP17-ATLANTIC (REP17) sea trials, in 2016 and 2017 respectively. The involvement of CMRE with the International Liaison Office for Submarine Escape and Rescue (ISMERLO) [7] and Submarine Escape and Rescue Working Group (SMERWG) led to the participation in the Dynamic Monarch 2017 (DYMH17) exercise. This is reported in Section III. Finally, Section IV draws conclusions from the participation in DYMH17 and opens, what we believe to be, disruptive perspectives for the future of interoperable submarine rescue operations.

II. Background

After the initial involvement of CMRE with ISMERLO and the SMERWG, it became clear that the operational submarine rescue community was very receptive to the potential benefits of digital underwater communications for their scenarios of interest. Digital underwater communications are surely not new but the interoperability prospect offered by JANUS plays a fundamental role in rescue situations, more strongly so in a multi-national environment. Below we briefly describe the DISSUB-related experimental activities conducted during two major sea trials. These activities laid the foundation for the participation of CMRE in DYMH17.

A. REP16-Atlantic

The REP16 sea trial was organised by the Portuguese Navy, CMRE and the Faculty of Engineering of the University of Porto (FEUP) through the Laboratório de Sistemas e Tecnologias Subaquáticas (LSTS). It took place in Portuguese Atlantic waters during the month of July 2016. During REP16, CMRE experimented with JANUS-based services in support of submarine operations. The interested reader is directed to [8] for a detailed description of the different services implemented. In one of the exercised scenarios, a distressed situation is declared on board a submarine and periodic packets with vital data are sent out via JANUS without further need for an operator. The data sent in the JANUS packet consisted of latitude, longitude, depth, O_2, CO_2, CO, H_2, pressure, temperature and number of survivors. The definition of such packet (beyond the scope of this paper, but fully described in [8]) was iterated with the submarine Commanding Officer to guarantee maximum relevance. The experiment conducted during REP16 followed the concept illustrated in Fig. 1. It was the first proof-of-concept demonstration of such JANUS-based service showing the benefits of automation of data transmissions in case of incident. For this test, the data was artificially generated as there was no link between the on-board systems of the submarine and the JANUS equipment. CMRE installed JANUS-capable prototype equipment on board the Portuguese Navy submarine NRP Arpão (see Fig. 2). This was the transmitter of the DISSUB packets. For reception, two nodes were used: one on a gateway buoy and another one deployed from CMRE vessel NRV Alliance.

A total of 22 bytes were used to encode position and status information on the JANUS packet. The overall transmission duration of such packet was roughly 3 seconds. A comparison

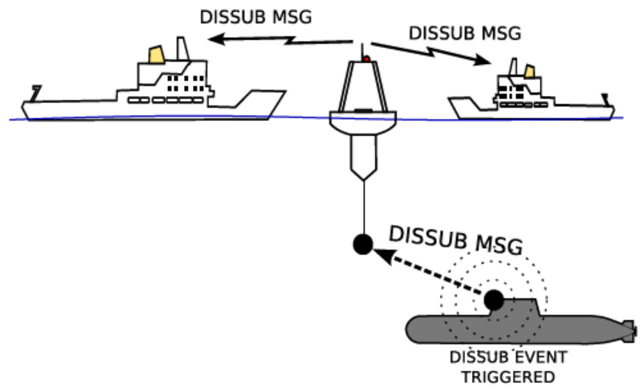


Fig. 1. JANUS-based DISSUB communications concept.

Fig. 2. Equipment installed onboard the NRP Arpão. Left: The acoustic elements inside the tower of the submarine, including an hydrophone and projector; Top right: The NRP Arpão on dock; Bottom right: A view of the working place occupied by the CMRE staff member that was deployed on the submarine.

of the channel time required by JANUS and UT to transmit the same information is shown in Fig. 3 where the efficiency of the digital method is evident. The use of the UT was performed according to the NATO ATP/MTP-57 submarine rescue manual [4]. The UT transmission length was obtained by averaging a number of test transmissions performed by an officer on board the Portuguese submarine NRP Arpão.

B. REP17-Atlantic

In July 2017, CMRE, the Portuguese Navy and FEUP joined efforts again for the REP17 sea trial. This time, the main objectives were to build on the previous year experiments and to test implementation and procedures ahead of DYMH17.

With this in mind, the JANUS system on board the submarine (same configuration of REP16) was connected to the navigation output and was provided with the actual estimated position. The remaining info was inserted manually by the

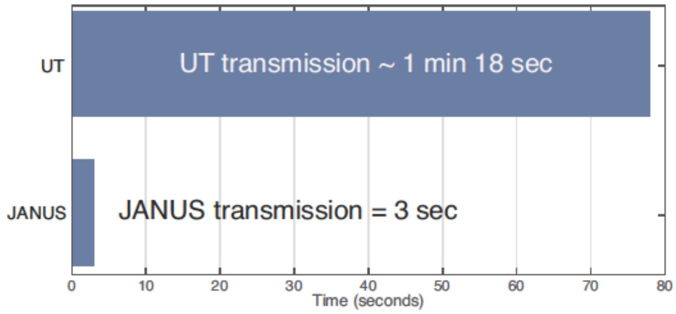


Fig. 3. Comparison of transmission duration for digital (JANUS) and analogue (UT) signals containing comparable information.

embarked CMRE staff member (a future capability will, without a doubt, benefit from full integration with on board systems). This allowed the implementation of an automated DISSUB info demonstrator in which, once emergency is declared on board the submarine, a periodic transmission of vital information is triggered without further need to involve an operator. Additionally JANUS was also employed to send the information structures defined in Submarine Rescue Manual (and under the current procedures transmitted via UT) demonstrating the increased efficiency introduced by the usage of a digital means of communication.

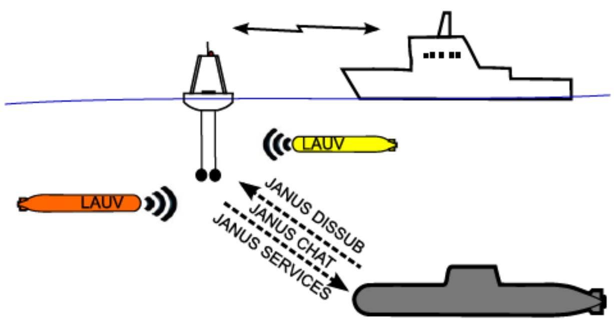


Fig. 4. The concept of experimentation exercised during REP17, employing a submarine, a surface ship, a gateway buoy and two LAUVs.

A series of pre-established communication scripts like "mating" and "de-mating", used in a submarine rescue situations to coordinate hatch coupling, were also performed using JANUS. During REP17, FEUP deployed two LAUVs [9] to take part in the DISSUB scenario. The concept was the introduction of unmanned vehicles in an undersea networked environment, benefiting from the automation of processes for a quicker and more effective operation. Upon reception of a DISSUB acoustic message, the LAUVs were automatically triggering search behaviours, using the received DISSUB position as the search starting point. This is a concept that can be further explored in the future, spawning new DISSUB concepts supported on digital underwater communications.

The LAUVs did not have JANUS capabilities and were equipped with Evologics modems [10]. The translation of DISSUB data from JANUS to the LAUV acoustic network

Fig. 5. The LAUV vehicles from FEUP.

was implemented in a gateway buoy, deployed in the area. All communications and networking tasks were performed using the CMRE Cognitive Communications Architecture (CCA)[1]. The CCA is CMRE's underwater communications software architecture and is capable of hosting a suite of protocols and support dynamic switching between them. All JANUS functionalities were implemented in the CCA.

REP17 played a fundamental role in the preparation of equipment and procedures to be employed during DYMH17.

III. Dynamic Monarch17

Dynamic Monarch is the world's largest submarine rescue exercise. It is organised every 3 years by ISMERLO and is designed to test interoperability and ability to respond to submarines that may require support anywhere in the world. The exercise DYMH17 took place in Turkish waters, in the Marmaris region (see Fig. 6) in September 2017. CMRE participated in DYMH17 with the objective of exposing JANUS and its benefits to the operational submarine rescue community. During DYMH17, the concept of employing digital underwater communications in a rescue context was introduced for the first time in a NATO-wide exercise. This represented a major milestone towards more effective rescue missions that could benefit from modern underwater communications techniques avoiding the phonetic biases and inherent difficulties of the 70-year-old UT. CMRE employed JANUS to deliver, in an automated way, DISSUB information (contents following the current rescue manual) from the Spanish Navy submarine ESPS Tramontana to the different rescue ships involved in the exercise. JANUS was also successfully used for different communication scripts that are currently implemented using the underwater telephone (like pod delivery and ventilation). these scripts are sequences of trigger messages exchanged between the DISSUB and the rescue ship. Additionally, JANUS was used to transmit Automatic Identification System (AIS) contacts from the rescue ships to the submarine and to

[1]At the time of publishing there is no openly available reference for the CCA.

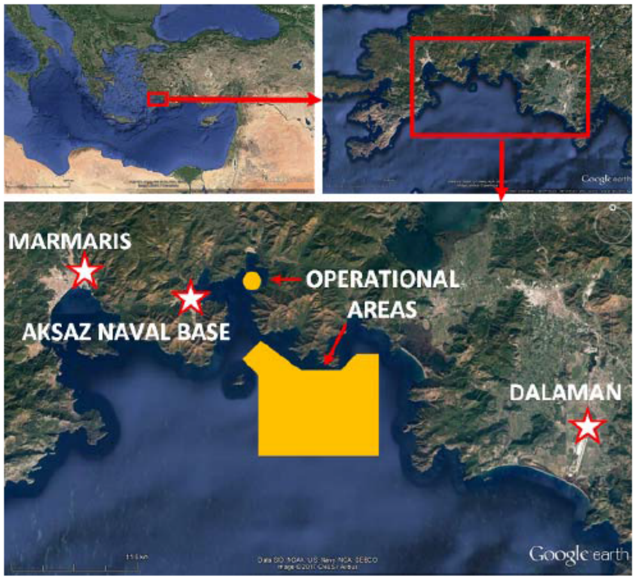


Fig. 6. Operational areas for the Dynamic Monarch 2017 exercise.

Fig. 7. Installation on board the Spanish submarine ESPS Tramontana. Top: The submarine in dock; Bottom left: Circled in red, the secondary underwater telephone transducer that was used for JANUS; Bottom right: CMRE canister, installed inside the submarine, with JANUS software and electronics.

establish a much-welcomed feature of chatting. This digital chat allows any conversation to be established pretty much in the same way of the ubiquitous cellphone instant messaging services. The introduction of interoperable underwater digital communications in the rescue scenarios opens the way for more effective operations where information is more rapidly and readily available and where personnel may not be required for data exchange. This paves the ground for the seamless employment of unmanned vehicles.

In what follows we describe the JANUS-related activities conducted in the preparation and execution phases of the Dynamic Monarch exercise emphasising on the benefits and novel opportunities opened by the introduction of digital communications in DISSUB operations.

The installation of the JANUS transmission/reception system on board the Spanish submarine was performed in the naval base of Cartagena (Spain). The technical solution adopted to enable JANUS on board the submarine included the installation of prototype hardware (developed at CMRE and including computing board, acquisition system, amplifier and impedance matching circuit) connected directly to the transducer of the secondary underwater telephone system. This is illustrated in Fig. 7.

On the rescue ship side, CMRE employed two different JANUS-capable systems, supporting two different concepts of operation:

i. A portable JANUS system with a transducer directly deployed over the board of the rescue ship;
ii. A JANUS system installed on a portable drifting gateway buoy (Fig. 8) with radio links to the rescue ship. The buoy offered a choice of radio links at either sub-GHz frequencies for long range or 2.4 GHz frequencies for fast, short range data exchange. Radio modems and a PC terminal were installed on the rescue ship to control the buoy hardware and software. The gateway buoy was employed mainly to avoid interference with the propulsion of the rescue ship but its use opened to the possibility to explore different geometries and communication links with the DISSUB.

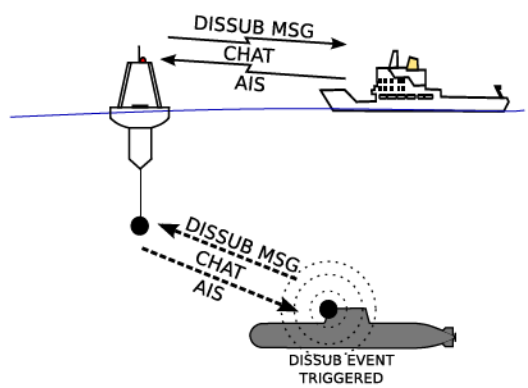


Fig. 8. The JANUS-based concept employed during DYMH17, using a portable, drifting gateway buoy.

A. *Automatic transmission of DISSUB and AIS data*

After a hypothetical emergency is declared, the JANUS module on board the submarine periodically sends messages with position and vital data, providing an initial snapshot of the status of the DISSUB. This followed the same definition previously employed during REP16 and REP17. This information was acquired automatically from the relevant systems of the submarine (in the case of navigation information) or was inserted by the operator (in the case of air quality measurements). These vital parameters were received on board the rescue ship and visualised on the map as presented in Fig. 9. Similarly, AIS data was transmitted from the rescue ship, received and visualised on the DISSUB. AIS and DISSUB data transmissions were occurring simultaneously with the CCA handling the sharing of the communications medium.

This proof-of concept introduced the automation of vital data transmission to and from the DISSUB. Air quality measurements are key to assess the situation on board the submarine and plan the actions to be taken by a rescue team.

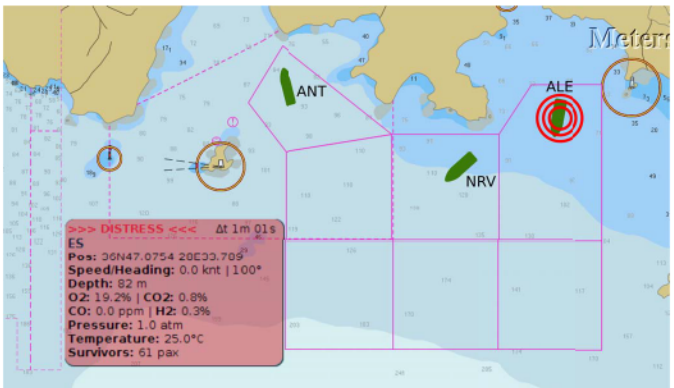


Fig. 9. Screen capture of the surface display showing AIS elements (the three vessels conducting operations in the area) plus a red radar icon signalling the position of a DISSUB and a red pop-up box with the vital information being received via JANUS. The same display was available at the submarine, with the AIS contacts received via JANUS.

B. JANUS chat

The JANUS chat was used for bidirectional communication between the rescue ship and the submarine. It was used to exchange any type of alphanumeric information, and to coordinate and plan activities. The chat functionality was very appreciated throughout the exercise. It was used for informal exchanges, coordination of serials and, in several occasions, as a direct replacement of UT communications. The usage of the chat proved to be particularly effective to deliver relevant information in the cases where there was poor UT reception, when operators with strong/mismatching accents were operating the UT and when there was the need to transmit position or other numeric information (*e.g.* on-board measurement readings) that are easy to misunderstand on the UT. In several cases during the exercise, the coordinates of the submarine transmitted over the UT were not correctly understood at the rescue ship and wrongly plotted in the nautical charts.

Fig. 10 shows two chat snippets relative to interactions between the submarine and a Spanish Navy liaison officer on board the rescue ship in a situation where the UT communication was imperceptible. In one of the cases a bottom report (depth, heading, latitude and longitude) is provided by the submarine. In the other case two Spanish officers interact (in Spanish) about the number of available air bubbles in the submarine.

```
2017-09-16 08:26:47Z --> 2, D43:H217
2017-09-16 08:27:10Z --> 2, 36.85567;28.44567

2017-09-16 08:27:42Z --> 2, Good morning!
2017-09-16 08:28:15Z --> 2, UT is bad today.
```

```
2017-09-16 08:29:50Z <-- TRANSMITTED: Cuantas veces mas
2017-09-16 08:29:53Z <-- DELIVERED: 2, Cuantas veces mas

2017-09-16 08:30:06Z <-- TRANSMITTED: podeis lanzar
2017-09-16 08:30:12Z <-- DELIVERED: 2, podeis lanzar

2017-09-16 08:31:22Z <-- TRANSMITTED: Burbujas?
2017-09-16 08:31:26Z <-- DELIVERED: 2, Burbujas?

2017-09-16 08:32:10Z --> 2, STBY
2017-09-16 08:35:50Z --> 2, soy el JOPS,
2017-09-16 08:36:26Z --> 2, para localizarnos
2017-09-16 08:38:23Z --> 2, dos burbujas mas
```

Fig. 10. JANUS chat snippets. Top: The submarine provides a position report (depth=$43m$, Heading=$217°$, lat=$36.85567°N$, long=$28.44567°E$. Bottom: The officer on board the rescue ship asks (in Spanish) how many more air bubbles (*burbujas*) can the submarine employ for localisation. The submarine replies that they have two more air bubbles (*dos burbujas mas*).

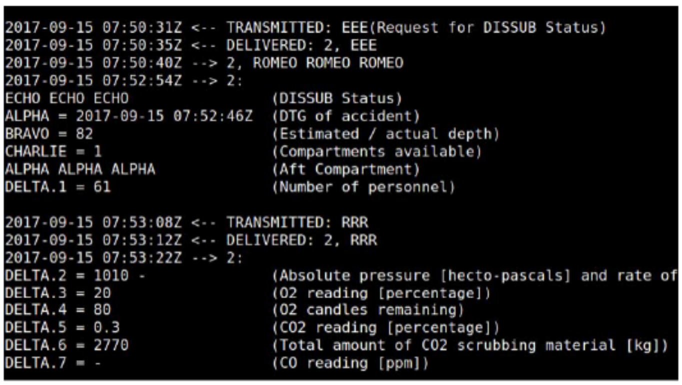
C. JANUS chat with enhanced data support

Enhancements to the JANUS chat tool were implemented in order to allow the easy and comprehensive display of the data structures currently defined in the submarine rescue manual. This goes beyond the reduced data structure sent in the automated DISSUB transmission of Section III-A and includes the full status information as defined in page 78 of the ATP/MTP-57 [4] (Submarine Rescue Manual) Edition C Version 2 - PARA 3.A.1.3-58. This allows rescue operators to have access to the full DISSUB data, defined as:

a) Date-time group of accident
b) Estimated / actual depth
c) Compartments available
d) In each of these compartments:
   1. Number of personnel
   2. Absolute pressure and rate of rise
   3. O_2 reading
   4. O_2 candles remaining/Amount of oxygen left (in litres)
   5. CO_2 reading
   6. Total amount of CO_2 scrubbing materiel (in kg)
   7. CO reading
   8. Damage report
   9. Injuries
   10. Senior Survivor's intentions/requirements.
   11. Communication capabilities
   12. In case of the DISSUB being nuclear powered all details of radiological activity and measurements taken to date

13. Electrical supplies available within DISSUB
e) Heading
f) Aspect - heel and trim
g) Indicator buoy(s) or Emergency Position Indicator have been released, if equipped.

Figure 11 shows a screen capture of the ATP/MTP-57 information being received at the rescue ship. Note that this bulk of data is sent in encoded form to reduce the number of transmitted bits (and therefore channel occupancy). All contextual information, such as field annotations and units is added locally by the chat application and is not transmitted through the water. The enhanced JANUS chat was also employed to transmit trigger messages as defined in procedural scripted protocols (described in page 116 of the ATP/MTP-57 submarine rescue manual Edition C Version 2 - ANNEX 5.A. Communication Scripts). These protocols are used to coordinate escape and rescue operations like mating, ventilation procedures and delivery of pods.


```
2017-09-15 07:50:31Z <-- TRANSMITTED: EEE(Request for DISSUB Status)
2017-09-15 07:50:35Z <-- DELIVERED: 2, EEE
2017-09-15 07:50:40Z --> 2, ROMEO ROMEO ROMEO
2017-09-15 07:52:54Z --> 2:
ECHO ECHO ECHO                (DISSUB Status)
ALPHA = 2017-09-15 07:52:46Z  (DTG of accident)
BRAVO = 82                    (Estimated / actual depth)
CHARLIE = 1                   (Compartments available)
ALPHA ALPHA ALPHA             (Aft Compartment)
DELTA.1 = 61                  (Number of personnel)

2017-09-15 07:53:08Z <-- TRANSMITTED: RRR
2017-09-15 07:53:12Z <-- DELIVERED: 2, RRR
2017-09-15 07:53:22Z --> 2:
DELTA.2 = 1010 -              (Absolute pressure [hecto-pascals] and rate of
DELTA.3 = 20                  (O2 reading [percentage])
DELTA.4 = 80                  (O2 candles remaining)
DELTA.5 = 0.3                 (CO2 reading [percentage])
DELTA.6 = 2770                (Total amount of CO2 scrubbing material [kg])
DELTA.7 = -                   (CO reading [ppm])
```

Fig. 11. Enhanced ATP/MTP-57 chat with automated transmission of established information, as per above listing.

Fig. 12. CMRE operations during Dynamic Monarch 2017 with the TCG Alemdar rescue ship from the Turkish Navy (top left) and the deployment of CMRE light-weight drifting gateway buoy (right).

IV. Conclusions and New Prospects

CMRE demonstrated the ability of JANUS to deliver successfully, in an automated way, vital submarine information from a DISSUB to a rescue ship. The transmission of automated distress messages (including the DISSUB position automatically obtained from the vessel navigation system, air quality information, ventilation data, pressure, temperature and number of survivors) was also successfully demonstrated. Different communication scripts that are currently implemented using the UT in accordance with the current NATO rescue standards were performed successfully between the submarine and the rescue ships using the JANUS communication protocol. Additionally, JANUS was also used to transmit AIS contacts from the surface to the submarine and to introduce a much-welcomed chat feature. This digital chat allows conversations to be established in a “WhatsApp-style” providing a familiar way to exchange information with the submarine without any phonetic biases. The use of the chat proved to be very effective and was highly welcomed by the users. Using the digital chat or the automated DISSUB messages, coordinates and other measurements were immediately available and displayed on a digital chart. The usage of the chat also provides an easy and effective interaction between the DISSUB and the rescue ship. In several occasions, the operators on board the submarine and the the rescue ship requested the usage of JANUS to deliver information in a quicker and more effective way.

The introduction of interoperable digital underwater communications in rescue scenarios opens the way for a different operational approach. The data availability is improved and the information exchange is quicker and can be automated. This enables the seamless employment of unmanned vehicles. The use of these vehicles could be of great benefit during the searching phase and can provide better communication links (relaying information) during submarine rescue operations. Using JANUS, the DISSUB, the rescue ship(s) and rescue vehicles can all be part of the same network thus cooperating to distribute and relay relevant information to any other assets in an automatic and effective way. This can facilitate different dimensions of the operation including the command and control aspects and water space management. During the preparation and execution of DYMH17, great interest was shown by the operational community to equip Submarine Rescue Vehicles (SRVs) with a JANUS system, thus making the simultaneous interaction between the different rescue players (DISSUB, SRV and rescue ships) more orderly and easier to manage. Dynamic Monarch, being an unclassified exercise, driven by humanitarian purposes and involving NATO and non-NATO nations in a predominately non-military framework provides the ideal setup to demonstrate novel search, escape and rescue capabilities with the intention to transition into operation.

Acknowledgements

The authors would like to thank the captains and crews of the ships operating with CMRE throughout the experiments that led do DYMH17, namely from the NRV Alliance, the NRP Arpão, and the NRP Hidra. A very special word of appreciation goes to the captains and crews of the units operating with CMRE during DYMH17 namely the ESPS Tramontana, the ITS Anteo, the SD Northern River, the TCG Alemdar, the TCG Inebolu and the NATO Submarine Rescue System team. Special thanks goes also to the support officers that enabled and facilitated CMRE participation in DYMH17: RADM Lennon (COMSUBNATO), CAPT Wheeler (MARCOM), CAPT Cuciniello (ITA Navy), CAPT Cuerda (ESP Navy), CDR Dickmen (TUR Navy), LT Ozer (TUR Navy), the Submarine Escape and Rescue Working Group (SMERWG) and all Turkish Navy Officers and staff that offered tremendous support throughout the exercise.

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Abstract

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Keywords

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NATO Science and Technology Organization
Centre for Maritime Research and Experimentation

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