VisGap'23 – The Gap between Visualization Research and Visualization Software (2023)
C. Gillmann, M. Krone, G. Reina, T. Wischgoll (Editors)

The Lack of Specialized Symbology and Visual Interaction Design Guidance for Sub-Sea Military Operations

G. Walsh[1], N. S. Andersen[1], N. Stoianov[2], and S. Jänicke[1]

[1]Department of Mathematics and Computer Science, University of Southern Denmark, Odense, Denmark
[2]Department of Computing, Bulgarian Defence Institute, Sofia, Bulgaria

Abstract

This paper addresses the lack and need for specialized and visually effective interaction design guidance for sub-sea military operations. We identify gaps in the implementation of best practice visualization techniques, building upon our recently published survey on visual interfaces used in military decision support systems. Our analysis focuses on the current NATO symbology standard and several sub-sea military frontend systems to identify deficiencies and their underlying causes. Such origins of deficiencies include inadequate design consideration of environmental conditions, as well as incomplete hardware and software requirements for sub-sea conditions. While many such gaps exist, for the purposes of this paper, we narrow our focus to exploring the potential for a new sub-sea symbology for the maritime domain, drawing from insights gained and developed through our participation in the EDIDP (European Defence Industrial Development Programme) project CUIIS (Comprehensive Underwater Intervention Information System). We propose extending existing NATO military standards by creating a comprehensive framework for a new sub-sea symbology and visual interaction design. This framework includes a set of semiotic communication symbols for military divers, which can easily be combined based on the most common messages required for effective communication between command and military divers. This paper concludes by highlighting the opportunities for improvement in NATO Military Symbology for sub-sea military operations.

CCS Concepts
• ***Human-centered computing*** $\rightarrow$ ***Human computer interaction (HCI); Interaction design; Visualization application domains;*** • ***Applied computing*** $\rightarrow$ ***Military;***

1. Introduction

We recently published a survey [WASJ23] that analyzed over twenty frontends of military Command, Control, and Communication (C3) systems through a domain-specific design space that enabled the identification of gaps, opportunities, and guidelines for improving the implementation of best practice interaction and visualization techniques. In particular, our analysis focused on C3 systems with frontends that integrate information visualizations and visual analytics tools with advanced graphical user interfaces, producing Visual User Interfaces (VUIs). We found that many of the surveyed military products fail to use a comprehensive graphic design language and do not consider all domain-specific requirements that arise from the environments and settings in which military organizations operate. These types of failures in military products are particularly prevalent in bespoke military operations, where requirements at a strategic level (related to the tasks of commanders and their staff in a remote location) and tactical level (related to military forces on site carrying out orders) demand specifically-tailored VUIs that enable easy interactions and a concise and precise overview of information for situational awareness and swift decision-making.

The survey also uncovered a lack of military products specifically designed for sub-sea (underwater) military operations. The lack of products may be because military operations, such as air and land, are typically more common. Furthermore, the technologies used in air and land operations have (i) a more extended history, allowing more time for development and refinement, and (ii) more apparent civilian applications, leading to greater standardization and adoption.

Regarding related academic work, the most relevant work is the scoping review presented in [BZLPK22], which examines the capabilities of wearable devices for underwater use at a tactical level. At the same time, some studies examine visual interaction in the context of aquatic experience systems [HNH19, GMHP17, CCG22]. Yet, no existing research focuses on the capabilities and features of VUIs supporting C3 systems and connected devices for military sub-sea purposes.

Designing new VUI solutions that address requirements at a

DOI: 10.2312/visgap.20231117

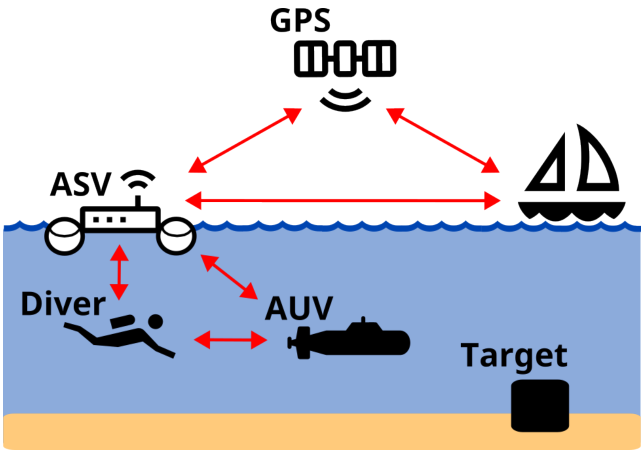

Figure 1: *Illustration of the practical organization of technologies behind C3 systems used to support sub-sea military operations at a strategic level (above the surface) and a tactical level (below the surface) with the integration of Autonomous Surface Vehicles (ASVs) and Autonomous Underwater Vehicles (AUVs).*

strategic and tactical level in the unique setting of sub-sea military operations thus presents a critical challenge. To address this challenge, we will in this paper focus on VUIs for use in sub-sea military operations by proposing a new sub-sea symbology and visual interaction design. This initiative aims to create a basis for designing more effective and user-friendly VUIs that facilitate enhanced communication and decision-making for surface personnel (at a strategic level) and divers (at a tactical level), as illustrated in Figure 1.

A versatile and robust sub-sea military symbology and visual interaction design could operate similarly across, not just ordinary small and large screens, but also head-mounted devices [KS11, SKESS12] and augmented reality displays [MGHIP17, BBM*19].

The subsequent sections of this academic paper are outlined as follows. Section 2 describes the sub-sea environmental conditions that result in stringent hardware and software requirements (HRSs) for underwater military devices subsequently presented in Section 3. Section 4 introduces the current NATO Military Symbology Standard APP-6(D) (referred to as the *NATO MSS* hereafter) and assesses the current standard through the lens of the HRSs defined in Section 3. Subsequently, additional HRSs are identified in Section 5, highlighting shortcomings in the current NATO MSS, prompting the development of guidelines (in Section 6) for a new, more comprehensive semiotic visual interaction system for Sub-Sea Military Operations (SSMOs). Finally, in Section 7, we conclude that military symbology and visual interaction design for SSMOs have ample opportunities for improvement. Furthermore, we present future work.

2. Environmental Conditions

Military operations can occur in extreme and harsh environments. The sub-sea environment, in particular, is associated with unique conditions that can negatively affect divers and their various digital devices. The environmental conditions include:

EC1 (Pressure): As depth increases, water pressure increases. For divers, an increasing depth (and bottom time) is associated with an increased risk of decompression sickness which can occur if a diver ascends too quickly. Correspondingly, for devices, increasing pressure affects the structural integrity of casings, seals, and electronic components.

EC2 (Temperature): The sub-sea environment can experience significant temperature variations that affect not just divers but also the performance and efficiency of electronic components, batteries, and device screens.

EC3 (Salient Water): The salt content affects the density of water, which in turn makes objects, including divers, more buoyant. Divers may need to adjust their buoyancy control devices or the weight they carry to achieve neutral buoyancy in saline water compared to freshwater. For devices, saltwater is corrosive, particularly if the salt content is high.

EC4 (Lighting Conditions): Underwater lighting conditions vary greatly, from bright sunlight near the surface to complete darkness at depth. Lighting conditions affect divers' ability to carry out tasks and orient themselves.

EC5 (Turbulent Underwater Conditions): Rough underwater conditions can lead to high-stress and dangerous situations for divers. For devices, there is an increased risk of seals or casings breaking, leading to damage to the devices' electronic components.

EC6 (Information Transfer): Underwater wireless communication is challenging due to water's absorption and scattering of radio frequency signals. Acoustic and optical communication methods are often used instead, but these have limitations, such as range, data rate, and susceptibility to interference.

These environmental conditions result in strict military standards that describe a set of formal specifications, guidelines, or requirements designed to ensure the reliability, interoperability, performance, and durability of equipment, systems, and software used by the military. For example, the conditions EC1-EC6 result in hardware requirements that demand underwater digital devices to be designed to be waterproof to extreme depths and corrosion, shock, and vibration resistant. Furthermore, additional standards may require that equipment be neutrally buoyant (not to cause unwanted ascent or descent for divers) and have minimal electromagnetic interference (EMI) not to disrupt possible communication with devices, systems, sensors, or other electronic equipment.

3. Hardware & Software Requirements

The environmental conditions EC1-EC6 affect hardware design and downstream software (VUI) design possibilities and decisions. In this context, hardware and software innovations that aim for optimal end-user usability should take into account several central and interrelated hardware and software (VUI) requirements:

HSR1 (Visibility): Underwater visibility can be significantly reduced due to low light conditions at low depth (EC1) and varying water clarity, e.g., due to algae growth (EC2) or rough underwater conditions (EC5). A device should allow the high-contrast

Proceedings published by Eurographics - The European Association for Computer Graphics.

Step No.	Step	Examples
Step 1	Choose frame according to standard identity	
Step 2	Choose and add functional icon	
Step 3	Choose and add a modifier in either sector 1 or sector 2 position if applicable or deemed necessary for visualization.	B N
Step 4	Choose and add a second modifier (if applicable and/or deemed necessary for visual representation. NOTE: only one modifier is permitted per modifier position	B N

Maritime Standard Identities and Frame Shapes

	Pending	Unknown	Assumed Friend	Friend	Neutral	Suspect	Hostile
Sea Sub-surface							

Table 1: *Excerpt from the NATO MSS illustrating the construction of sub-sea representative icons based on a 4-step process including selection of standard identity, functional icon, modifier, and second modifier as deemed suitable. Source: [NAT19].*

DESCRIPTION	ICON	LOCATION : MAIN	REMARKS
OTHER SUBMERSIBLE			None
AUTONOMOUS UNDERWATER VEHICLE/ UNMANNED UNDERWATER VEHICLE (AUV/UUV)			None
NON-SUBMARINE	NON SUB	NON SUB	None
DIVER, MILITARY			None

Table 2: *Excerpt from the NATO MSS illustrating the functional icons associated with military sub-sea conditions. Visible in this excerpt is the outdated and ambiguous functional icons. E.g., the diver icon can easily be misunderstood, as it is unclear whether it is related to a tethered or untethered diver. Source: [NAT19].*

display of information with appropriate coloring or adjustable brightness to accommodate these conditions.

HSR2 (Power Supply): Battery life is critical in sub-sea environments due to the lack of readily available power sources. Devices should be energy efficient and have power-saving modes to extend battery life.

HSR3 (Device Size): Devices should be compact and lightweight to reduce drag and minimize the impact on user mobility. This consideration can, in turn, limit the size of display screens and the number of input controls.

HSR4 (Cognitive Load): The sub-sea environment is a high-stress environment that can impose a significant cognitive load on a diver due to the typically very dynamic environment (EC1-EC5). Devices that support divers should have clear and concise user interfaces that prioritize essential information and minimize the need for complex decision-making.

HSR5 (Information Transfer): Underwater communication can be challenging (EC6), and devices should be designed to store and display critical information locally. Furthermore, since communication may be via a low-bandwidth communication network, a device should ensure that exchanged data is small.

HSR6 (Diver Dexterity): The ability of divers to interact with a VUI through a touchscreen and/or buttons may be limited, e.g., due to a low-precision touchscreen or the diver wearing gloves because of low temperatures (EC2). Devices should be context-aware or have large, easy-to-use buttons and touchscreens that can be operated with gloved hands.

Both hardware and software innovations play crucial roles in addressing these challenges. Hardware design focuses on the physical aspects of devices, ensuring they can operate effectively underwater. On the other hand, software design focuses on optimizing performance, ease of use, and information processing. In practice, hardware and software innovations are typically employed to address the unique challenges faced by SSMOs.

4. NATO Military Symbology Standards

The NATO MSS provides a standardized, structured set of graphical symbols to consistently represent military units, equipment, installations, and tactical graphics on maps, charts, etc. The primary purpose of the NATO MSS is to facilitate joint and multinational military operations by providing a common visual language for better communication, understanding, and coordination. In particular, C3 systems and related applications extensively use NATO MSS.

The symbology standard allows for a systematic process of symbol construction using building blocks based on a combination of geometric shapes, icons, and alphanumeric characters that convey specific information about the type, size, and affiliation of military units or objects. The symbols are further classified into several categories: land, air, maritime, space, and special operations forces.

The NATO MSS has evolved over the years and has undergone multiple revisions to accommodate the changing nature of warfare, technological advancements, and the growing requirements of NATO forces. The most recent version, APP-6(D), was released in 2021, introducing new symbols and refining existing ones to better represent modern military capabilities and concepts.

The current standard allows for creating some new symbols (based on its basic building blocks, as shown in Table 1), which may be needed in the future. Yet, some aspects of the standard, particularly those for the sub-sea environment, are outdated and lacking. Nonetheless, the standard plays a significant role in addressing some of the challenges associated with SSMOs. In this context, we refer to Table 3 and point out that:

- HSR1 is addressed by the NATO MSS as underwater reduced visibility conditions due to EC1-2, and EC5 are overcome by the incorporation of functional icons designed to be concise, minimal, and easily and distinctly recognizable from a variety of visibility levels.
- HSR2 is addressed by the implementation of functional icons and symbols, which only require low computational power, as opposed to other visualization methods such as animations or dynamic displays of information.
- HSR3 is satisfied as symbols can be easily scaled without affecting the identification and visibility. This aids the development of a consistent cross-platform symbology that is responsive across various devices.
- HSR4 is addressed since symbols are i) instantly recognizable ii) convey essential information. However, as the symbols of actors and assets in the NATO MSS are outdated, there is an opportunity to address HSR4 better.

The remaining hardware and software requirements, HRS5-12, which we uncover next, are not addressed by the current NATO MSS.

	NATO Military Symbology
HSR1	✓
HSR2	✓
HSR3	✓
HSR4	☆
HSR5	×
HSR6	×
HSR7	×
HSR8	×
HSR9	×
HSR10	×
HSR11	×
HSR12	×

Table 3: *Overview of hardware and software requirements (HSRs) that the current NATO MSS addresses. The checkmark ✓ indicates HSRs that is or can be addressed, while the star ☆ indicates HSRs addressed, but with opportunity for improvement. Lastly, the cross × indicates HSRs not addressed at all.*

5. Sub-Sea Symbology & Visual Interaction Implementation

Sub-sea symbology and visual interaction implementation needs to be designed to operate as two levels as shown in Figure 1, i) at a command level, which typically utilizes larger desktop displays at the surface level, and ii) at a tactical level, which typically involves smaller screens of underwater wearable devices or tablets. Careful consideration of the design of symbology at both levels of operation is required to improve the execution of SSMOs by increasing situational awareness, enhancing communication, and ultimately further enhancing the ability of personnel to carry out SSMOs as well as respond to a variety of threats they might encounter during such operations.

5.1. Visual Interaction at a Strategic Level

Visualization at a strategic level in SSMOs is primarily concerned with representing actors and assets on cartographic maps during the planning, execution, and assessment phase of operations [WASJ23, NAT22, Dep19, RB11, Dep04, Dep05]. Actors in this context can refer to distinct military divers, submarine personnel or equipment, AUVs, support personnel, and identified enemy forces. Currently, many software products in the sub-sea domain do not implement existing military symbology relating to sub-sea conditions, as a gap exists with updating NATO MSS to reflect modern developments in military diving equipment, manned-unmanned teaming, and modern sub-sea weapons as shown in Table 2 [BMPC20, RS20, NRM*]. As a result, visualizations at a strategic level in SSMOs can be lacking in communicating essential information (such as the type of military divers) to the command. This can result in decreased situational awareness and reduced decision-making capabilities.

Common to both levels of operations in SSMOs is the overarching deficiencies in the NATO MSS. However, these deficiencies particularly impact visual interaction at a strategic level relating to:

HSR7 (Complete Symbol Set): Lack of symbology specific to the underwater environment as it is primarily designed for land and air operations. SSMOs require a complete and modern symbology set that reflects the current and future sub-sea threat environment. For example, SSMOs require distinguishable and easily recognizable symbology regarding a multitude of underwater equipment, submersibles, or underwater environment typologies used in modern SSMOs.

HSR8 (Implementation of Amplifiers): Modern amplifiers for SSMOs should be specified such that they can be easily implemented and understood by users to avoid confusion about the amplifiers' semiotics. For example, updated use of an amplifier as a directional marker or demonstrating depth through visual means of actors and assets. The incorporation of a broader and more modern visual representation of such metrics can more astutely satisfy user requirements.

HSR9 (Interoperability of Products) Individual manufacturers of frontend software for SSMOs should be able to use the NATO MSS to ensure clear and concise implementation of comprehensive sub-sea symbology in their systems.

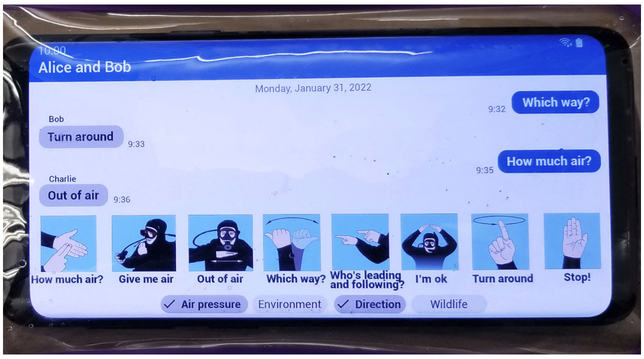

Figure 2: *An image illustrating a novel communication method in terms of visual interaction for civilian divers underwater that utilizes a small number of diver hand-signal images as easily selected statuses and messages to be communicated. Source: [CCG22].*

This should be done to safeguard against manufacturers implementing their proprietary symbology system for their products [Aer, Arv, RTS21, Hof20, Nor]. Furthermore, suppose the implementation of symbology is not universal. In that case, it can lead to confusion among divers, misinterpretation of messages from fellow divers, command, and poor cooperation among member forces.

5.2. Symbology at a Tactical Level

Visualization, at a tactical level in SSMOs, is constrained by extreme environmental factors Section 3, resulting in display devices that are typically very small. Furthermore, communication to the command at the surface is also limited, due to the limited applicable interaction methods possible, partly due to low bandwidth capabilities underwater, impracticality of verbal communication, and limited input of such touchscreens. As such, a greater emphasis is placed on information that can be easily communicated bi-directionally, briefly, concisely, and using low bandwidth.

Methods of using predefined messaging for underwater communication have been researched by [CCG22] and are shown in Figure 2 in a civilian context. However, no research has been conducted on applying similar visual interaction and symbology techniques to be used in a military context. To enable such possibilities, the NATO MSS should provide clear and comprehensive guidance relating to the following:

HSR10 (Symbols for Bi-directional Communication): Hand signals are widely and efficiently used by divers to demonstrate meaning, such as "there is a problem", "stay close", or "stop". It should be a requirement that such signals be included in a complete symbol set (HSR7).

HSR11 (Information Exchange Protocol): A protocol should be provided to establish a standardized exchange process for communicating text-based messages (possibly incorporating symbology) and predefined messages bi-directionally between divers and surface personnel.

HSR12 (Sequence-able Messages): Guidance on how predefined messages (incorporating symbology) may be combined or sequenced to communicate more specific meanings or intel.

Field	*Field Title*	*Description*	*Text/Graphic*
P	Identification, Friend-or-Foe (IFF)/Selective Identification Feature (SIF)	Identification modes and codes.	Text
Q	Direction of Movement Arrow/Offset Location Indicator	With arrow, it denotes the direction symbol is moving or will move. Without arrow, it is used to denote precise location or to declutter, except headquarters.	Graphic
S	Headquarters Staff Indicator/Offset Location Indicator	Identifies unit symbol as a headquarters or used to indicate precise location or to declutter.	Graphic
T	Unique Designation	An alphanumeric designator that uniquely identifies a particular unit (designation).	Text
V	Type of Equipment	Identifies unique designation (such as M-2 for infantry fighting vehicle).	Text
W	Date-Time Group	An alphanumeric designator for displaying a date-time group (DDHHMMSSZMONYY) or "O/O" for on order. The date-time group is composed of a group of six numeric digits with a time zone suffix and the standardized three-letter abbreviation for the month followed by two digits. The first pair of digits represents the day; the second pair, the hour; the third pair, the minutes. The last two digits of the year are after the month. For automated systems, two digits may be added before the time zone suffix and after the minutes to designate seconds.	Text
X	Altitude/Depth	Altitude as displayed on the global positioning system (GPS).	Text
Y	Location	Latitude and longitude; grid coordinates.	Text
Z	Speed	Displays speed in nautical miles per hour or kilometres per hour.	Text
....	....	....	....

Table 4: *Excerpt from the NATO MSS illustrating various types of amplifiers which can currently be assigned to symbols, along with their text or graphic specification. Source: [NAT19].*

6. A New Symbology and Visual Interaction Design for Sub-Sea Military Operations

The issues prevalent in the current implementation of sub-sea military symbology call for a revision, not only because they are limited and ambiguous but also because of their underutilization in VUIs designed to support SSMOs. These VUIs [WASJ23] have been developed without satisfying general visualization guidelines [Mun14, War19]. To solve this problem, a revision of the sub-sea military symbology must include:

Revision of Sub-sea Functional Icons: Update the existing functional set of icons to comprehensively cater to modern military practices that meet HSR needs, e.g., in Table 2 the military diver icon should be updated to allow for distinctions between tethered and untethered military divers, as well as other sub-sea typologies to support HSR4 and increase situational awareness. Such functional icons should be clearly visible (HSR1) on the relevant implementation devices (HSR3 and HSR6).

Symbols in/as Predefined Messages: Guidelines should detail how and when symbols can be used in/as predefined messages to reduce cognitive load (HSR4) and account for the constraint of information transferal (HSR5). For example, how functional icons could be used in conjunction with established diving symbols as shown in Figure 2.

Symbols as Directional Markers: While the NATO MSS does provide a specification as to how to assign directional movement to a symbol as shown in Figure 3, it does not fit the purpose of

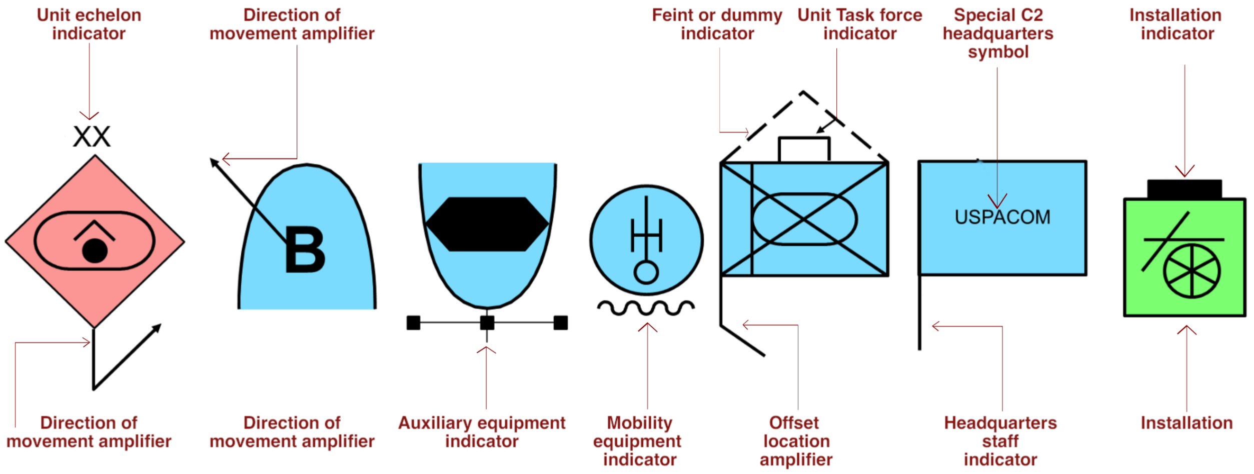

Figure 3: *Excerpt from NATO MSS illustrating how directional amplifiers can currently be assigned to symbols, highlighting an opportunity for improvement in a NATO MSS extension.*

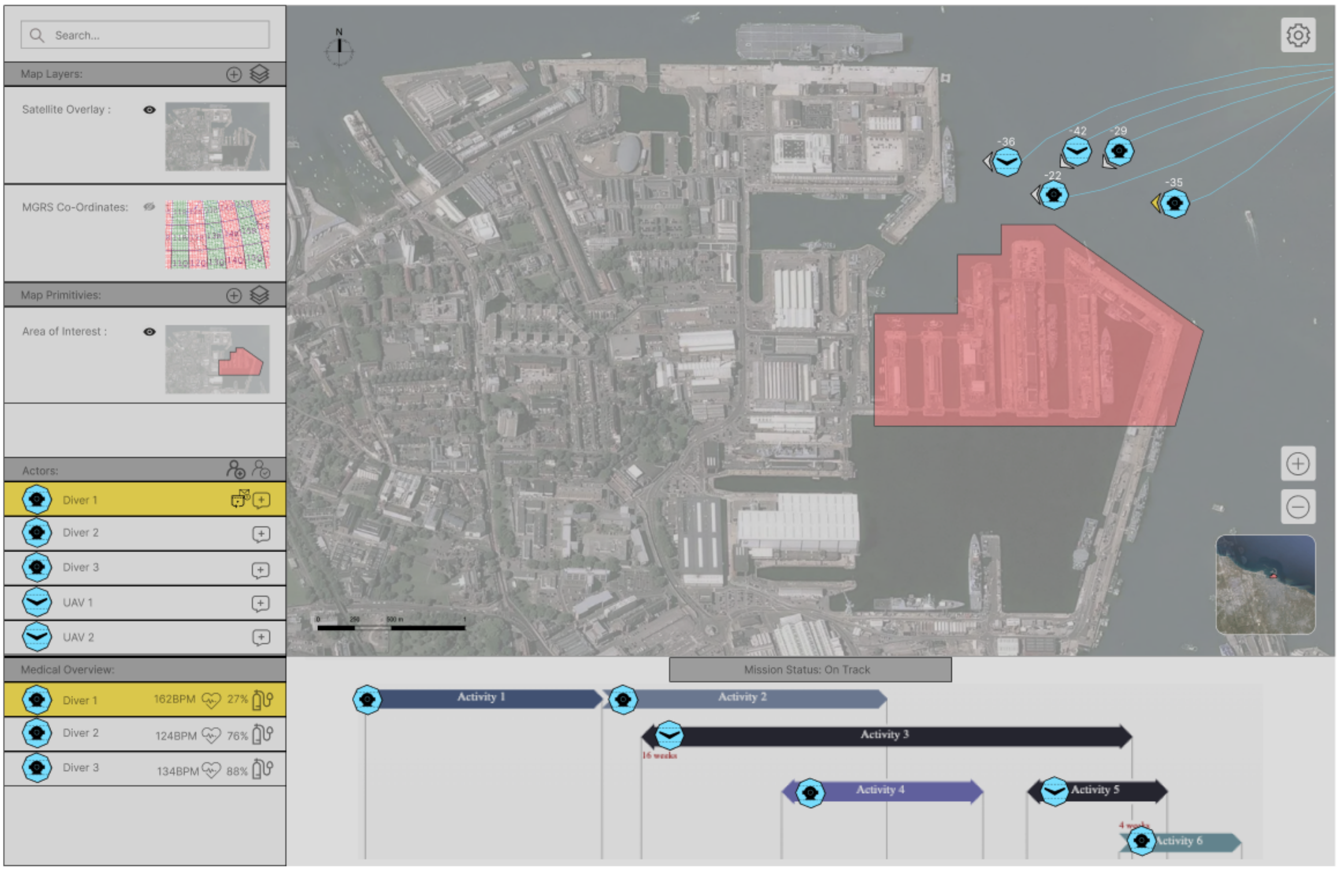

Figure 4: *Illustration depicting how a new comprehensive symbology and visual interaction design for sub-sea military operations could aid the development of VUIs of software applications supporting such operations.*

Proceedings published by Eurographics - The European Association for Computer Graphics.

SSMOs. This results in individual products with a wide array of VUI elements being utilized. Updated specifications should be provided for the universal implementation of amplifiers such as directional marks for SSMOs, as seen in Figure 4, to satisfy HSR4 and HSR6-12.

Depth of Actors and Assets: Sub-sea symbology should accurately represent the depth of actors and assets. This could be represented by a standard text presentation or incorporation of color gradient (HSR7). Currently, the NATO MSS only permits text-based representation as shown in Table 4. However, further design emphasis on such an indicator could improve HSR4 and HSR7-9.

Representation of Sensory Data: Guidelines should specify the key vitals of military divers that should be available to view and their format while considering EC6. Similarly, guidance for AUV specifications should make clear which vitals may be desirable to represent, as well as their display format and suitable alternative methods of representation feeding into HSR3-4 and HSR6. Examples of such metrics for a diver could include heart rate, oxygen saturation, carbon dioxide concentration expressed as partial pressure, blood pressure, and body temperature.

Instruction for Use on Display Device: Explicit specification should be provided regarding how symbology and amplifiers should be altered or represented differently on small screens below the surface and large screens above the surface to ensure visual consistency and responsiveness across a variety of devices used in SSMOs (HSR1-12).

A symbology extension is required to overcome these shortcomings in the NATO MSS for SSMOs.

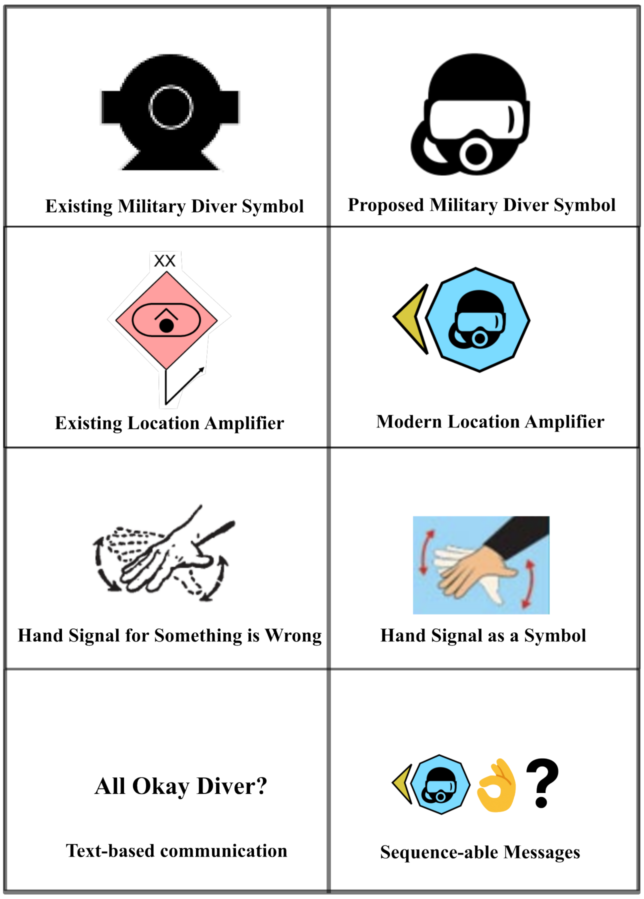

Figure 5: *Example of how functional icons could be updated in an extension to the NATO MSS to provide more modern and universal iconography for sub-sea activities and threats. The figure illustrates how functional icons (such as the military diving symbol), amplifiers (such as location), incorporation of diving hand signals, and sequence-able messages could be incorporated into an extension of the NATO MSS.*

7. Conclusion

The gap between implementing best practices in terms of visualization and visual interaction in SSMOs is partly due to the current NATO MSS, which is not fit for purpose and is outdated for the current sub-sea environment both at a command and tactical level in military software applications. We argue that the current gap can be closed by creating a revised NATO symbology standard that creates a common and standardized new symbology and visual interaction design. Our revision proposal is rooted in understanding the environmental considerations impacting sub-sea symbology and the hardware and software requirements for such symbology standards. Our analysis of the current NATO MSS found that only 3 HSRs are properly addressed. Furthermore, 8 HSRs still need to be addressed, while HRS4 is only partially addressed and thus offers an opportunity for further improvement.

We propose that the current NATO MSS revised bearing in mind the following areas: i) the low cognitive load required to use such symbology ii) sub-sea information transferal constraints iii) the need for diver dexterity iv) the need for a comprehensive set of symbols and icons v) the need to be able to provide a modern implementation of amplifiers vi) the need to cater for and promote interoperability vii) the need for an extended symbology of diver hand signals for non-verbal communication viii) the need for an information protocol for how symbols may be used for communication with divers ix) the need to provide guidance on sequence-able messages or symbols for communication with divers.

We argue the case for these modest yet achievable and implementable revisions to the current NATO MSS can create a basis for a new symbology and visual interaction design for SSMOs. Advancements of this kind could enable the standardized development of more user-friendly and cognitively efficient VUIs that improve the communication and interaction between users at command and tactical levels throughout the planning, execution, and assessment phases of operations. We are currently conceptualizing and designing a prototype of the command and control desktop application (over the surface) using the described new symbology and visual interaction design as part of our work on the CUIIS project. Our proposed design is illustrated in Figure 4. Its primary component is a geospatial-temporal data view that tracks divers, displaying their depth and medical conditions. We will evaluate the effectiveness and appropriateness of our functional prototype with military divers, marine commanders, and NATO policymakers associated with the CUIIS project, ensuring it meets the needs of the military

Proceedings published by Eurographics - The European Association for Computer Graphics.

forces while complying with existing and new developing NATO standards.

Implementing this new symbology and visual interaction design for SSMOs will improve military personnel's situational awareness and decision-making ability at strategic and tactical levels.

Acknowledgements

Certain images in the paper are included under the fair use copyright principle, which allows for the free use of portions of copyrighted materials for commentary and discussion. Images courtesy of [CCG22, NAT19, Arv].

The European Defence Industrial Development Programme has supported this research under the project CUIIS (https://cuiis.eu/), grant agreement EDIDP-UCCRS-EDD-2020-059 — CUIIS). However, the authors are solely responsible for this work which does not represent the opinion of the European Commission. Furthermore, the European Commission is not responsible for any use that might be made of the information contained in this paper.

References

[Aer] AEROSPACE C.: Artemispro m military underwater navigation system. URL https://www.collinsaerospace.com/what-we-do/industries/military-and-defense/navigation/ground-products/artemispro-m-military-underwater-navigation-system. Accessed: 2023-05-09. 5

[Arv] ARVONEN P.: A revolutionary and proven to work system for underwater tracking, navigation and communication. URL: https://uwis.fi/en/. Accessed: 2023-03-21. 5, 8

[BBM*19] BRUNO F., BARBIERI L., MANGERUGA M., COZZA M., LAGUDI A., ČEJKA J., LIAROKAPIS F., SKARLATOS D.: Underwater augmented reality for improving the diving experience in submerged archaeological sites. *Ocean Engineering 190* (2019), 106487. doi:10.1016/j.oceaneng.2019.106487. 2

[BMPC20] BANAS J., MEHLING T., PAUL T., CORDS A.: Manned-unmanned teaming challenges in the maritime environment. In *76th Annual Forum of the Vertical Flight Society* (2020). 4

[BZLPK22] BUBE B., ZANÓN B. B., LARA PALMA A. M., KLOCKE H.: Wearable devices in diving: Scoping review. *JMIR mHealth and uHealth 10*, 9 (2022), e35727. doi:10.2196/35727. 1

[CCG22] CHEN T., CHAN J., GOLLAKOTA S.: Underwater messaging using mobile devices. In *Proceedings of the ACM SIGCOMM 2022 Conference* (New York, NY, USA, 2022), SIGCOMM '22, Association for Computing Machinery, p. 545–559. doi:10.1145/3544216.3544258. 1, 5, 8

[Dep04] DEPARTMENT OF THE ARMY (DA): *Operational Terms and Graphics (FM 1-02 / FM 101-5-1/ MCRP 5-12A)*. Independently published, 11 2004. URL: https://army.rotc.umich.edu/public/resources/FM1-02OperationalTerms.pdf. 4

[Dep05] DEPARTMENT OF THE ARMY (DA): Map reading and land navigation. URL: https://irp.fas.org/doddir/army/fm3-25-26.pdf, 1 2005. Field Manual. Accessed: 2023-03-30. 4

[Dep19] DEPARTMENT OF THE ARMY (DA): The operations process (adp 5-0). URL: https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN18126-ADP_5-0-000-WEB-3.pdf, 9 2019. Doctrine on the Operations Process. Accessed: 2023-03-30. 4

[GMHP17] GALLAGHER D. G., MANLEY R. J., HUGHES W. W., PILCHER A. M.: Divers augmented vision display (davd) emerging technology development. In *OCEANS 2017-Anchorage* (2017), IEEE, pp. 1–7. 1

[HNH19] HATSUSHIKA D., NAGATA K., HASHIMOTO Y.: Scuba vr: Submersible-type virtual underwater experience system. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2019), IEEE, pp. 962–963. doi:10.1109/VR.2019.8798052. 1

[Hof20] HOFFMAN W.: Enc3m- multi-waypoint underwater navigation system. URL: https://seacraft.eu/products/military-and-special/enc3-mil/, 11 2020. Accessed: 2023-05-09. 5

[KS11] KOSS B., SIEBER A.: Head-mounted display for diving computer platform. *Journal of Display Technology 7*, 4 (2011), 193–199. doi:10.1109/JDT.2010.2103299. 2

[MGHIP17] MANLEY R. J., GALLAGHER D. G., HUGHES III W. W., PILCHER A. M.: Divers augmented vision display (davd). In *ASME International Mechanical Engineering Congress and Exposition* (2017), vol. 58493, American Society of Mechanical Engineers. doi:10.1115/IMECE2017-70026. 2

[Mun14] MUNZNER T.: *Visualization analysis and design*. CRC press, 2014. 5

[NAT19] NATO STANDARDIZATION OFFICE (NSO): Nato joint military symbology app-6(d). URL: https://litpolukrbrig.wp.mil.pl/u/APP-6D_JOINT_MILITARY_SYMBOLOGY._16_October_2017.pdf, 2019. Accessed: 2023-03-23. 3, 5, 8

[NAT22] NATO'S GEOSPATIAL MARITIME WORKING GROUP (GMWG): Nato additional military layers handbook: Information superiority in the maritime environment. URL: https://assets.admiralty.co.uk/public/2022-06/20220322_NATO%20AML%20Handbook%20Edition%205.pdf?VersionId=in9okGHLWSu0hqMdO0ihTlNgWggo86hq, 2022. Edition 5 March 2022. Accessed: 2022-11-15. 4

[Nor] NORTHERN DIVER MILITARY: Nimrod elite. Accessed: 2023-05-09. URL: https://www.ndiver-military.com/nimrod-elite. 5

[NRM*] NICHOLS R. K., RYAN J. J., MUMM H. C., LONSTEIN W. D., CARTER C. M., SHAY J., MAI R., HOOD J. P., JACKSON M.: Chapter 6 uuv integrated autonomous missions & drone management. URL: https://kstatelibraries.pressbooks.pub/nicholsproject/chapter/chapter-6-uuv-integrated-autonomous-missions-drone-management-mumm/. Accessed: 2023-05-09. 4

[RB11] REILY T., BALESTRA M.: *Applying Gestural Interfaces to Command-and-Control*, vol. 6770 of *Design, User Experience, and Usability: Theory, Methods, Tools and Practice, Part 2*. Springer Berlin Heidelberg, Berlin, Heidelberg, 2011, ch. 2, pp. 187–194. doi:10.1007/978-3-642-21708-1_22. 4

[RS20] ROTH G., SCHULTE A.: A concept on the shared use of unmanned assets by multiple users in a manned-unmanned-teaming application. In *Engineering Psychology and Cognitive Ergonomics. Cognition and Design* (Cham, 2020), Harris D., Li W.-C., (Eds.), Springer International Publishing, pp. 189–202. 4

[RTS21] RTSYS: Handheld sonar and navigation system sonadive by rtsys. URL: https://rtsys.eu/diverheld-system-sonadive#1595147835743-34159f81-0cf6, 9 2021. Accessed: 2023-05-09. 5

[SKESS12] SIEBER A., KUCH B., ENOKSSON P., STOYANOVA-SIEBER M.: Development of a head-up displayed diving computer capability for full face masks. *Underwater Technology 30*, 4 (2012), 195–199. doi:10.3723/ut.30.195. 2

[War19] WARE C.: *Information visualization: perception for design*. Morgan Kaufmann, 2019. 5

[WASJ23] WALSH G., ANDERSEN N. S., STOIANOV N., JÄNICKE S.: A survey of geospatial-temporal visualizations for military operations. In *International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications* (2023), SciTePress Digital Library, pp. 115–129. doi:10.5220/0011902500003417. 1, 4, 5