A Novel Sonar and TMA Interface: Do Operators Get the GIST?

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Abstract — Future submarine control rooms will be required to utilise new sensors and process more data, without crewing increases. While current submarine control rooms are highly capable, new ways of working may be required to meet these future challenges. The User Interfaces on board submarines are fundamental to facilitating completion of command team objectives and so understanding how to optimise future UI design is a critical area of research. Contemporary UIs have evolved over time to match current requirements, but this approach might not be suitable for future requirements. As the work of submarine command teams becomes more complex, new interfaces might be required to maintain sufficient performance. A potential design methodology to explore could be Ecological Interface Design, as it aims to make environmental constraints apparent and reduce operator workload. These goals are synergistic with control room operation and their future operations. Thus, the current work presents an overview of the development of a novel Sonar and Target Motion Analysis proof-of-concept interface, using the Ecological Interface Design paradigm.

1 Introduction

Submarine control rooms have evolved across a century of operations and so represents a high state of maturity, but this does not mean that their design cannot be improved [1]. Improvements may be required to meet future challenges, which include enhanced sensor capabilities, new sensor types, a requirement to process larger volumes of data [2], and a drive to reduce, or at least maintain crew sizes [3, 4].

The Command Teamwork Experimental Test-bed (ComTET) project aims to undertake systematic, statistically robust, and repeatable experiments to understand where performance benefits may be gained on future platforms [5] to meet these challenges. A sociotechnical systems approach is used to appreciate the interactions between highly trained operators interacting with advanced technological systems. Sociotechnical systems are defined as the interaction of multiple operators utilising technology for the completion of purposeful goal-directed behaviours [6].

One area of investigation for the ComTET project is to assess the impact of utilising novel User Interface (UI) design paradigms. Current UIs facilitate interaction between skilled operators and advanced modern combat systems, ensuring that the three primary tenets of submarine operation are maintained: remain safe, remain undetected, and complete the mission [7-9]. However, aspects of contemporary UIs are a product of evolution over several decades and may not be optimal for modern command team requirements [10]. The original designs were influenced by constraints such as computer processing power, legacy ways of working, and distributed system architectures. Over time, these constraints have been removed, or largely addressed. Despite this, legacy design decisions continue to shape modern systems. Currently operational submarines are highly capable, however, continued adherence to historic design principles may reduce maximal utilisation of technological advancements. In turn, this could mean that there is capacity for optimisation of control room operation; a less than optimal sociotechnical subsystem could reduce holistic control room effectiveness [11], and UIs are no exception. This potential is not just theoretical, incidents have occurred where a UI was deemed to be a significant contributory factor [12, 13].

This paper will present the creation of a proof-of-concept UI named Graphically Integrated Sonar and Target Motion Analysis (TMA) (GIST). This was developed using the Ecological Interface Design (EID) paradigm, which aims to explore if improvements can be made to submarine control room UIs. Sonar and TMA were chosen due to their prevalence in tactical picture generation [10] and the relatedness of their functionality when generating a tactical picture.

2 Ecological Interface Design (EID)

EID is a theoretical framework for designing complex Human-Machine Interfaces (HMIs) [14]. It proposes to make the affordances and constraints of an operational environment apparent to operators [15]. The paradigm is synergistic with a submarine control room's (system) aim of constructing, understanding (affordances and constraints) and acting upon the current tactical picture (environment). This motivated the selection of EID as the optimal design paradigm for UI development in the current context. EID is based on the Abstraction Hierarchy [16, 17] and Rasmussen's' Skills Rules Knowledge (SRK) Taxonomy [18], which are utilised to inform the design.

The SRK Taxonomy describes behaviour and skill levels in response to fundamentally different representations of environmental constraints [16, 18, 19]. Skill-Based Behaviour (SBB; expert) is autonomous responses to the environment; Rule-Based Behaviour (RBB; intermediate) is the application of responses to familiar triggers, and Knowledge-Based Behaviour (KBB; novice) requires full conscious attention to address challenging or unknown situations. Workers Competency Analysis (WCA) is a subsection of the Cognitive Work Analysis (CWA) process. It facilitates representation of the cognitive requirements in a work domain as a matrix of tasks and the SRK taxa. For each task, behaviours that could apply are populated within each taxon.

Abstraction Hierarchies (AHs) are the output of Work Domain Analysis (WDA) in CWA. They model a domain using five abstraction levels to reveal its constraints, facilitating an understanding of its operation and reasons for existing [14, 16, 20]. Each level is connected via means-end links, representing a how-what-why triad. Any given node is the 'what'. Following connections up the Abstraction Hierarchy reveals 'why' it exists and following connections down the Abstraction Hierarchy reveals 'how' it is achieved.

EID has two main objectives: not requiring cognitive processing above that required for a task and supporting all levels of control described by the SRK Taxonomy [21]. To support this EID interfaces should adhere to the following:

- SBB – Direct manipulation should be possible in the display and skeuomorphism should be employed;
- RBB – Consistent one-to-one mappings of cues or signs in the interface
- KBB – Represent the work domain as an AH to serve as an externalised model to support knowledge-based reasoning

Adherence is achieved by displaying both Physical and Functional information on a user interface, with the intent of capitalising on innate perception and psychomotor capabilities [22, 23]. Physical information represents system components and Functional information represents system structure and constraints [24]. Displaying both can lead to better performance than traditional interfaces, which typically display only Functional information [19, 25].

3 Approach

Two CWAs were conducted, one for Sonar and TMA, each consisting of a WDA and WCA. Both provide a detailed representation of each workstation's functionality and operation The analyses were completed using submarine and Human Factors Subject Matter Experts (SMEs) as part of the ComTET project [26].

There is no prescribed translation process from CWA to EID, and there is a dearth of literature describing how it is best achieved. Thus, a process was proposed to elicit initial design directions for the interfaces [8]. This process aimed to ensure that all design objectives of EID were met, by systematically enumerating all objects that would be represented, affordances they provided, and any constraints that they had. In doing so, each design requirement stemming from the SRK Taxonomy was addressed. These design directions allowed the creation of novel interface designs for the Sonar (Fig. 1) and TMA (Fig. 2) workstations. Additionally, it was observed that both stations were closely aligned in terms of the information they required and how contacts were processed for tactical picture creation; thus, it was decided to create a shared common design for both that would facilitate this alignment. This would allow both tasks to be performed using one interface and facilitate the potential for unified operation of roles. This would facilitate operators managing a contact throughout its entire lifecycle (e.g. detection to designation to solution generation).

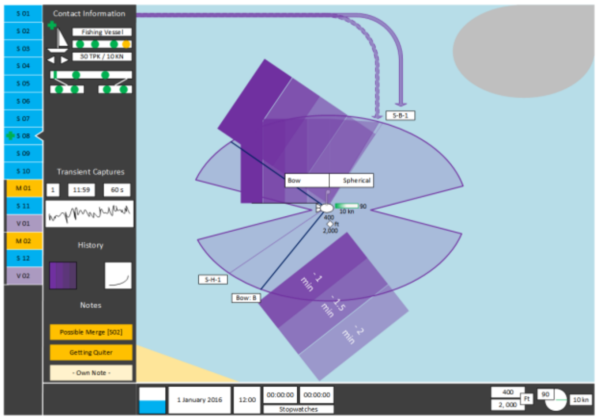

Fig. 1 - Initial design for the sonar component of GIST

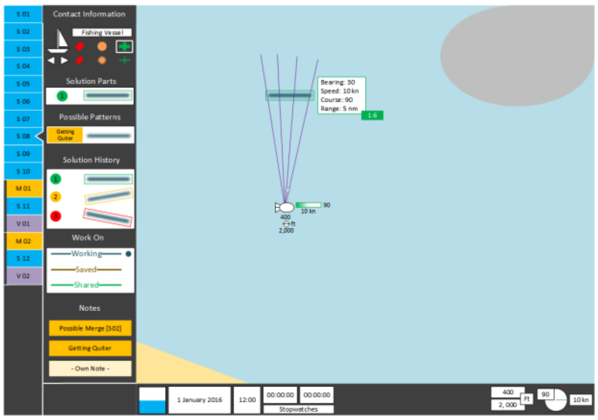

Fig. 2 - Initial design for the TMA component of GIST

Initial development of the designs was completed during a three-month visit to a leading naval simulation company. During this period, the company provided support on using their latest simulation engine and the associated Software Development Kit (SDK). The SDK provided the capability to create custom plugins, such as interfaces. An agile approach was used, with the software company providing daily development support and making changes as required to ensure the simulation engine provided all required functionality. After the three-month development period, most initial aspects of the interfaces were close to completion and the developer was sufficiently trained with the simulation engine to continue development efforts. Using this training, GIST was progressed to a proof-of-concept with support from the software provider, who provided additional builds of the simulation engine to enhance functionality where required.

Due to the size and complexity of GIST, this lasted significantly longer than the first stage. However, this ensured that GIST was feature complete, robust, and ready for further development, or evaluation in ComTET.

4 Proof-of-Concept Design

The GIST proof-of-concept design with the Sonar information panel open is presented in Fig. 3. Ownship information is displayed at the bottom of the interface, along with a messaging system that allows operators to see text-based information from other operators or the system. Detections and contacts are displayed in the left-hand pane. Once a detection has been assigned a tracker, the information panel can be opened for the contact. Both Sonar and TMA operators perform job-specific roles by opening the relevant information panel tab for each contact. To achieve this, relevant contact parameter and ecological information is displayed on the map to assist operators with understanding their environment and tactical picture, including: ownship movement, sonar sensor coverage, current sonar detections, tracker cuts, and speedstrips.

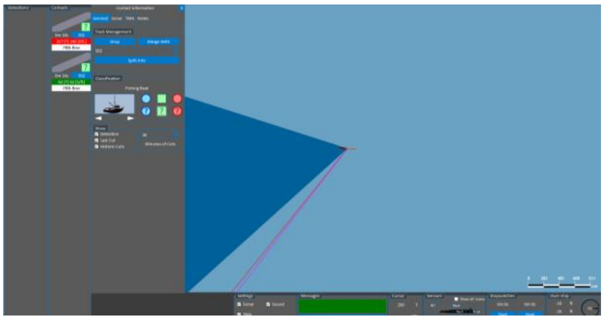

Fig. 3 - GIST as a proof-of-design interface

Whilst the roles of Sonar and TMA can still be carried out separately using GIST, it is also possible for operators to utilise functionality from both interfaces as required. This provides operators with the functionality and flexibility to manage a contact throughout its lifecycle, one of the core driving features of GIST identified during analysis. For example, consider the scenario of a TMA operator requiring Sonar information on an established contact as it has deviated from the shared solution, but all Sonar operators are processing new contacts during a Return to Periscope Depth (RTPD) operation. Whilst the TMA operator could request information from the Sonar operators, this may be subject to a temporal delay [27] due to communication bottlenecks present in the submarine control room identified by the ComTET project [28]. The issue with this is two-fold, delayed information for the TMA operator, and the Sonar operator shifting their focus from not yet established contacts. Both could potentially affect ownship safety. However, GIST would permit the TMA operator to access Sonar functionality and information that they need to maintain the tactical picture effectively. This shared access to functionality could potentially also allow both Sonar and TMA to be completed by a single operator, contingent on rigorous and robust studies to determine the effectiveness of merging these roles. In doing so, it is hypothesised that the synergies elicited using the CWA could be fully exploited to ensure an optimal working environment for all operators.

It should be noted that the current work does not suggest command team ineffectiveness. Rather that benefits may be gained from the combat system facilitating operator workflows, instead of constraining and shaping them, especially from legacy ways of working and capability. It is this shift in ways of working that makes GIST highly novel and potentially effective at maximising the capacity of submarine command teams. The interface not only seeks to move to an evidence-based design paradigm, but also to facilitate command teams in achieving their goals by supporting how they actually work.

5 Future Work

Future work will continue development of the proof-of-concept design, based on SME feedback. The finished UI will be deployed to the ComTET laboratory and used to test the impact of utilising EID as a design paradigm on broader submarine command team performance. It is hypothesised that synergy between the goals of EID and the submarine command team's aims will provide a platform to effectively meet challenges faced by future submarine control rooms.

6 Conclusions

A departure from contemporary control room UIs may be required to help meet challenges faced by submarines in future maritime environments. A proof-of-concept UI has been developed using the EID paradigm, which will be used to assess whether differing designs offer benefits. If benefits are found to exist, exploiting the EID paradigm to meet future submarine control room challenges could prove a worthwhile endeavour.

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