Designing Future Submarine Control Room HMIs

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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 and maintain safety. Human-Machine Interfaces on board submarines are fundamental to facilitating the completion of command team objectives and so understanding how to optimise their design is critical. Contemporary interfaces have continuously evolved to match contemporary 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 effective performance. A potential design methodology to address this is Ecological Interface Design, as it aims to make environmental constraints apparent and reduce operator workload. This is synergistic with the goals of submarine control rooms. 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.

KEYWORDS

Submarine Control Room, Ecological Interface Design, Cognitive Work Analysis

Introduction

Submarine control rooms are vastly capable, having evolved across a century of operations, but this does not preclude improvements to design. Changes may be necessitated to meet future requirements, which include enhanced sensor capabilities, new sensor types, a requirement to process larger volumes of data, and a drive to reduce, or at least maintain crew sizes (Fay, Roberts, & Stanton, 2019).

One area of investigation is to assess the impact of utilising novel Human-Machine Interface (HMI) design paradigms. Products of evolution over several decades, HMIs may no longer be optimal for modern requirements (Fay et al., 2019). Original designs were influenced by constraints such as computer processing power and legacy ways of working. Over time, these constraints were removed, or largely addressed, helped by the introduction of modern combat systems and technological advances. Despite this, legacy design decisions continue to shape modern systems. Continued adherence to historic design principles may reduce maximal utilisation of technological advancements and compromise safety; a less than optimal sociotechnical subsystem could reduce holistic control room effectiveness. This potential is not just theoretical, incidents have occurred where HMIs were deemed to be a significant contributory factor (Fay et al., 2019).

This paper will present the creation of a proof-of-concept HMI 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 HMIs, concentrating on identified issues, to meet future challenges and always ensure ownship safety. Sonar and TMA were chosen due to their prevalence in tactical picture generation (Stanton & Roberts, 2018) and the relatedness of their functionality when generating a tactical picture. Sonar detects, classifies, localises, and tracks other contacts (such as boats). TMA collates information from other stations, such as Sonar, to create a tactical picture of ownship's environment. This enables decisions to be made by command and to keep the submarine safe. As sonar is often the most used sensor on a submarine, Sonar and TMA operators must work closely together to ensure information exchanged is valid and reliable.

It should be noted that the current work does not suggest command team ineffectiveness. Rather, 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; GIST seeks to facilitate command teams in achieving their goals by supporting how they actually work.

Ecological Interface Design

EID is a theoretical framework for designing complex HMIs (Vicente & Rasmussen, 1992), making the affordances (possible actions) and constraints of an operational environment apparent to operators. It is based on two stages of Cognitive Work Analysis (CWA). The first, Work Domain Analysis (WDA), is represented by an Abstraction Hierarchy. The second is Workers Competency Analysis (WCA), based on Rasmussen's (1983) Skills Rules Knowledge (SRK) Taxonomy. 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 (McIlroy & Stanton, 2014). 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 (Dinadis & Vicente, 1996). Physical information represents system components and Functional information represents system structure and constraints. Displaying both can lead to better performance than traditional interfaces, which typically display only Physical information (Vicente, 2002). The paradigm was chosen, as it is synergistic with a submarine control room's (system) aim of constructing, understanding (affordances and constraints) and acting upon the current tactical picture (environment).

Approach

Two CWAs were conducted, one each for Sonar and TMA, with extensive input from submarine and Human Factors subject matter experts (SMEs). The analyses revealed changes that could be exploited in both Sonar and TMA to meet future challenges and ensure ownship safety. For Sonar, these changes largely pertained to the waterfall, which represents 360° data in rectangle with bearings displayed across the top. The incongruence between the 360° aural data and its flat waterfall representation may increase operator workload, which in turn could reduce their performance. As sonar is the primary sensor used to maintain safety underwater, it is vital that operator performance is suitably maintained to avoid incidents. For TMA, changes largely pertained to automation offered by the command system; certain tasks are still manually completed by the operator, despite computational advances providing the capability to assist operators or automate tasks entirely. This could improve the timely completion of the tactical picture and its accuracy, maintaining ownship safety.

There is no concrete prescribed translation process from CWA to EID. Thus, a process was proposed to elicit initial design directions for the interfaces (Fay, Stanton, & Roberts, 2017). Existing literature was adhered to for design principles, with the process ensuring that all interface aspects were considered. The process iterated interface components from the WDA to generate new forms that were suitable for inclusion in an EID interface. For example, as per EID, skeuomorphism was encouraged, with affordances and limits designed to be readily perceptible. It was observed that both Sonar and TMA workstations were closely aligned in terms of the information they required and how contacts were processed for tactical picture creation; thus, a shared common design was created for both that would facilitate this alignment. This would also allow operators to manage a contact throughout its entire lifecycle (e.g. detection to designation to solution generation), potentially improving Situation Awareness. For example, Sonar operators determine the speed of contacts, which they verbally pass to TMA operators to create solutions, representations of a contact's location and velocity, which form the tactical picture. A combined interface would allow this information to be passed automatically thereby reducing communication errors.

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 for using its latest simulation engine and the associated Software Development Kit (SDK). The SDK provided the capability to create custom plugins, such as interfaces. After the three month development period, most initial aspects of the interfaces were close to completion and sufficient training had been received to enable continuing 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.

Proof-of-Concept Design

A screenshot of the GIST proof-of-concept design with the Sonar information panel open is presented in **Error! Reference source not found.**. Detections and contacts are displayed in the left-hand pane. Both Sonar and TMA operators perform job-specific tasks by opening the relevant information panel tab for each contact. Contact parameters (bearing, speed, course, and range) and ecological information (ownship movement, sonar sensor coverage, current sonar detections, tracker cuts, and speedstrips) are also displayed on a map view to assist operators with understanding their environment and the tactical picture. This allows Sonar operators to perceive aural data directly, without having to interpret waterfalls. Improvements were also made to the TMA process, allowing operators to enter contact solution information with minimal interaction; solution parameters are automatically calculated, and operators can adjust as desired. This assistance should reduce the workload associated with manual calculations and interactions. By reducing workload for each contact, operators could manage more contacts, enabling future requirements to be met effectively and ownship safety to be maintained. Furthermore, should workload be reduced enough, it could be possible for fewer operators to manage the number of contacts necessitated by future requirements.

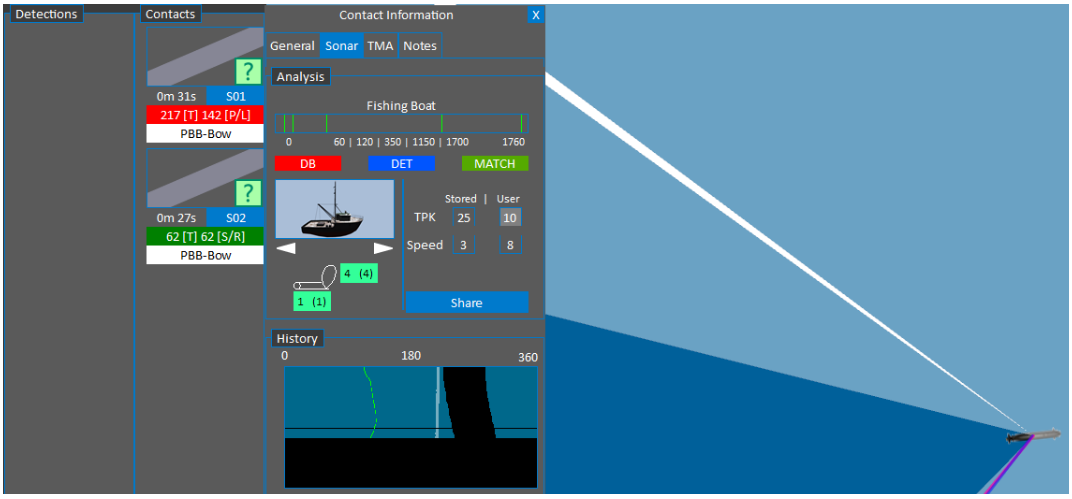

Figure 1: GIST as a proof-of-design interface

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. 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.

Conclusions and Future Work

HMI design changes may be required to help meet challenges faced by submarines in future maritime environments in order to maintain safety. A proof-of-concept HMI was developed using EID to determine its suitability as a design paradigm to address these challenges. Future work will continue developing the design based on feedback from submarine control room SMEs. The finished HMI will be tested to ascertain the effect, if any, it has on operator performance and the submarine control room.

Operators would retain their role in initial testing to determine the effects of GIST. Should performance improvements be evident further testing would determine the feasibility of crew reduction. Recommendations will be reported to stakeholders, allowing for consideration of implementation, such as secondary role (e.g. firefighting or medical) implications, branch structures, and other system effects. Information and processing synergies between both roles could be fully exploited to ensure an optimal working environment for all operators, facilitating accurate tactical picture maintenance. 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, maintaining effectiveness in an ever-changing global maritime environment.

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