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Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context

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ABSTRACT

In recent years there has been increasing research and commercial activities regarding the development of remotely monitored and controlled unmanned ships. Much of this focus is related to the intended migration of operators from ship to shore and the integration of a decision support system to maintain safety of navigation. For this reason, the centralized context onboard could shift to a distributed context characterized as a ¨ship-shore system¨. Although there is substantial research on situation awareness (SA), most tend to view operators as both physically and cognitively situated in the field in a centralized system. Few are paying attention to how SA might be influenced in distributed working domains and their implications on interface design, particularly possible adaptation of those technologies used in a centralized system. In this paper, we developed a remote supervisory control prototype on top of a fully-fledged ship bridge system to support monitoring and controlling of remote simulated unmanned cargo vessels. Six participants were invited to conduct scenario-based simulation trials as proposed shore based operators. Their objective performance and subjective SA assessment was collected and analyzed. The results suggest human factor issues could remain in systems assembled by assumed reliable technological components. Prominent challenges include psychophysical and perceptual limitation for the operators, decision making latencies and automation bias which is applicable to usability issues of interfaces, deprivation of ship sense and lack of current regulatory oversight. The results have important relevance to socio-technical system and interface design that the design also needs to take the context and work domain constraints into account via an ecological approach. As socio-technical systems become less centralized and more globalized, our study suggest the necessity to incorporate the ecological concerns in design to shape the technological artefacts in a way that can truly support the operators to deal with complexity in the field.

1. Introduction

The increasing concerns for safety, efficiency and environmental sustainability creates demands on the development of future maritime transportation strategies, an industry that is already associated with high work pressure and fatigue (Hetherington et al., 2006). One way to address many of these demands is the concept of unmanned vessels. The prevalence of fully- or semi-autonomously controlled systems in other transportation industries, such as unmanned underwater vehicles (Ho et al., 2011) and military-oriented unmanned surface vessels (Osga et al., 2013; Osga and McWilliams, 2015) has prompted the shipping industry to explore similar applications. Research and development into unmanned surface vessels for military applications has been on-going for years, yet the conceptual applications for merchant deep-sea shipping and its implications for human factor issues onshore remain relatively unexplored. These issues supported the award of a three year European Union 7th Framework Project called MUNIN (Maritime Unmanned Ship through Intelligence in Networks) in 2012 to examine the feasibility of autonomous unmanned cargo vessels and their human centered automation governance from a Shore-based Control Center (SCC).

In MUNIN, a simulated 200 m long dry bulk carrier is mostly autonomously controlled with elaborately designed artificial intelligent controller while monitored by a SCC operator. Thus, most supervisory monitoring and controlling operations are allocated to the shore side. While the main hypothesis of the MUNIN project was "unmanned ship systems can autonomously sail on an intercontinental voyage at least as safely and efficiently as manned ships", the self-navigation technology readiness level was proven to be merely above 3 under a controlled lab environment (MUNIN, 2015) and the problem of inadequate

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observability and understandability due to various factors including technical glitches in the software was observed (MacKinnon et al., 2015; Man et al., 2014; Man et al., 2015). Navigation is a safety-sensitive activity (Grech, 2008). When self-sufficiency of the machine capabilities is inadequate to deal with certain safety-sensitive situations, then autonomous systems should be over-ridden through manual control (Bradshaw et al., 2013). van der Kleij et al. (2018) argued that it is better to frame the systems as "semi-autonomous" to reflect the active involvement of a human operator as a "backup", although the "backup" role do not really suit the human operators in human-automation interactions (Hancock et al., 2013).

In a ship-shore system, regardless of the maturity of the automation, there are still people involved, but within a system organized in a distributed manner instead of centralized monitoring typical of a conventional ship's operations. There are many well-known human performance problems related to remote supervisory control (Sheridan, 1992, 2002; Sheridan and Parasuraman, 2005), such as out-of-the-loop syndrome that describes the inability of the human operators to take over the control when automation fails (Endsley, 2016b; Metzger and Parasuraman, 2005). The key question concerning the human performance has never deviated from how to increase the observability, understandability and transparency in the feedback (Bradshaw et al., 2013; Liu et al., 2016; Norman, 1990; Wu et al., 2016) and how to increase human-system integration (Endsley, 2016a; Hobbs, Adelstein, O'Hara and Null, 2008; Orellana and Madni, 2014; Wu, 2018). In terms of understandability, one of the widely mentioned theoretical concepts is situation awareness (SA) (Endsley, 2015b) – "being aware of what is happening around you and understanding what that information means to you now and in the future" (Endsley, 2011). Operators need to quickly recover their SA when automation fails and the design should support them to detect changes in the key information for improved observability and understandability (van der Kleij et al., 2018; X. Wu et al., 2016).

The process of alarming the operator and providing relevant resources for decision support is one key aspect of automation (Bradshaw et al., 2013; Endsley, 2011; Feigh and Pritchett, 2006; Sturm, 2016). Nevertheless, there has been little research reported on SA and decision making support interface design for the applications of autonomous unmanned ships and its SCC. While the traditional shipping is standing on the edge of transferring the ship-based monitoring and navigation activities into such a newly emerged ship-shore system, it is vital to understand how operators obtain and maintain SA under such a socio-technical system, and more importantly how the interfaces could impact their subsequent decision-making. Such understanding is essential for interface design for the emerging ship-shore system in the future.

In this study, the monitored unmanned ships were assumed to be semi-autonomous simulated ships: they were not programmed with the capabilities to avoid collisions but they were featured with advanced autopilot functionality to enable autonomous sailing from A to B. Plus, "intelligent" HMIs were developed to presumably "automatically" detect remote problems on or near the ship, "informatively" alarm the operator so that the operator could supposedly efficiently and safely monitor and control the unmanned vessels in a SCC-like environment. Six participants, with seafaring experience, were invited to conduct scenario-based simulation trials as SCC operators. The key research foci in this study were not limited to addressing prominent human factors issues associated with SA during remote monitoring and controlling tasks in a ship-shore system, but also to get a deeper understanding of the shore-based Human Machine Interfaces (HMIs) in the ship-shore system and their relation to the distributed properties of the system. The HMIs were designed and configured in a way that there were no technical glitches (software bugs that can influence the human performances), but there would be deliberate "automation failures" or "malfunctions". The observations on human performance and their subjective evaluations about SA would not only contribute to the interface design of future SCCs and ship/cargo safety, but also contribute to our understanding of this emerging technologically complex work domains. Our purpose is two-fold: Firstly it aims to gain a deeper understanding of how the human element would be affected in such a distributed socio-technical system for remote autonomous ship monitoring and controlling. Secondly it aims to generate insights and knowledge about the remote control tasks for autonomous unmanned ships and how future HMI design should be accommodated to the emerging new field of remote supervisory monitoring and control in shipping.

2. Related work

SA is typically defined as an operator's dynamic understanding of "what is going on" in Endsley's widely recognized SA-decision making model (Endsley, 1995b). This model consists of three levels: perception of the elements, comprehension of situation, and projection of future states. A mental model was considered as one of the most important cognitive underpinnings to direct an individual's attention to the pertinent elements in the environment, to assist in making sense of the circumstances and to foresee the evolving situation in a non-linear process (Endsley, 2015a, 2015b). Based on its concept, many freeze probe techniques were developed to evaluate an operator's situation awareness, such as SAGAT (Endsley, 1995a; Motz et al., 2009; Wei et al., 2013), SALSA (Hauss and Eyferth, 2003; Hauss et al., 2001) and SACRI (Hogg et al., 1995). Besides Endsley's interpretation of SA, there are other models which also received wide attention regarding the constructs and evaluation of situation awareness. Bedny and Meister (1999) proposed an interactive sub-systems approach to describe the development of SA as a goal-directed activities in the lens of activity theory. Smith and Hancock (1995) chose to take an ecological approach to reveal the perceptual cyclic characteristics of development of situation awareness, which is "adaptive, externally-directed consciousness". Taylor (1990) outlined a post-trial less-intrusive Situation Awareness Rating Technique (SART) to assess a pilot's situation awareness by self-rating the ten dimensions of performance: familiarity, focus, information quantity, instability, concentration, complexity, variability, arousal, information quality and spare capacity and became a quite popular subjective measurement technique due to its simplicity and convenience to administer the evaluation (Salmon et al., 2008) and was found that it could contribute sensitivity and diagnosticity regarding the effects of the display concept, the same as the freezing probe technique SAGAT (Endsley et al., 1998). Nevertheless SART was criticized for its validity to indicate an operator's actual SA as a cognitive construct in information processing, since the subject's confidence level could highly influence the measurement meanwhile without knowing what he/she didn't know and what erroneous mental model was possessed (Salmon et al., 2009). However Endsley argued that subjective techniques could "provide a critical link between SA and performance" as "a person's perceived quality of SA may be important in determining how a person will choose to act on that SA" (Endsley et al., 1998).

Among all the individual SA measurement theories, the application domain is basically for aviation (e.g. air traffic control), nuclear power plant and military sectors (Salmon et al., 2008). The reason is probably that remote monitoring and controlling in the control room have been more practiced in the aviation industry and nuclear power plant, compared to the maritime domain where SA measurement is primarily for the onboard bridge operations onboard ships (Sandhåland, Oltedal and Eid, 2015a; Sandhåland, Oltedal, Hystad and Eid, 2015b). There were a few studies regarding SA or the traffic management in the sector of Vessel Traffic Service (Praetorius et al., 2015; van Westrenen and Praetorius, 2014a, 2014b; Wiersma and Mastenbroek, 1998). Although VTS centers do share similarities with the MUNIN projects' SCCs in terms of monitoring vessels and the goal of ensuring safety at sea, their functionality is very different: VTS centers aim to provide information services to the manned ships for onboard navigational decision making (IMO, 1997). They do neither control ships directly nor see each