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ICMASS 2018

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PREFACE

These proceedings contain selected papers from the first International Conference on Maritime Autonomous Surface Ships (ICMASS), held in Busan, Republic of Korea, on November 8th and 9th, 2018. The first day of the conference had ten invited presentations from the international autonomous ship community, while the second day contained parallel sessions on industrial and academic topics respectively. A total of 20 industrial and 16 academic presentations were given. From the presentations, six full manuscripts are presented in these proceedings after peer review by two Korean and Norwegian experts.

ICMASS is an initiative from the International Network for Autonomous Ships (INAS, see http://www.autonomous-ship.org/index.html), an informal coalition of organizations and persons interested in autonomous ship technology. In 2018 it was organized by KAUS – Korea Autonomous Unmanned Ship Forum. The plan is to make this a yearly event in different places around the world. In 2019 it will take place in Trondheim, arranged by SINTEF Ocean AS and NTNU in cooperation with the Norwegian Forum for Autonomous Ships (NFAS).

The organizing committee would like to thank everyone who has helped with review of manuscripts, all those who helped to promote the conference and all authors who have submitted and presented their contributions.

Kwangil Lee & Ørnulf Jan Rødseth

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HUMAN FACTORS ISSUES IN MARITIME AUTONOMOUS SURFACE SHIP SYSTEMS DEVELOPMENT

Hannu Karvonen[1*], **Jussi Martio**[1]
[1] VTT Technical Research Centre of Finland Ltd, Espoo, Finland

* Corresponding author e-mail: hannu.karvonen@vtt.fi

Abstract

The human side of highly automated maritime systems can often be neglected in their development. Paradoxically, history and scientific studies have shown that with highly automated systems, there is still a crucial need for humans to monitor the automated operations. Humans also need to intervene to and control the automated operations particularly in exceptional situations and maintenance operations. Therefore, especially human factors engineering is in a key role when developing maritime autonomous surface ship (MASS) systems. This paper discusses some of the related issues, like automation awareness, cognitive workload, trust in automation and technology acceptance that should be considered in detail when developing MASS solutions. A case study is presented on the development of a ship-handling simulator with an autonomous ship collision avoidance system and it is discussed how to apply the simulator to human factors-oriented studies of MASS systems design and evaluation. The design implications for MASS development on a more general level are also presented. By taking the human aspects of MASS systems as a central focus point in the development, it is possible to create safe and successful maritime innovations for the future.

Keywords: *Human factors, Maritime autonomous surface ships, Collision avoidance, Systems development*

1. Introduction

In developing autonomous maritime systems, the technical efficiency, liability issues, and the reduced operational costs have drawn much of the attention. Consequently, the human elements of the operations seem often to be forgotten from the development. The reason for this phenomenon may be, for example, that with autonomous systems it can be thought that humans are no longer needed and their role in the final environment does not need much consideration.

Quite paradoxically, many previous human factors studies (e.g., [1-3]) have shown that typically with highly automated systems, there is still a crucial need for humans to monitor the automated operations. Therefore, system autonomy does not directly mean completely unmonitored operations. Hence, if the human's role in the development of autonomous systems is not considered on a sufficient level, shortcomings related to both safety and human well-being may arise.

Typically, humans still need to supervise and analyze the operations done by the autonomous systems. Humans also have to intervene and control the systems particularly in exception situations either on the spot or remotely. For example, humans are needed in conducting maintenance operations on-site if some mechanical or hardware fault happens with the used technology.

In this paper, we wish to address some of the relevant human factors issues in the development of maritime autonomous surface ship (MASS) systems. We also present a case study about the development of an autonomous ship collision avoidance system, discuss how to apply it to human factors-oriented research studies, and draw implications for the design of successful autonomous maritime solutions.

2. Background

To account for the human side of (semi-)autonomous systems already several approaches, methods, topics and fields of science exist that may be considered in systems development. First of all, the human factors and human-computer interaction (HCI) with these systems should to be taken into account in their design.

Second, considering the human aspects in the development of autonomous systems can include the study of ethical or moral issues of a certain automation system that brings about changes to work tasks and ***also*** possible reductions in workforce. Third, topics such as how to make autonomous systems more acceptable in the eyes of the users or the wider public are relevant.

Fourth, it is essential to assess what are the organizational, cultural, political and societal impacts of higher degrees of automation, and how to support the changes brought by the systems. Fifth, the utilization of different user-centered design approaches in the systems development is crucial in increasing the probability of success of the systems. Finally, possible privacy and security-related problems for humans may need addressing.

Out of these different human aspects of automated systems, the focus of this paper shall mostly be on the general-level human factors issues of remotely operated and highly automated maritime systems.

3. Some Relevant Human Factors Issues and Approaches in MASS Development

In this section, we first discuss some of the relevant human factors issues and challenges of autonomous systems in general. Second, we go through some analysis and design-oriented human-machine interaction approaches that can answer to these issues and challenges.

3.1 Human Factors Issues and Challenges

Some relevant human factors challenges of remotely operated and automated systems include issues like 1) situation and automation awareness, 2) division of tasks between the human and the automation, 3) level of user experience (UX) and usability of the solutions, 4) appropriate trust in automation, and 5) the provided user interfaces and data visualization techniques. Each of these will be discussed shortly next in more detail, one topic per paragraph.

With MASS, it is essential to think that how the remote human operators monitoring the autonomous systems can achieve and maintain an adequate situation and automation awareness. Situation awareness refers to "the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status" [4]. Additionally, in highly automated environments, also automation awareness becomes relevant. Automation awareness has been defined as "a continuous process that comprises of perceiving the status of the automation, comprehending this status and its meaning to the system behavior, as well as projecting its future status and meaning" [5]. In highly automated remote-operation settings with complex situations, the development and maintenance of both situation and automation awareness becomes often very challenging task.

It is also important to consider the division of the tasks between humans and the automation in order for the humans to not have too much cognitive workload or, on the other hand, too boring tasks in MASS operations. Here, for example, psychological knowledge about the limitations of human cognition and activity is needed. Optimal division of tasks guarantees not only safe operations, but also the well-being of the human operators working with the automated system for long periods.

In addition, the level of user experience [6] and usability of the automated solutions that humans are interacting with is crucial. If the systems are hard to understand and use, the users cannot comprehend what is the current situation and act accordingly. This can result in human out-of-the-loop performance problems (e.g., [7]), which can be detrimental in safety-critical operations.

Likewise, the building of appropriate human operator trust in automation, for example, by means of design is important. Here, trust can be defined as "the attitude that an agent will help to achieve an individual's goals in a situation characterized by uncertainty and vulnerability" [8]. The agent in this context is the (semi-)autonomous system that is working with the human to achieve the task objectives. Appropriate trust, on the other hand, is well-calibrated trust in automation that matches the capabilities of the automation (see Fig. 1). In contrast to appropriate trust, overtrust or distrust in the system may occur, which can result in safety- or performance-related problems.

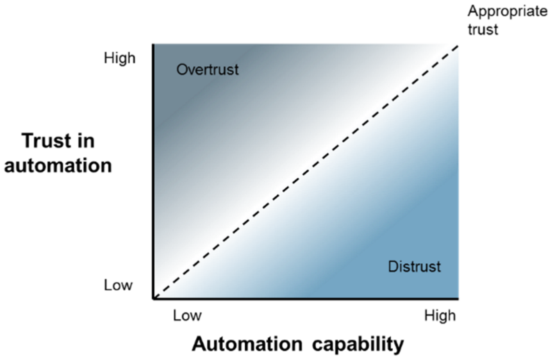

Figure 1. A simplified model of appropriate trust in automation. Figure adapted from and modified based on [8].

Finally, the human-machine or user interfaces, including their data visualizations and interaction techniques, need to be designed and utilized from the users' perspective. Specifically, the data visualizations in the user interfaces used to monitor the autonomous systems need to be simple and understandable for the users. In addition, modern user interface output techniques, like virtual and augmented reality, may be utilized in operations, for example, to highlight or visualize relevant issues from the object environment. In the input interface techniques side, for instance, novel speech and touch control approaches are becoming popular in many environments. However, from the human factors point of view, it should not be forgotten that it can often be much easier and more reliable to conduct routine tasks with a normal keyboard and a mouse compared to some flamboyant new interaction technique that becomes cumbersome in the long run.

Some of the above-mentioned and also some other MASS-related human factors challenges have already been discussed in the previous literature, for example, in [9]. For the purposes of this paper, we do not go into details of many of the other relevant issues and challenges here.

3.2 Human Factors Approaches

To consider more specifically the human factors and HCI issues in systems development, many human-machine interaction analysis and design approaches have been developed. In the analysis side, typically used data gathering methods include user interviews, questionnaires, and observations. The data gained with these methods can be analyzed later on from voice and video recordings, screen tracking videos and system usage logs. In the analysis phase, this data can be used, for example, to conduct task analyses, assess the user experience/usability of the used tools, or in evaluating the level of users' situation awareness and mental workload in different situations.

In addition, based on the analyzed data and gained results, it is often possible to give design recommendations and suggest concept design solutions. To further facilitate the concept design phase, there are several approaches, like focus groups, scenario stories, storyboards, and lo-fi sketches/prototypes that can help the users to understand what the designers have planned, give design feedback, and even possibly ideate new solutions. In an iterative manner, a Concept of Operations (ConOps, [10]) for the final system can ultimately be developed in the early phases of design.

When the final concept is chosen and the actual system development work starts on a more full scale, human factors engineering (HFE, [11]) approach should be systematically and holistically utilized. This can also include elements from conducting core-task design [12] and setting UX goals [13,14]. In addition, for the design of user interfaces in more detail, there are several approaches, like Ecological Interface Design (EID, [15]) or Information Rich display Design (IRD, [16]), to help the human-machine interface designs to be more intuitive from the users' perspective.

Shortly put, there are a lot of different methods and approaches available, but behind these various labels, there are a lot of similar aims and thinking. Typically, the basic idea in them is to put the human or user into the center of the design and evaluation work in order to produce systems that are successful and accepted by the stakeholders.

Next, we present a reference case study where we have utilized some of these approaches and methods mentioned above and elaborate on how they could be used in further studies.

4. Case Study: Autonomous Ship Collision Avoidance System Development

VTT's background in previous human factors-oriented studies has allowed the development of a ship-handling simulator system (see Fig. 2) based on the user needs, work demands and also the environmental constraints of different vessels. In addition to basic interview and observational studies of professional seafarers conducting navigational tasks in the simulator, we have conducted a core-task analysis [17] of the command bridge work done in several different ship types, such as tugs, container ships and platform supply vessels [18, 19]. In addition, the autopilot of the simulator has been programmed to work based on the decisions made by expert seafarers in earlier studies with the simulator. The ConOps of the ship-handling simulator is a result of years of iterative development work. As many parts of the simulator are self-developed by VTT and the whole system is aimed to be a research simulator (in contrast to a training simulator bought directly from a supplier), it is a very flexible tool that allows the modification of its different parts very fast and easily.

Figure 2. VTT's ship-handling simulator.

Recently, at VTT we have been developing a research tool that aims to be flexible enough also for the different needs of the development of MASS systems. This tool is an autonomous ship collision avoidance system that is implemented on our ship-handling simulator. The research objectives that the system allows to be investigated include, but are not limited to, the fulfilment of navigational regulations (e.g., COLREGs, The International Regulations for Preventing Collisions at Sea), simulations of realistic data connectivity errors and delays, functioning of the AI algorithms in different situations, and human factors issues of MASS systems.

Generally, an autonomous ship collision avoidance system includes three subsystems: Situation Awareness (SA), Decision-making and Autopilot systems (see Figure 3). Firstly, the SA system creates an assessment of the current surrounding traffic situation and environmental conditions by using different cameras and sensors, their sensor fusion and analysis algorithms. Secondly, the Decision-making system utilizes the evaluation of the current situation provided by the SA system and makes decisions based on the implemented rules (e.g., COLREGs). Finally, the Decision-making system commands the Autopilot (or a Dynamic Positioning [DP]) system to steer the vessel to the desired location. VTT's Autopilot includes three modes: track, heading and docking mode that are utilized for different navigational purposes. So far, the research and development of VTT's MASS collision avoidance system has been focused especially on the Decision-making and Autopilot modules, but future plans include to extend them to SA system aspects as well.

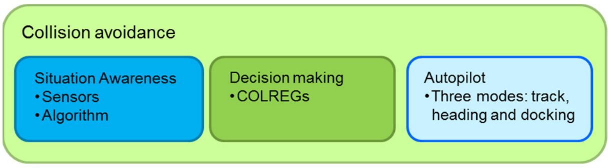

Figure 3. Subsystems of a Collision Avoidance System.

Together with the developed collision avoidance system, VTT's ship handling simulator offers a flexible platform for the verification and validation (V&V) of autonomous navigation systems. An autonomous navigation system can be integrated to the simulator similarly as it would be installed to a real ship. With the simulator, different scenarios can be conducted in specific regions applying the desired environmental conditions easily. As a supervisor of the operations, an experienced seafarer is used. From the human factors perspective, the supervisor can also self-evaluate, for example, the level of her situation and automation awareness during different situations where the autonomous system conducts operations, the appropriateness of her trust in the system, and the experienced workload in supervising the various operations.

Method-wise, VTT has a long history of conducting similar human factors V&V studies in the control room simulators of nuclear power plants [20,21]. In addition, VTT has recently been looking at how to conduct safety qualification related especially to autonomous ships [22,23]. Naturally, conducting studies in simulated environments offers a much more cost-effective and safe way of validating different safety-critical scenarios compared to real-world scenarios. However, the ecological validity of the simulator is crucial. Therefore, we aim to offer as realistic vessel models and operations as possible.

In general, we see that the developed collision avoidance system and the ship-handling simulator can be used for the design and evaluation of autonomous ship systems both in virtual and mixed (virtual and real-world) settings. More specifically, we suggest the following application areas for the system: 1) development of autonomous navigation systems, 2) human factors studies with potential users, 3) verification and validation activities, 4) scenario tests before real implementations on actual autonomous vessels and 5) mixed tests by combining simulation-based and real-world environment testing. Out of these application areas, the last one is particularly novel and innovative approach, to which also human factors studies should be conducted in more detail.

5. Implications for the Design of MASS Systems

Based on our previous contemplations and the presented case simulator environment, in this chapter, we suggest some preliminary implications for the design of MASS systems from the HFE point of view and discuss a few design process implications.

5.1 Human Factors Engineering Implications to be Taken into Account in the Design of MASS

Often, in highly automated environments maintaining operator vigilance may become problematic as the users of autonomous systems do mostly monitoring tasks through their displays. This phenomenon can have a root-cause in the lacking of a proper HFE process and a suboptimal task division between the automation and the human in the system's original development. As a result, the tasks left for the human are monotonous and boring [24,25]. This problem is highlighted by the fact that most of the time in supervisory control work, nothing interesting really happens. However, when something critical happens, it can be very surprising for the operators. In this kind of a situation, the operators should still be ready to act promptly and in a safe manner. The challenge therefore is that how the operators can keep their vigilance level up, notice an exception situation, and act accordingly in a proper manner. To mitigate this challenge, we suggest, for example, meaningful secondary tasks with training-related and technology-supported activities to be provided for the operators during primary tasks' idle time.

In addition, cognitive overload may occur when information about the automated environment is condensed into one place, such as an individual display. This may result in a "keyhole effect" where users focus in on only a small portion of the display space and are unaware of important changes in the object environment's status that are indicated in other parts of the display space where they are not looking [26]. This problem may be exacerbated during alarm situations where the operator can receive a vast amount of information to one's display at once [27].

Both the vigilance and cognitive overload issues contribute to maintaining situation and automation awareness, which were discussed earlier. If these are not taken into account on a sufficient level in the design, it may be very difficult for the operators to stay in the loop of what is happening currently both in the object environment and also with the automation system.

Consequently, the loss of good situation and automation awareness may result in suboptimal level of trust in the system. If the operator does not understand what is going on, it is often too easy for her to trust the automated system too much in situations with which the system has not originally been designed to cope with and therefore where it should not be trusted. Hence, both system design and operator training should aim for appropriate trust instead of maximum trust. If the operator's trust is at an appropriate level, also the operator's decisions and actions from the performance perspective of the joint cognitive system [28] formed by the human and automation are optimal.

5.2 Design Process Implications of MASS from the Human Factors Point of View

Firstly, before starting the design work, there should be human factors-oriented analysis studies of the existing non-automated work setting. In this way, it is possible to understand the users and their work's demands on a deep enough level. Also, benchmarking similar autonomous systems environments may help here. This understanding on the other hand allows the designers to better comprehend how the division of tasks between the human and the automation should be done. This division should take into account that in which tasks the human operator is really needed and which can be automated. Also, the workers' tasks should not be too monotonous or boring so that they can keep their vigilance level up in every situation [29,30].

Secondly, in the co-design phase, relevant stakeholders should participate to the design work through workshops conducted with different co-creation and innovation methods. This allows bringing in not only the voice of the users more clearly to the design phase, but also other relevant groups, such as the system buyers or maintenance personnel perspectives.

Thirdly, to account for good user experience, UX goals [13,14] can be utilized. The UX goals should work like guiding stars throughout the design process to steer the development towards the right direction from the UX perspective [31]. A detailed case study of the utilization of UX goals in a highly automated remote operation setting of container cranes is available in [32-34].

Fourthly, early prototyping should be preferred with different types of visualizations and mock-ups. Prototypes of different maturity levels work well when iteratively evaluating the suggested designs with real users towards the final solution.

Finally, human factors-oriented verification and validation activities form the basis of a safe socio-technical system. The results of these systems engineering activities also provide evidence about the system safety, for example, for authorities regulating the systems. In addition, the operators monitoring and using the systems should be integrated to this process. Without systematic V&V activities, the end-result may cause accidents that ultimately affect the progress of the entire MASS industry.

6. Conclusions

By taking the human aspects of MASS systems as a focus point in the development, it is possible to create safe and successful maritime innovations for the future. In this paper, we have discussed only a fraction of the relevant human factors issues in developing highly automated systems, such as MASS systems. In addition, we have presented a short case study in how human factors has been taken into account in our simulator development.

Theory-wise, future work should focus on identifying more relevant challenges and solutions from the human perspective. We have given some suggestions on these relevant human aspects in this paper.

Further practical work should include different HFE-oriented simulator-based studies. Consequently, we see that a good balance in simulator and real-world-based studies is crucial in the development of safe MASS applications in the future.

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