International Journal of Industrial Ergonomics 66 (2018) 75–84

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Change detection support for supervisory controllers of highly automated systems: Effects on performance, mental workload, and recovery of situation awareness following interruptions

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ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form
24 October 2017
Accepted 12 February 2018

Keywords:
Situation Awareness Recovery (SAR)
Dynamic positioning
Management-by-exception
Out-of-the-loop (OOTL) performance problem
Human-automation collaboration

ABSTRACT

Dynamic Positioning (DP) is a computer-controlled process to automatically keep a floating vessel at a specific position or to follow a pre-defined path (tracking) by using its own propellers and thrusters. The human supervisory controller has no direct need to constantly know what the status is of all parts of the automation and the system it is controlling, because the highly automated DPS is controlling all components itself. Only after a failure arises, the operator needs to take over manual control and take appropriate action(s) to prevent the failure from harming the operation. As the supervisory controller may be out of the loop, swiftly taking over control may be problematic when failures arise. The purpose of the current study was to investigate whether automation of change detection enables human operators with low awareness of the automation and the system it is controlling to quickly recover awareness in emergency take-over situations. A 2 by 2 within subjects experiment was conducted using a DP simulation ($n = 22$). Within-subjects factors were support (Yes, No) and interruption (Yes, No). Results showed that change detection support helps in the process of recovering situation awareness after it has been reduced, due to an interruption of the primary task of overseeing the automation. Interestingly, support was not beneficial to the participants in all conditions. In non-interrupted conditions the support unexpectedly resulted in higher workload, raising questions whether supervisory controllers should be supported continuously or only when it is required. Relevance to industry: The results show that change detection support has potential value in operational maritime environments, especially in situations where the DP operator has low situation awareness. Future research should investigate whether adaptive aiding could alleviate some of the negative effects of non-adaptive operator support in maritime environments.

1. Introduction

Many systems operate autonomously or are envisioned to do so in the near future. Such systems have the capacity to operate independently without human participation in the task execution phase (this does not preclude human involvement during other stages). An autonomous system may function fine for the range of situations it is designed to address. More interesting is what happens in situations that were not foreseen by its makers (cf. Bainbridge, 1983; Woods and Cook, 2006). Boundaries are reached when situations become manifest that the system designers have not anticipated or foreseen. For instance, when a critical system component fails, when critical parameters are exceeded, or an unforeseen incident occurs, an anomaly response is required, usually from a human operator. Hence, autonomous systems need a human operator as backup, in case the automation fails, and the ability is required to improvise and use flexible procedures (cf. Fitts, 1951). It is therefore better not to use the term ‘autonomous’, but to refer to these systems as *semi-autonomous*, reflecting the active involvement of a human operator as backup. Semi-autonomous systems, which can be characterized by varying degrees of autonomous capabilities, will retain the possibility of manual control and may require an engaged human operator to monitor the system and assume control under conditions when the system cannot control

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https://doi.org/10.1016/j.ergon.2018.02.010

itself (Rousseau and Crane, 2016).

A special instance of a semi-autonomous system is a Dynamic Positioning System, or DPS in short. A DPS is a computer-controlled system to automatically keep a floating vessel at a specific position or to follow a pre-defined path (tracking) by using its own propellers and thrusters (Fossen, 1994). Applications include shuttle tanker operations, deep water drilling (e.g., drilling rigs), dredging and rock dumping, pipe laying and pipe trenching operations, cable lay and repair operations, but also military operations (e.g., mine countermeasures). The number of vessels with DPS has increased in the last decade. This is mainly due to increased oil and gas exploration at sea, as well as offshore operations, such as drilling, diving support, wind mill park maintenance, and anchor handling.

There is a long history of literature showing that operators do not function well as backup of automated systems (see, for example, Hancock et al., 2013; Onnasch et al., 2013; Wickens et al., 2015). Often, operators need more time to intervene under automated than under manual control. Operators need to first recover awareness of the state of the automated system before taking back control (see Metzger & Parasuraman, 2005, p. 37). When an operator needs to regain control over a large oil platform after the initiation of a drive-off incident to prevent an imminent collision with another platform, this extra time is often not available. These types of problems related to changes in task demands stemming from automation have been summarized as the *out-of-the-loop* (OOTL) performance problem: the disability of human operators to control an automated system when automation fails or malfunctions (Metzger & Parasuraman, 2005; Moray, 1986; Wickens and Kessel, 1979; Wiener and Curry, 1980).

Overall semi-autonomous system performance is highly dependent on how operator and automation function as a team (cf. Christoffersen and Woods, 2002; De Visser and Parasuraman, 2011). Both components are highly interdependent. Between manual control and full automation, different levels of automation, or collaboration forms, can be distinguished. Well known classifications are made by Sheridan and Verplank (1978) and by Endsley and Kaber (1999), with different variations. A special form of human-automation collaboration are *adaptive systems*. Adaptive systems are systems in which the locus of control between human and automation varies over time (Rouse, 1988; Parasuraman et al., 1996). This implies that the responsibility for a specific subtask moves from the automation to the operator or vice versa. Adaptive automation is a subset of an adaptive system. The preposition ‘adaptive’ implies that the automation takes over tasks from the human operator when the need arises, for instance due to high operator workload (cf. Parasuraman, 2000). *Management by exception*, as noted by Dekker and Woods (1999), is, in a figurative way of speaking, the mirror image of adaptive automation, where instead of the automation, the human supervisor, or exception manager, takes over tasks from the failing automation. This form of supervisory control bears high resemblance to the situation in which the DP operator is monitoring the semi-autonomous system for boundary conditions.

Exception managers often perform different tasks concurrently. Because human attention is limited, attention needs to be shifted between tasks (Squire and Parasuraman, 2010). Shifts in attention may result in fluctuations in awareness of the state of the supervisory control system and the environment (e.g., the weather, ship state). Moreover, it is often difficult for human operators to notice changes to relevant parameters that are under supervision (cf. Simons & Rensink; Simons and Levin, 1997). This implies that the operator may be unaware of an unfolding emergency situation that requires operator involvement. When the need for operator involvement on the supervisory tasks becomes apparent, the operator must reassess the environment and system state to recover situation and system awareness, a process which Gartenberg et al. (2013) have called *Situation Awareness Recovery (SAR)*.

Despite the increasing usage of semi-autonomous systems, little research has addressed the need for better tools to help human supervisors to recover awareness, for instance following interruptions in multitasking or emergency situations. This lack of research is surprising, because incidents may lead to considerable costs, especially in the maritime domain (cf. Payne, 2001). These costs include, but are not limited to, (1) injuries and fatalities, (2) severe equipment damage or destruction, (3) major pollution, and (4) rig downtime with significant loss of revenue and contractual problems. Because the estimated arrival of first-generation fully autonomous DPS is not foreseen in the near future, we thus need to consider how human operators could be aided in their role as backup for handling exceptional situations (cf. Endsley, 2016).

In this paper we address the question how to speed up SAR. We deduced several design principles for support of supervisors of highly automated systems to help them cope with regaining situation and system awareness as quickly as possible in emergency situations. Based on these principles, we then designed an adaptive support concept which we tested in a DP simulation. The remainder of this paper is structured as follows. First, we describe relevant literature to provide a better understanding of what situation awareness recovery is, how it may be distinguished from other forms of interruption management, and how this process may be supported. Next, we detail the support concept and our expectations on how this concept would compensate for the degrading effect of loss of awareness typically associated with the out-of-the-loop performance problem. Then, we outline the present research and present the findings of our studies. We conclude by summarizing the implications of our research.

1.1. *Deciding on how to support Dynamic Positioning operators*

During stationary operations, the main goal of the DP operator is to maintain the platform on a predefined position. During this task the operator is supported by a DPS. A DPS is a highly autonomous system. Based on predefined settings they are able to keep the platform in position. Position sensors like Differential Global Positioning System (DGPS) sensors and gyro sensors give information about the platform's actual position. Wind sensors and information about current give input about the forces that work upon the platform. By using the right thruster power the platform is kept in place. A control system calculates the required power and position of the thrusters.

However, the system is not infallible. Sensors may not work perfectly, and thrusters and power supply can be suboptimal. Because of incorrect position information, or insufficient thrust the system may not be able to maintain position and the platform will drift off. The DP operator must recognise these failures in time and take appropriate actions to prevent position loss and accidents.

As long as the system works properly, DP operators do not have much work to do. However, the operator has to be constantly alert to detect failures on time and take immediate action. During interviews we asked two DP operators with extensive experience on Floating Production Storage and Offloading (FPSO) vessels about the cognitive strategies they use to detect these impending failures. One prominent strategy is monitoring for changes in key information presented through the DP interface. Changes in sensor values may indicate that something is wrong. For example, changes in thruster power values can be a sign that thrusters do not work properly. Changes on the state of the automation and the system it is controlling play an important role in the assessment of possible operational threats, so that the operator can take the right