Reliability Engineering and System Safety 161 (2017) 12–24

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

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

A multi-sensor fusion framework for improving situational awareness in demanding maritime training

Filippo Sanfilippo[a,b,*]

[a] Faculty of Maritime Technology and Operations, Norwegian University of Science and Technology (NTNU) in Aalesund (the former Aalesund University College), Postboks 1517, 6025 Aalesund, Norway
[b] Department of Engineering Cybernetics, NTNU in Trondheim, 7491 Trondheim, Norway

ARTICLE INFO

Keywords:
Maritime operations
Situational awareness
Offshore simulator

ABSTRACT

Real offshore operational scenarios can involve a considerable amount of risk. Sophisticated training programmes involving specially designed simulator environments constitute a promising approach for improving an individual's perception and assessment of dangerous situations in real applications. One of the world's most advanced providers of simulators for such demanding offshore operations is the Offshore Simulator Centre AS (OSC). However, even though the OSC provides powerful simulation tools, techniques for visualising operational procedures that can be used to further improve Situational awareness (SA), are still lacking.

Providing the OSC with an integrated multi-sensor fusion framework is the goal of this work. The proposed framework is designed to improve planning, execution and assessment of demanding maritime operations by adopting newly-designed risk-evaluation tools. Different information from the simulator scene and from the real world can be collected, such as audio, video, bio-metric data from eye-trackers, other sensor data and annotations. This integration is the base for research on novel SA assessment methodologies. This will serve the industry for the purpose of improving operational effectiveness and safety through the use of simulators.

In this work, a training methodology based on the concept of briefing/debriefing is adopted based on previous literature. By using this methodology borrowed from similarly demanding applications, the efficiency of the proposed framework is validated in a conceptual case study. In particular, the training procedure, which was previously performed by Statoil and partners, for the world's first sub-sea gas compression plant, in Aasgard, Norway, is considered and reviewed highlighting the potentials of the proposed framework.

1. Introduction

Nowadays, increasingly demanding maritime operations are at the heart of the maritime industrial cluster. Such operations are usually conducted in a dynamic environment in which technical, human and organisational malfunctions may cause accidents. Under such circumstances, situational awareness (SA) for the operators plays a crucial role in effective risk reduction [1]. Executing and assessing demanding maritime operations is a vital issue for the European as well as for the entire world economy as reported in several risk governance gap analyses [2].

The classic methodology for risk estimation is generally adopted as an accepted practice to improve safety of offshore installations. Experts commonly define risk as the danger unwanted events may have on human, environmental, and economic values [3]. Operators must respect the regulations defined by the Offshore Safety Case for identifying the major hazards and to reduce risks to As Low As is Reasonably Practicable (ALARP) [4]. Quantitative Risk Assessments (QRA) must be used when preparing the Safety Case, as stated by the regulations [5]. Risk is evaluated within the framework of the Formal Safety Assessment (FSA), introduced by the International Maritime Organisation (IMO) [6]. However, this formal risk estimation does not necessarily correspond with individual risk perception. Taking this into account, improving the user's risk perception becomes of crucial importance. There is an urgent need to develop faster methods and tools that enhance SA on board a vessel so that accidents can be avoided.

Developing and testing such methods in a real set-up environment is very difficult because of the challenging operational workspace of maritime installations. Due to the demanding operational scenario in

* Correspondence address: Faculty of Maritime Technology and Operations, Norwegian University of Science and Technology (NTNU) in Aalesund, Postboks 1517, 6025 Aalesund, Norway.
E-mail address: filippo.sanfilippo@ntnu.no.

http://dx.doi.org/10.1016/j.ress.2016.12.015
Received 29 February 2016; Received in revised form 22 December 2016; Accepted 27 December 2016
Available online 31 December 2016
0951-8320/

real applications, a promising approach consists in using sophisticated training programmes within specifically designed simulator environments. Training programmes have been succesfully adopted to reduce risk and to improve efficiency of maritime operations. Training personnel in simulators makes it possible to improve the overall understanding of different operations to be performed [7–9].

In this perspective, the Offshore Simulator Centre AS (OSC) [10] is one of the the world's most advanced provider of simulators for demanding offshore operations. Together with the Norwegian University of Science and Technology (NTNU) in Aalesund (the former Aalesund University College), the OSC has implemented a highly regarded and sophisticated team-training concept for offshore crews, both for crane operations, anchor handling, and platform supply vessel operations. However, even though the OSC provides very powerful simulation tools, effective techniques to visualise and analyse operational procedures that can be used to further improve SA are still lacking, though. This lack is especially noticeable when unique operations have to be performed. For instance, this is the case of one of the most technologically demanding projects that was recently developed in Norway by Statoil. This project concerned the deployment of the world's first subsea gas compression facility at Aasgard, in the Norwegian Sea [11]. To cope with the uniqueness of this challenging operation, the full subsea installation and the entire procedural training was simulated in the world's first integrated Subsea Simulator, developed by the OSC. This experience highlighted the need for developing instrumentation and methods for improving SA as an integrated component of simulation training.

In this work, a multi-layer and multi-sensor fusion framework is integrated with the OSC simulator for planning, executing and assessing demanding maritime operations and procedures by adopting newly designed risk-evaluation tools that take human factors into consideration and focus on SA. The underlying idea is shown in Fig. 1. The proposed integrated framework allows for collecting different information from the simulator scene, such as audio, video, bio-metric data from various sensors and annotations. Annotations can be added during the training phase by different observers such as researchers, supervisors, instructors and other participants. A specifically designed time-line allows for playing back the collected historical data and to present them for analysis and evaluation studies. Different human factors indicator can be obtained. This integration establishes the base for the research of novel methodologies for training and for assessing SA. Operational effectiveness and safety, an industry priority, can be

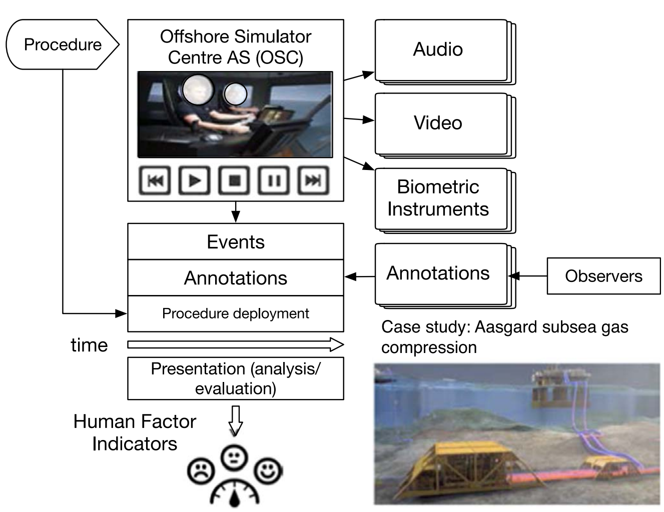

Fig. 1. The underlying idea of developing an integrated multi-sensor fusion framework for planning, executing and assessing demanding maritime operations. Some elements of this figure are credit to the Offshore Simulator Centre AS (OSC), to Statoil and partners. Any person depicted in the image is being used for illustrative purposes only. People's faces are obscured for privacy concerns.

improved through the use of simulator technology and facilities. In this study, a briefing/debriefing model [12] is adopted as training methodology. Based on this method, the training procedure that was performed for the Statoil Aasgard subsea gas compression plant is reviewed and analysed as a conceptual case study to highlight the potentials of the proposed framework. The information used in this paper concerning the Statoil Aasgard subsea gas compression is of public domain as it is available on several newspaper pages, websites [11,13] and articles [14].

The paper is organised as follows. A review of the related research work is given in Section 2. In Section 3, the OSC facilities are first described, then the focus is on the description of the selected training methodology. The developed framework architecture is then presented together with the constituting components and the adopted multi-layer and multi-sensor organisation. A review of the unique training procedure for the Statoil Aasgard subsea gas compression plant is presented in Section 4 as a conceptual case study. In Section 5, a discussion regarding the validation of the proposed framework is outlined. Finally, conclusions and future works are outlined in Section 6.

2. Related research work

In existing literature, not much work has been done to develop specifically designed tools for assessing SA during maritime training operations. In order to understand SA within maritime applications, several examples of similarly demanding applications can be considered as sources of inspiration. For instance, in the last years, the performance assessment was successfully combined with a psycho-physiological approach for the objective assessment of the levels of physiological arousal and psychological load. This approach was validated and tested in simulators for civil airlines and space applications [15].

A key aspect of demanding maritime operations is the interaction between humans and machines. When considering human-machine interactions, human operators have to be considered in the centre of the loop. Considering this aspect, again space research can provide solid directions. The National Aeronautics and Space Administration (NASA) is a worldwide leading institution in redesigning novel methodologies as well as tools for complex distributed systems [16] by keeping human in the centre of the loop. In programmes established or supported by NASA and other research institutes [17], human error analysis due to procedures, operations, design or personnel stress have been addressed by adopting structured approaches. These methods may be adapted for similar analysis in the maritime domain.

Making decisions and managing competences in complex systems is a challenging task to accomplish. In this perspective, another significant example that can be taken as a source of inspiration comes from the process industry. For instance, the *Plant Simulator* (PS) is the expression coined in [18] for chemical production sites, to address something that is in analogy with the flight simulator paradigm. The PS is an information technology (IT) infrastructure created to replicate the exact plant conditions and to enable both expertise and field operators to cooperate as they would do in reality, i.e. as a team. The PS allows expertise and field operators for experiencing both rationally and emotionally the same situations they would live in reality in terms of process behaviour and consequences originated by either nominal or abnormal operating conditions. The PS can be surely taken as an example, however several elements would need to be adapted to the different domain of offshore applications.

Demanding offshore operations place workers in dynamic, rapidly changing conditions, which impose the need for effective teamwork among crew members to successfully achieve the desired tasks. Under such conditions, learning to work effectively in a team environment is challenging. Several factors need to be taken into account, such as emergency response as a team, crew resource and crisis management.