A Multi-Sensor System for Enhancing Situational Awareness in Offshore Training*

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Abstract—**Real offshore operational scenarios are particularly risky. Training programmes involving specifically designed simulators constitute a promising approach for improving human reliability and safety 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.**

In this work, an integrated multi-sensor fusion system is integrated with the OSC. The proposed system 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.

A training methodology based on the concept of briefing/debriefing is adopted. By using this methodology, the efficiency of the proposed system is validated in a conceptual case study that considers the training procedure performed by Statoil and partners for the world's first sub-sea gas compression plant, in Aasgard, Norway.

Index Terms—**Maritime Operations, Situational Awareness, Safety, Training, Offshore Simulator.**

I. INTRODUCTION

The operation of an offshore installation is associated with a high level of uncertainty and risk. Under such circumstances, situational awareness (SA) for the operators plays a crucial role in effective risk reduction [1]. 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 real applications, a promising approach consists of using 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 [2], [3].

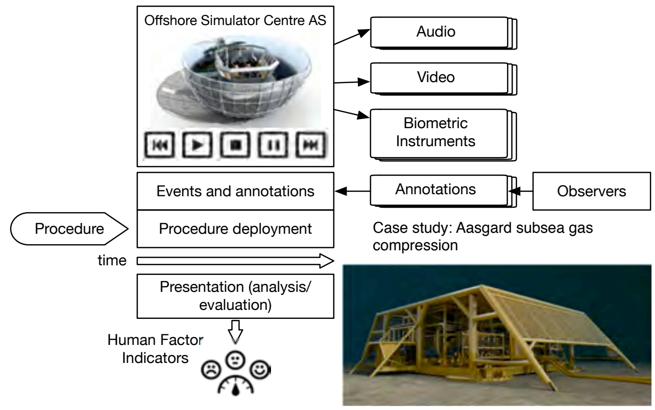

Fig. 1: The proposed multi-sensor fusion system for planning, executing and assessing demanding maritime operations.

In this perspective, the Offshore Simulator Centre AS (OSC) [4] is one of the the world's most advanced provider of simulators for demanding offshore 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 [5]. 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 system 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

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system 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. In this study, a briefing/debriefing model [6] 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 system. 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 [5], [7] and articles [8].

The paper is organised as follows. A review of the related research work is given in Sect. II. In Sect. III, the focus is on the description of the proposed training methodology. The developed system architecture is then presented. A review of the unique training procedure for the Statoil Aasgard subsea gas compression plant is presented in Sect. IV as a conceptual case study. In Sect. V, conclusions and future works are outlined.

II. Related Research Work

To understand SA within maritime applications, several examples of similarly demanding applications can be considered as sources of inspiration. For instance, 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 [9] by keeping human in the centre of the loop. In programmes established or supported by NASA and other research institutes [10], 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.

To monitor human factors during maritime training operations, it is necessary to transforms the simulators into research laboratories by instrumenting them with sensors for studying complex biological and socio-technical relationships. Even though independent sensor information is conducive to revealing an overview of the considered operation to some extent, a comprehensive multi-parameter sensing model is more effective for analysis and evaluation of potential operational risks. To the best of our knowledge, multi-sensor fusion is one of the most suitable technologies to use when dealing with data from disparate sources [11], [12].

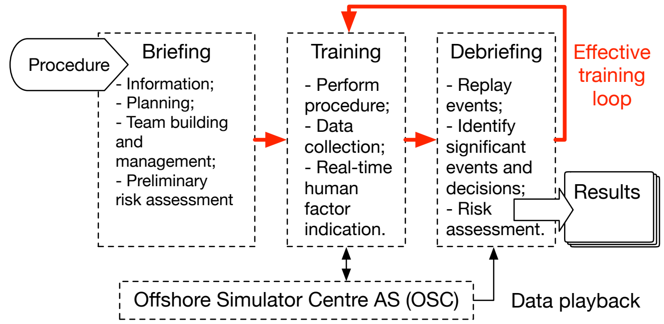


Fig. 2: The adopted training methodology.

The problem of identification of dangerous zones in offshore installations by using a sensor-fusion approach was investigated by our research group in [13]. This approach is based on a node positioning algorithm that allows for tracking and identifying the operational movements on board the vessel. In [14], our research group successively presented a wearable integrated health-monitoring system that can be used for maritime applications.

It should be noted that most of the currently available systems based on sensor-fusion technology have exclusively been employed to monitor real applications. However, to the best of our knowledge, no integrated systems for planning, executing and assessing SA in demanding maritime operations exist as a built-in part of simulation training facilities. The main contribution of this paper is to propose such integrated system.

III. System Architecture

A. Training methodology

The proposed training methodology is based on previous literature. In particular, the briefing/debriefing model [6] is adopted as training methodology. The choice is motivated by the fact that this team-based, reflexive organisational model borrowed from the military was proved to be very effective in several group psychological interventions under acute stressor situations. When considering offshore training operations, for instance, this method was successfully applied to improve safety in maritime crane and lifting operations [15].

The selected training methodology is described in Fig. 2. Each session comprehends three different phases: briefing, training and debriefing. These phases are described in the following. The training and debriefing phases are iterated to achieve an effective training loop.

Briefing: during this phase, all personnel is thoroughly briefed on the purpose of an operation prior to participating in it. Briefings are structured according to the specific needs of the operation. Borrowing the main concepts from the "Information, Intention, Method, Administration, Risk Assessment, Communications, Human rights and other legal issues" (IIMARCH) model [16], which is adopted for the briefing of other similar acute stressor situations such as police operations, the briefing phase may be structured in the following steps: information, planning, team building and management, preliminary risk assessment. By the end of this phase, it is necessary to check whether all the briefing objectives are achieved.

Once the briefing phase is terminated, the training loop iteration starts alternating training and debriefing sections.

Training: the training phase is the key stage of the proposed methodology. During this phase, personnel get a first-hand experience within a simulated operation scenarios that is as close to reality as possible. This phase can be efficiently performed within the training facilities provided by the OSC simulator. The OSC simulator is designed for optimal training and education of maritime operation personnel. Based on advanced simulation and visualization technology, the simulator can be configured in a number of ways, regarding hardware setup, display solution, and software setup (including all the required modules such as the type of crane, types of vessels/lifting objects and training scenarios).

The training phase may be structured in the following steps:

- perform procedure: the planned procedure is executed in the simulation environment;
- data collection: during the training phase it is essential to collect data concerning both the real scene as well as the simulated world. Concerning the simulator real scene, different information such as audio, video and bio-metric data from various sensors must be collected. In addition, possible annotations may be added during the training phase by different observers such as researchers, supervisors, instructors and other participants. Concerning the simulator virtual scene, it must be possible to store important information that may be played back at a later stage according to the certain time reference settings. This data collection is of crucial importance for the purpose of improving operational effectiveness and safety through the use of simulator facilities. All the collected data is relevant for the subsequent phase of debriefing;
- real-time human factor indication: during the training phase it is also important to provide personnel with tools that can improve their perception and SA of the ongoing simulated operational procedure. For instance, real-time visual indicators highlighting some estimated stress parameters may certainly improve the training experience. A real-time human factor indication may be achieved by interpreting data coming from different bio-metric sensors. These data may be processed in real-time by adopting proper methods based on a multi-sensor fusion concept.

It should be noted that the first of these steps can be easily achieved by using the tools originally provided by the OSC since the main objective of such an advanced simulator is to provide a realistic training environment. However, the steps concerning data collection and real-time human factor indication cannot be originally performed since the OSC does not naturally offer any integrated and flexible method for these purposes. The integration with the proposed system makes these steps possible.

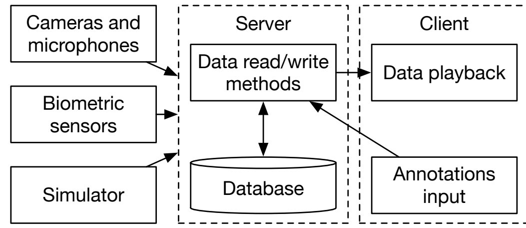


Fig. 3: The proposed system architecture.

Debriefing: the purpose of debriefing is to identify good practice and areas for improvement, which could include organisational learning. The debriefing phase is structured in a way that it is possible to achieve the following steps: replay events, identify significant events and decisions, risk assessment. It should be noted that none of these steps can be originally performed within the training facilities provided by the OSC simulator. The integration with the proposed system makes these steps possible.

B. *Architecture Technology*

The architecture technology is presented in the following. The reader is referred to Fig. 3. In particular, a client-server pattern is adopted.

Server

The server is designed to collect data from the following different sources:

- cameras and microphones: video and audio sources can be collected from the real scene of the different simulator stations and streamed to the server;
- bio-metric sensors: different data from various sensors, such as eye-trackers, ECG sensors or other bio-metric sensors, can be collected. These data may provide very valuable information for both the training phase as well for the debriefing phase. For instance, a Tobii Pro Glasses 2 eye-tracker [17] was employed in this initial study to track eye-tracking data of the personnel while training. Some results are reported in Sect. IV;
- simulator: data from the simulator are collected regarding both the simulated physics and scenes.

On the server side, the collected data are logically organised according to a multi-layer configuration, as shown in Fig. 4-a. This particular multi-layer configuration allows for overlapping different data according to a multiple information stack and a modular approach. The stack includes the simulated scene layer, the real scene layer, the bio-metric data layer and the annotations layer. By using specifically designed data read/write methods, the collected data can simultaneously be streamed from the server to the client in real-time, for the training phase, and together be stored in a database on the server side, for the debriefing phase. It should be noted that some of the presented features for the server are currently under developing.

Client

The client application is designed to realise the following features: to visualise in real-time or to playback the collected data; to allow for adding annotations; to visualise human factor indicators. These features are intended to be used during both the training phase as well as the debriefing phase. During the former phase data are visualised in real-time, while during the subsequent phase data are played back on demand. Each training participant can run the client application on a tablet device while participating in the training. An interactive user interface is proposed for the client, as shown in Fig. 4-b. In particular, different video sources coming either from the simulated scene or from the real scene can be simultaneously visualised on the top panel. Sensor data are overlapped and synchronised on top of the videos. For instance, a circular marker (superimposed on the video) is used to indicate the gaze data point collected by an eye-tracker, as shown in Fig. 4-b. Annotations are visualised on another overlapping layer on top of the previous ones. An interactive chat log is provided in the lower panel of the proposed interface. New annotations can be typed through a specific text input field and send to the server to be shared with all the training participants.

Simple and yet effective input buttons representing emoticons are visualised on the right panel of the developed interface symbolising human factor indicators. According to an individual estimation of the current training situation, each participant can click on the corresponding emoticon button. As a result of a collective estimation given by different participants, a corresponding emoticon is shown.

A common slider make it possible to control the timeline and allows for synchronously playing the data and for displaying annotations in chronological order. By moving the slider is possible to play data back and forward and to review particularly significant events of the selected training procedure. It should be noted that, as at the time of writing, the entire system implementation is still in a prototype stage and the complete integration with the OSC simulator is currently an undergoing process.

IV. Conceptual Case Study

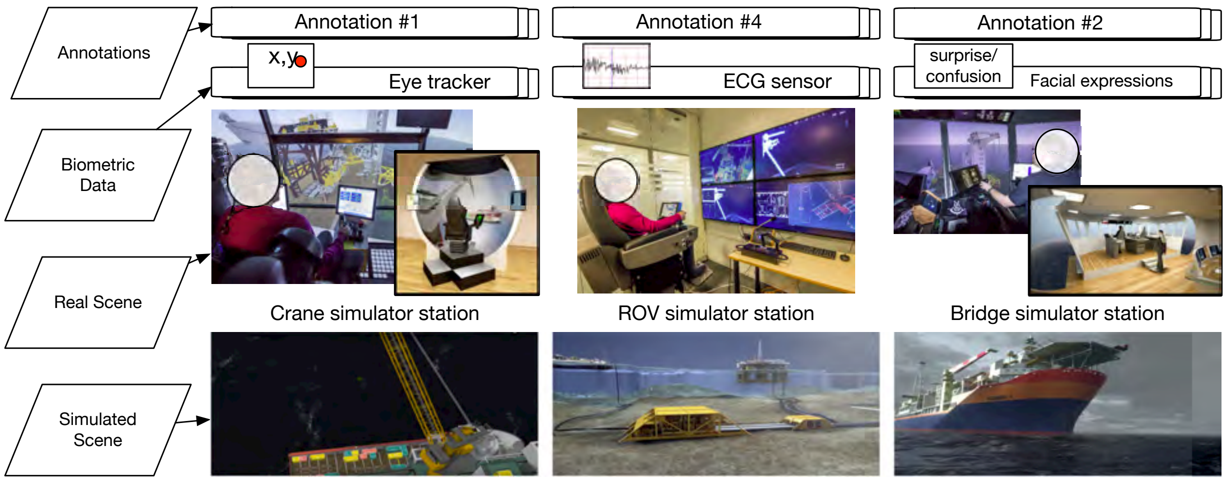
In this section, a conceptual case study is presented. In particular, the training procedure that was previously performed for the Statoil Aasgard subsea gas compression plant [5] is considered. The information related to the Statoil Aasgard subsea gas compression is of public domain as it is available on several newspaper pages, websites [5], [7] and articles [8]. This information is only intended to contextualise the selected case study. Based on this information, the selected training procedure is hereafter reviewed and analysed according to the proposed system.

The considered case is probably one of the most unique and technologically demanding maritime projects that was recently developed in Norway. Ranking among the largest developments on the Norwegian continental shelf, the Statoil Aasgard field lies on the Halten Bank in the Norwegian Sea, about 200 kilometers off Norway. The Aasgard subsea gas compression facility is the world's first project of its kind. Using new technology, the compression process enables the gas to gain sufficient additional pressure for it to be transported through the pipeline to the platform. This helps boosting the recovery factor and producing life for gas fields. The Aasgard subsea gas compression facility is built by using a modular design approach where different interfaces are adopted including a spool interface, a scrubber and a compressor. A more detailed description of the Aasgard subsea gas compression facility is reported in [18]. The deployment and installations of the facility building modules required a coordinated team work involving different maritime expertise and devices. For this purpose, Statoil also involved the expertise provided by Technip [7] and other partners.

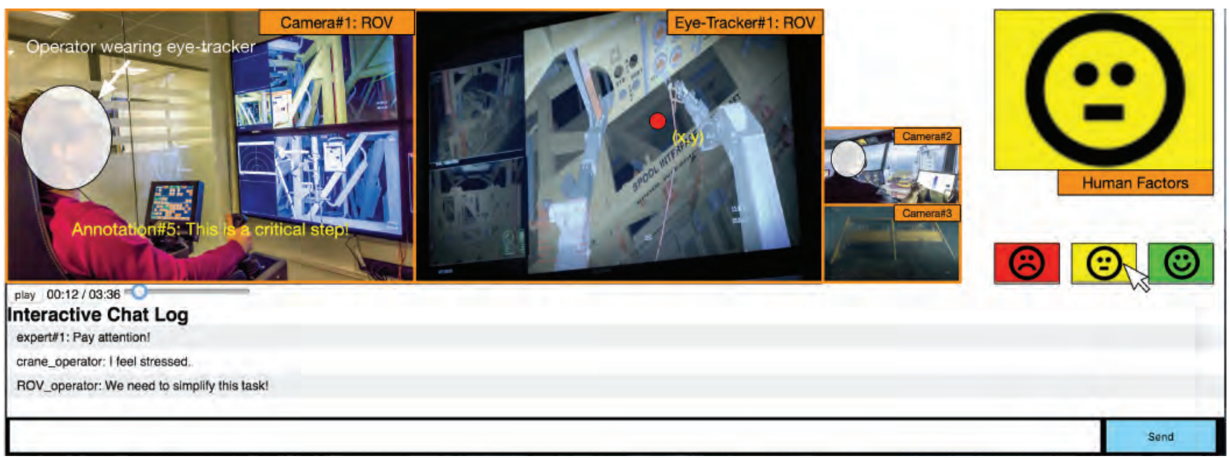
To exploit the uniqueness of this demanding procedure, the world's first integrated Subsea Simulator was developed by the OSC to make it possible the simulation of the entire procedural training. OSC simulated the full subsea installation including the following modules: the North Sea Giant vessel [19]; the crane system that has been modified to incorporate a so-called special handling system (SHS) [20]; two remotely operated underwater vehicles (ROVs); one observation-class ROV and the instructors station.

In this conceptual case study, some steps of the considered training procedure have been repeated to collect some meaningful data. In particular, eye-trackers were used to collect eye-tracking data from personnel while training. In particular, a Tobii Pro Glasses 2 eye-tracker [17] was employed for this purpose. The Tobii Pro Glasses 2 eye-tracker is a wearable eye-tracker with wireless live view function for insights in any real-world environment.

Concerning the training phase, the data collected from the Tobii Pro Glasses 2 eye-tracker can be directly streamed to the client and then to the server. This functionality can be achieved by using the Tobii Pro software development kit (SDK) APIs. On the client user interface, these data can be visualised according to the adopted multiple information stack protocol, as shown in Fig. 4-b. It should be mentioned that this feature is still under developing. The information carried by these data are significantly relevant for estimating the level of attention of a trainee wearing the eye-tracker while performing demanding procedures.



(a)



(b)

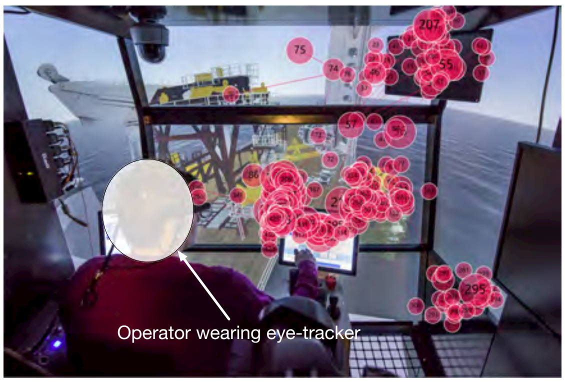
Fig. 4: (a) The proposed concept for the multi-layer and multi-sensor fusion system. (b) The proposed interactive user interface for the client.

For instance, lifting or lowering loads through the splash zone is a very challenging procedure to be accomplished for a crane operator. To successfully perform this procedure, several elements need to be taken into account such as slamming forces, added mass and drag of the lifted object, which can increase the forces transferred to the crane and the object by many times the weight of the object. In addition, snap loads caused by wave or boom-tip motion may be very large. Considering this sub-routine of the deployed procedure, different post-analysis results can be obtained. For instance, a heat map can be produced as shown in Fig. 5-a. A heat map is a gaze data visualization on top of a snapshot image that uses colors to represent how much the participants gazed on (attended to) different areas of an object or an environment. In this case, the crane operator gazed more on the crane control interface and on the module to be deployed. For the same sub-routine, a gaze plot can also be obtained as shown in Fig. 5-b. A gaze plot is another interesting mapping that shows the sequence and position of fixations (dots) of the operator. Gaze plots can be used to illustrate the gaze pattern of a single test participant throughout the entire eye-tracking session. The numbers and the connecting lines shown in Fig. 5-b are used to highlight the time sequence concerning this particular case. Concerning the considered case study, a demo video is available on-line at: https://youtu.be/F705LwlGTIw.

V. Conclusion and Future Work

A system for improving SA in demanding maritime training was proposed based on a multi-layer and multi-sensor fusion design approach. An innovative training methodology was also discussed based on the concept of briefing/debriefing and on an interactive and effective training loop. The developed system is integrated with the Subsea Simulator developed by the OSC [4]. Different information from the simulator scene and from the real world can be collected, such as audio, video, bio-metric data from eye-trackers and

(a)



(b)

Fig. 5: (a) A heat map and (b) a gaze plot of the sub-routine used for the deployment of a module through the splash zone.

other sensor data. This integration represents the base for research on novel SA assessment methodologies.

To highlight the potentials of the proposed system, a conceptual case study was also presented. In particular, the training procedure performed for the world's first sub-sea gas compression plant, in Aasgard, Norway, was analysed and reviewed. For this conceptual case study, eye-trackers were used to collect eye-tracking data from personnel while training and repeating some steps of the considered procedure. Related results were reported.

As future work, the possibility of using the proposed system as a tool to develop new training programmes for unique operational procedures is being considered. Starting from a preliminary procedural plan, the entire operational procedure may be developed by using the proposed training iteration loop and based on the concept of briefing/debriefing.

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REFERENCES

[1] G. Salvendy, *Handbook of human factors and ergonomics*. John Wiley & Sons, 2012.

[2] F. Sanfilippo, L. I. Hatledal, A. Styve, H. Zhang, and K. Y. Pettersen, "Integrated flexible maritime crane architecture for the offshore simulation centre AS (OSC): A flexible framework for alternative maritime crane control algorithms," *IEEE Journal of Oceanic Engineering*, vol. PP, no. 99, pp. 1–12, 2015.

[3] F. Sanfilippo, L. I. Hatledal, H. Zhang, W. Rekdalsbakken, and K. Y. Pettersen, "A wave simulator and active heave compensation framework for demanding offshore crane operations," in *Proc. of the IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), Halifax, Nova Scotia, Canada*, 2015, pp. 1588–1593.

[4] Offshore Simulator Centre AS. (2015, December) "OSC". [Online]. Available: http://www.offsim.no/

[5] Statoil. (2015, December) "Aasgard". [Online]. Available: http://www.statoil.com/

[6] R. Lipshitz, N. Ron, and M. Popper, "Sensemaking when accuracy matters: Post flight reviews in the israeli defense force air force," *Probing the future: Developing organizational foresight in the knowledge economy, University of Stathclyde Graduate School of Business, Glasgow, UK*, 2002.

[7] Technip. (2015, December) "Technip awarded contract for intervention services on Asgard Subsea Compression Stations". [Online]. Available: http://www.technip.com/

[8] M. Person, "Aasgard subsea compression project," in *Haramskonferansen*. Haram Nring og Innovasjonsforum, 2014.

[9] W. J. Clancey, M. Sierhuis, C. Seah, C. Buckley, F. Reynolds, T. Hall, and M. Scott, "Multi-agent simulation to implementation: a practical engineering methodology for designing space flight operations," in *Engineering Societies in the Agents World VIII*. Springer, 2008, pp. 108–123.

[10] S. A. Shappell and D. A. Wiegmann, *A human error approach to aviation accident analysis: The human factors analysis and classification system*. Ashgate Publishing, Ltd., 2012.

[11] G.-Z. Yang, J. Andreu-Perez, X. Hu, and S. Thiemjarus, "Multi-sensor fusion," in *Body sensor networks*. Springer, 2014, pp. 301–354.

[12] A. Van den Broek, R. Neef, P. Hanckmann, S. P. van Gosliga, and D. Van Halsema, "Improving maritime situational awareness by fusing sensor information and intelligence," in *Proc. of the 14th IEEE International Conference on Information Fusion (FUSION)*, 2011, pp. 1–8.

[13] F. Sanfilippo and K. Y. Pettersen, "XBee positioning system with embedded haptic feedback for dangerous offshore operations: a preliminary study," in *Proc. of the MTS/IEEE Oceans '15 Conference, Genova, Italy*, 2015, pp. 1–6.

[14] F. Sanfilippo and K. Y. Pettersen, "A sensor fusion wearable health-monitoring system with haptic feedback," in *Proc. of the 11th IEEE International Conference on Innovations in Information Technology (IIT), Dubai, United Arab Emirates*, 2015, pp. 241–245.

[15] R. Botnevik, A. Midtgaard *et al.*, "Development and use of an advanced offshore crane simulator: A tool to improve safety in crane and lifting operations," in *SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production*. Society of Petroleum Engineers, 2002.

[16] College of Policing. (2015, December) "Briefing and debriefing". [Online]. Available: http://www.app.college.police.uk/app-content/operations/briefing-and-debriefing/

[17] Tobii AB. (2015, December) "Envision human behavior". [Online]. Available: http://www.tobiipro.com/

[18] P. V. Fossum, T. K. Moum, E. Sletfjerding, K. Taugbol, B. Brechan, H. Hogstol, P. A. Olsen, J. Fjorden, C. Van Der Zwaag *et al.*, "Design and utilization of low solids obm for aasgard reservoir drilling and completion," in *European Formation Damage Conference*. Society of Petroleum Engineers, 2007.

[19] North Sea Shipping. (2015, December) "The North Sea Giant vessel". [Online]. Available: http://www.northsea.no/

[20] AxTech AS. (2015, December) "The Special Handling System (SHS)". [Online]. Available: http://www.axtech.no/index.php/system-solutions/420t-special-handling-system