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Concept of an augmented virtuality marine simulator

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Abstract

This paper presents the assumptions for the concept of a full mission ship's bridge simulator prototype using innovative augmented virtuality technology. A description of a possible development process is provided as well as two potential applications in the field of marine simulation: operator motion tracking techniques, MoCap, which entails interacting with the environment and generating of synthetic images via HUD; and implementation of the latest technology, data gathering and analysis methods, which would replace current visualization methods and equipment used in maritime simulators.

Introduction

The purpose of any simulator is to replicate the real object's behavior and its interaction with the environment as closely as possible. Most existing simulators are based on computer-based representations of objects and phenomena with mathematical models. Due to restrictions of human perception and interactions with computer-simulated devices, modern simulators are often equipped with such real devices as a ship's bridge or an airplane's cockpit. The key element of every simulator is the vision generation system, which often determines the level of realism achieved and the workload of the operator.

The history of first ship's simulators dates back to 1959, when first radar simulators were being developed. The first ship's bridge simulator that used computer generated vision, the Visual Bridge Shiphandling Simulator (Puglisi, Case & Webster, 2010), was constructed in 1975 in the United States Merchant Marine Academy. Over the next decades, many of the changes in simulator technology consisted of advances in visualization systems, including improved screens and projectors, as well as more advanced graphic processing units. A modern example of this trend is the NTPRO 5000 full-mission ship's bridge simulator, developed by the Transas Company (Transas, 2014). It offers a high resolution picture enhanced with water translucency, light reflection, soft edge blending, dynamic shading, foam, and splash effects.

Higher quality visualizations and better picture projection technology do not by themselves solve the basic problem of a full-mission ship's bridge simulator. The largest problem consists of the limited number of options for modifying the physical environment of the simulator. Critical aspects of this physical environment include adding and removing pieces of equipment as well as changing the simulator layout and the interfaces of installed equipment.

The Offshore Vessel Simulator for Seismic Streamer Operations, developed by Kongsberg Group (Figure 1), attempts to solve this problem. Whole simulated environments are generated on three screens, and user interaction is provided by a small panel and the Microsoft Kinect controller that models position and movements of operator's body. A similar approach is used in the Maersk

Figure 1. Offshore Vessel Simulator for Seismic Streamer Operations manufactured by Kongsberg (Kongsberg Maritime, 2012)

Offshore Helicopter Landing Officer Training Simulator (Strazdins, Komandur & Styve, 2013). Despite its flexibility, such a solution is still imperfect, offering only a simplified and artificial representation of reality.

In the field of full-mission ship's engine simulators, the Polish company Unitest used a combination of three-dimensional models of the engine room to give the operator the ability to move around using a keyboard and mouse (Tomczak, 2009). Consoles of the real devices were also replaced with touch screens, an innovation that increased the ability to change the location and interfaces of simulated equipment.

Other leading producers of marine simulators (e.g., Polaris, STSTC, Marin, L-3 DPA) make use of solutions based on real physical navigational equipment with separate visualization systems that, in some cases, provide a visual field of 360°.

Limitations of modern marine simulators

Full Mission Bridge Simulators suffer from two basic types of limitation. The first is related to the administrator of the equipment and to associated economic criteria. The second type concerns the people using the infrastructure, and the resulting criteria for the technical capabilities of the equipment.

The economic criteria of a simulator are tied to the purpose and specifications of the simulator. Typically, simulators require construction of a new space for their use, or the remodelling of an existing space. Either way, options are limited by the infrastructure that is available to the administrator.

Differences in purpose and structure of maritime simulators are so large that it is usually necessary to build dedicated solutions (it is, for example, impossible to simulate the engine room on the bridge of the ship). Even if additional space is available, such dedicated solutions and their associated infrastructures require a considerable commitment of energy and funds.

Secondly, a ship's bridge or engine room simulator, unlike a car's interior or an airplane's cockpit, has a large surface area. In practice, this means that built-in consoles with screens, desktop steering systems, and other automation equipment must be purchased. Due to the ergonomics of the rooms as well as conditions and rules of construction, it is often impossible to integrate a simulator into the small, compact areas characteristic of automotive or aeronautical simulators. Consequently, the total cost reflects not only all the necessary electronic devices, but additional costs of labor and materials for construction. This increases the overall costs related to simulator purchase.

In light of these conditions, attention needs to be given to the amount of both the exploitation and maintenance costs of devices within a simulator.

From a technical perspective, the quality and usefulness of a simulator depends on many specific factors, one of which is the number of dedicated equipment units used in simulating specific tasks. A simulator is designed for particular devices, so the number of interfaces, their functionality and location, are pre-defined. Thus, substantial modification of the simulator by the operator is impossible. Large modifications usually require the participation of authorized service personnel, which is very time-consuming and costly.

Even when the simulator is adapted to a specific operator, it is very often impossible to fit all required, additional equipment. This is because the producer does not offer a particular product, the product is incompatible with established systems, there is insufficient space to install the console, or it is installed in a place that does not exist in a specific simulator.

In such cases it is necessary to abandon or to reduce planned teaching processes, research, or training programs. Although another option would be to buy a new simulator that is compatible with the specifications of a given task, it is highly impracticable to build several simulators, used for similar purposes, in the same center. Technical and economic considerations make such actions inappropriate and unreasonable.

Secondly, depending on the technology used for visualizing the environment, the officer/operator has access to a limited and pre-determined field of view. This range is defined by the number of LCD displays or projectors of the vision system.

Manufacturers of navigation bridge simulators have proposed a standard by which visualization of a horizontal angle must be at least 270°, with a visualization of a vertical angle of at least – 15°. Because of technologically insuperable obstacles, no maritime simulators with a full, spherical visualization and real time simulation are currently available on the market. Instead, to direct the point of view of the officer/operator to areas not currently rendered by the vision system, like the stern of the ship, all current systems use something like a joystick or mouse that to rotate the image/virtual camera ("turning the head of the officer/operator").

This solution has three main limitations. First, for high vessels at the time of departure, it is not possible to observe the area blow the ship's wing. Second, for the vessels escorted by a tug, there is no possibility of observing what's happening over the available horizon. Third, when the vision angle is changing, the geometry of the scene is deformed.

Moreover, the appearance and functionality of the actual panels, consoles and interfaces of the simulator are copied from commercial equipment on the marine market. The general arrangement of a simulated workstation is inspired by the arrangements actually seen in the maritime industry. However, there are significant differences even between devices of the same type and function. In case of devices located on the bridge, the location of a navigation device is determined by its size and purpose, which affects the overall ergonomics and functionality of the bridge. Similar considerations apply to engine room spaces and to other facilities that are simulated.

The impact of diversity is magnified by the fact that equipment with the same functionality can have different interfaces, both in terms of panels (software panels), and mechanical devices (buttons, levers, and so on). Equipment used for the same task can differ operationally from each other if they are made by different manufacturers. For this reason, the officer/operator needs to be familiarized with device-specific features each time a new or altered device of a given type is introduced.

Modern simulators are quite inflexible in terms of the options they afford for optimizing ergonomics and personalizing the workspace. They consist of panels, consoles, levers and buttons that do not have plug/unplug functionality. Such devices are hard-wired, with no provisions for changing their position or detaching them according to the preferences of a particular officer/operator.

The latest maritime simulators are characterized by rigidly standardized solutions dictated by technological constraints. Such standardization does not accurately reflect the reality of the environment for different, currently simulated models and scenarios. Such solutions preclude workstation personalization in terms of the placement and selection of devices. In so doing, options to teach, research and train personnel in the operation of specific navigation devices or maritime units are severely constrained. Conducting the research to develop optimal solutions for ergonomic workstations, such as the use of eye tracking technology, is also very limited, and is possible only in the context of special, dedicated factory simulators.

Assumptions for an augmented virtuality marine simulator

Due to the aforementioned limitations of modern marine simulators, the authors began to develop the concept of a full mission ship's bridge simulator based on the innovative technology of augmented virtuality (AV).

Augmented virtuality is an innovative field of knowledge and engineering that allows the creation of new systems capable of presenting the real world, in part or in whole, in the form of three-dimensional computer-generated objects in real time. Augmented virtuality accounts for the position of the observer, and reflects this relative observational position on the screen (Milgram & Colquhoun, 1999).

In practice, this means the total replacement of actual devices in traditional maritime simulators with an artificially generated virtual environment, combined with a system that tracks the real movements of the officer/operator. The concept assumes developing the most important subsystems based on the results of a series of experimental studies and non-independent simulations that identify the assumptions of the main goal. These assumptions include:

1. Developing a subsystem of spatial positioning for the officer/operator (head, eyes, hands).
2. Developing a visualization subsystem of the virtual environment for the operator/officer.
3. Developing a subsystem by which the officer/operator interacts with the virtual environment.
4. Developing a subsystem of interfaces of the maritime simulator using AV technology.

Subsystem of spatial positioning

One of the most important – and most difficult – goals is constructing a functional subsystem that will position the officer/operator within the scene in which the simulation is performed. The prototype will provide a prompt and reliable telepresence figure in the virtual world that will provide an accurate projection of movements in six degrees of freedom, while also performing simulated tasks.

In the case of the ship's navigation bridge, the scene can be up to 30 m wide. In case of the engine room or the decks, it can reach up to several meters vertically. Control devices are not located next to each other, requiring the physical dislocation of the officer/operator to operate them.

To conduct the tracking process (an action referred to as "MoCap") on the bridge (Figure 2), mechanical and wired systems cannot be used because they would make it impossible for the subject to move freely. Wireless technologies with a narrow perspective are also precluded.

To achieve the proper tracking in a maritime simulator, it is necessary to carry out real tests and simulations. These tests create the possibility of constructing and implementing a prototype solution that positions points in a "large volume tracking space," adequate for areas ranging from 30 to 50 m^2. (Note that the average area for widely available, accurate tracking system currently is 3–8 m^2).

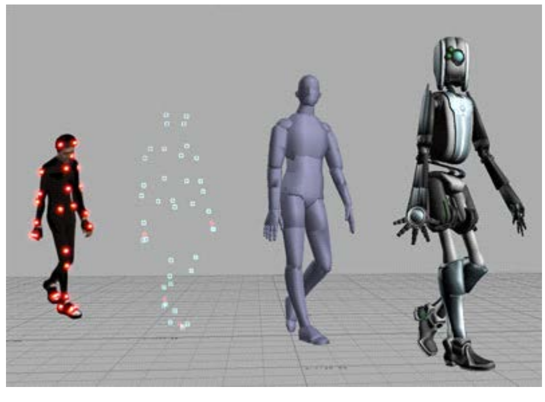
Virtual environment visualization subsystem

The assumptions and structure of the visualization subsystem of the virtual environment must be developed for the officer/operator. In the method based on AV, this task will be accomplished by the use of innovative wireless HMD, not see-through displays connected to the sound system. The prototype will provide stereographic, two- or three-dimensional visualizations of three-dimensional virtual geometric models of the bridge equipment and the surrounding world, augmented by accompanying sound effects.

Experiments using real methods and non-autonomous simulations will allow the development of guidelines for constructing the subsystem. Comparative analysis of results for different technologies will determine the applicability of implementation, as well determining how the system can be adapted to needs.

The functionality of the prototype will incorporate eye tracker devices (Figure 3). This functionality and capability opens up new possibilities in the field of scientific research in terms of the design and ergonomics of maritime devices. It may produce results that are unique on a global scale in the field of human behavior modelling.

Figure 2. Motion Capture technique (Qualisys, 2014)



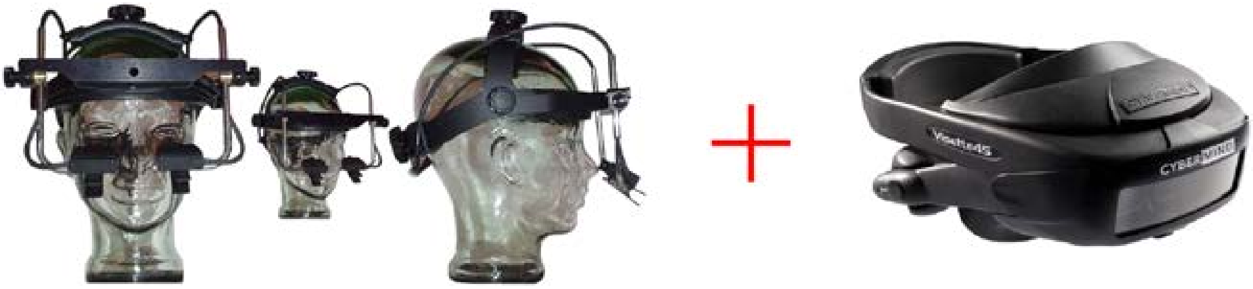


Figure 3. Connection of HMD and eye tracker

To achieve these results, mobile eye tracking sensors will be incorporated into the prototype. To accommodate innovative solutions, testing will be carried to develop cooperation algorithms, wiring schemes, cross-location of sensors and screens, and verification of correct operation procedures for the integrated devices. The results will be subjected to comparative analysis of significant parameters.

Subsystem for interacting with the virtual environment

An essential element of implementing a marine simulation in a virtual environment is a mobile, wireless subsystem enabling human interaction with other subsystems corresponding to the correct generation of the operating states of individual devices and objects.

This goal will be achieved through the development of principles and the construction of prototypes of mobile pointing devices using tracking systems of the body of the officer/operator in the decision-making process. It will provide an opportunity to interact with three-dimensional models of devices by appropriate changes in the position of the operators' hands in space, or by intuitive pointing mobile devices.

The most important parameters of the prototype include research on ergonomic shape, the operation principles, and the range and form of functionality. Comparative analysis of results for different technologies will determine the applicability of implementation and adaptation to the specified needs, or the necessity of constructing scenario-specific solutions.

Modern technology in the field provides the opportunity of characterizing gestures of each of the fingers. Combined with dedicated and declared algorithms in the interface system, this ability allows the extension of the functionality of motions of the officer/operator. To provide the correct handling of virtual devices on the bridge, gesture support algorithms with elements of fuzzy logic will be implemented.

Subsystems of the maritime simulator interfacing with AV technology

Subsystems responsible for accurately representing the virtual world, devices with their functionality, and phenomena occurring in the environment, are essential components of the interface of maritime simulators with AV. Interfaces integrate all components of positioning and spatial interaction with three-dimensional virtual models of equipment and surroundings. The aim of this integration is to develop partial assumptions regarding the interface with the marine simulator, providing complete interaction through the human-machine interface in the interpretation and actions necessary to carry out a specific task simulation.

Visualization of the surroundings will be realized by the use of real-time rendering methods based on a dedicated three-dimensional model. Testing will be carried out to determine the accuracy of these real-time renditions. These tests will indicate the effectiveness of the technology used, rendering polygons (a polygon mesh), and clouds of points (points cloud) in CAD modelling.

As a final step, the authors plan to use two of the leading game engines to generate high quality, detailed graphics. The game engines sought are Unreal Engine 4 and Unity3d 5. Both of these engines provide highly developed Software Development Kits, supporting such modern programming languages as the following: Java, C#, C++, integration with Oculus Rift through a dedicated Application Programming Interface, and support of such advanced graphic technologies as NVIDIA Waveforms, physically-based shading, tessellation, or full-scene HDR reflections. It is worth mentioning that both engines are provided free for academic and educational solutions, and both have been previously adapted for serious, professional

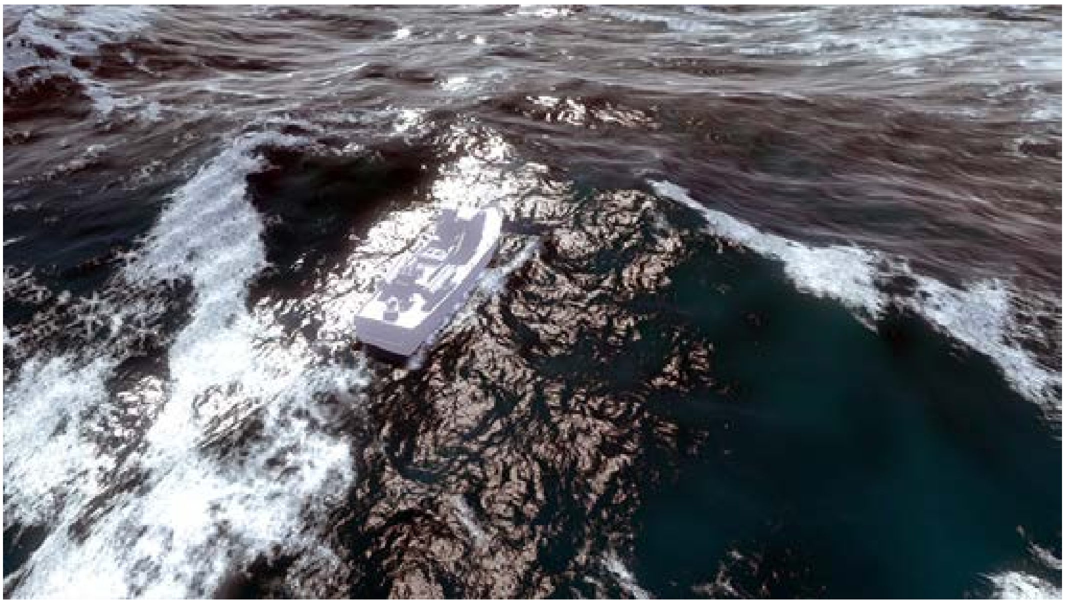


Figure 4. Waves generated in the Unreal Engine 4 programming environment (Unreal Engine, 2014)

applications (Petridis et al., 2010; Jones et al., 2015). Through various demos and showcases presented by the developers, it is possible to see the flexibility of this graphic environment as well as its capabilities when it comes to modelling ship and wave dynamics (Figure 4).

An essential element of the subsystem will be visualizing the operators/officers' body, which will have a direct impact on the change of such simulation parameters as the fingers. This subsystem will be responsible for correct positioning in space, and for the three-dimensional models generated in the visualization subsystem that will be a substitute for real counterparts. As a result, the officer/operator will gain knowledge of position, thereby obtaining support for the virtual ship's appliances.

Results

The assumptions developed will be used to build a concept of an ultra-modern, innovative prototype of a visualization system for a ship and its surroundings making use of AV technology. This goal will be reached through the construction of a simulator. The main task of the simulator will be to generate an environment, including both the area of the infrastructure and the environment outside it. This task will make use of its own dedicated three-dimensional geometric models, synthetically rendered in real time. It is assumed that it will be possible to faithfully reproduce the surroundings through the use of the most modern technology of visualization and visual effects.

The option of implementing simulated tasks through virtual representation of the equipment of a ship's bridge will be integrated into the prototype. The use of innovative interface algorithms and prototypes of tracking devices will allow the officer/operator to interact intimately with a virtual environment.

The prototype of a multi-purpose simulator of a ship's bridge in AV technology will take form of the scene. It will be equipped with specially developed subsystems to ensure its correct operation. Each human-machine interaction will be realized only in the virtual world, using innovative methods and technologies. The concept of the system architecture is summarized in Figure 5.

In order to carry out the simulated task the officer/operator will be equipped with innovative prototypes of dedicated devices which will be used to display the virtual world, and to provide continuous, real-time interaction with the simulated environment. The prototype will also be equipped with a system that will record all input variables from all connected subsystems. This will create a database of officer/operator motion, and the sequence of events in all devices on the bridge. Statistical analysis of this data will provide an opportunity to develop new research methods in the field of biomechanics and human behavior modelling (Morecki, Ekiel & Fidelus, 1971).

At the end of the project, the prototype will have the ability to simulate the dedicated bridge of the ship. In addition, the bridge interface will have an open architecture, allowing for the technical

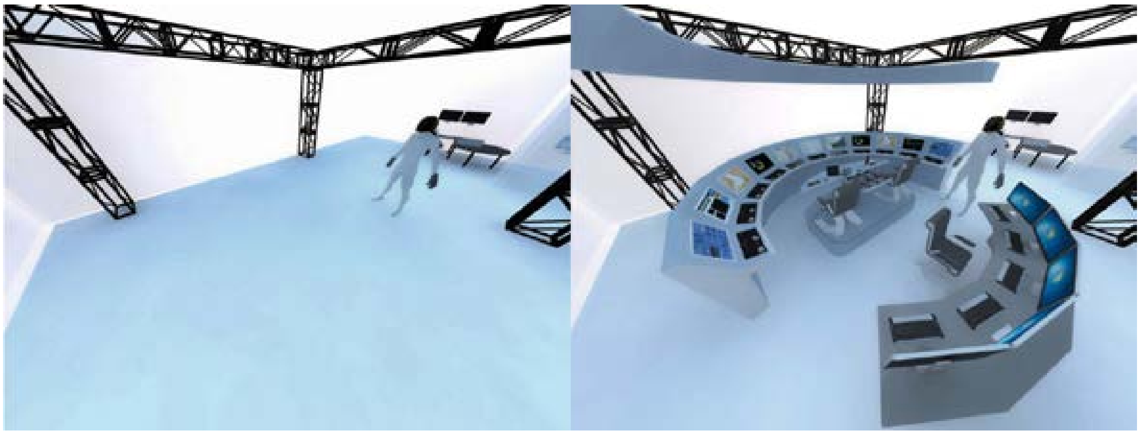


Figure 5. The architecture of the conceptual system

possibility of expanding of any chosen room or deck, including the simulation of assigned tasks to the selected scenario. Such functionality will enable the parametrization and simulation of an unlimited number of tasks encountered in the marine industry.

To verify the proper operation of equipment generated in the virtual world, the interface will be provided with selected subsystems to initialize remote commands and basic models of human – environment interaction.

Expected benefits from the implementation of proposed solutions

Future application of a prototype multi-purpose ship's bridge simulator incorporating AV technology provides clear economic benefits. It also eliminates the following problems affecting modern simulators:

1. Compared to traditional solutions, the costs associated with the construction or adaptation of the simulator's premises (including the actual physical equipment of the bridge) are eliminated or lowered. All elements of the premises will be generated in the virtual world giving the unlimited possibilities of adaptation and arrangement. Therefore, a related advantage of the proposed solution is the elimination of the need for a substantial amount of building space for different types of marine simulators.
2. The operation and maintenance costs of the simulator's equipment are incomparably lower. The probability of failure of electronic components and associated maintenance costs are also significantly reduced.
3. The application of the proposed solutions gives the opportunity to conduct simulation tasks using pre-defined virtual devices, customized to the officer's / operator's needs and habits.
4. The use of the most up-to-date solutions in the field of image projection eliminates the need to purchase and maintain expensive devices used for projection of synthetically generated scenarios. The use of such solutions in the simulation process gives unprecedented opportunities to observe the environment in full spherical space, with a field of view similar to the natural vision of the human eye. This degree of visual realism is technically impossible for conventional solutions.
5. The high mobility and open architecture of the completed prototype allows for the possibility of adapting it to most types of marine simulators. Introduction of the innovative technology for the tasks will expand the methodology of non-autonomous simulation methods.

New research methods

The practical use of the proposed solution allows for the introduction of innovative research methods on a global scale to two important non-autonomous marine environment simulation tests:

1. Biometric methods and techniques.
2. Eye tracking methods and techniques.

Analysis of human motion is one of the most important tasks of ergonomics and biomechanics. It is important to understand the biomechanics of the human body in order to create a virtual human-computer interface capable of simulating human movements. Creating a comfortable simulator requires the creation of a multi-virtual human model based on real anthropometric and goniometric parameters. The use of static analysis position based models open up the possibility of the widespread use of simulators and that fully exploit the potential of the human being as biomachine.

It is essential to carry out tests in order to obtain the data to describe the motor actions, structure and intentions of the officer / operator.

Due to the complicated mechanism of the human being, a simplified digital human model must be created to facilitate control. Using MoCap technology, it is possible to create a model that can be used as a bassline by other research teams.

An eye tracker gives the opportunity to register two types of eye movements:

1. The fixations that occur when visual information is obtained by a human being. Duration and location is measured in relation to the field of view.
2. Saccades, eye movements which are the fastest movements generated by the human body, can also be recorded. During saccades, the eye does not register any visual information, but merely moves from one point of fixation to another. Eye tracker technology allows the measurement of the length, duration, speed, and location of saccades movements.

The number and frequency of fixations and saccades in a particular area of the tested environment can also be measured. This information will allow the officer / operator to evaluate the search patterns used in acquiring and analysing information in the decision-making process. In turn, this information allows for assessment of the role of the human being in the process of navigation, and the impact of the ergonomic design of the bridge and the single interface on this process.

The analysis of the characteristics of fixations and saccades is a recognized indicator of stress, anxiety, exhaustion, and the difficulty of the task being performed. In this context, eye tracking data can be used as a measure the psychophysical condition of a person working under virtual reality conditions.

Taking into consideration the freedom to modify the simulation environment, including the amount and methods of information presented, eye tracker technology can be also used to examine the phenomenon of information overload. Information overload has been recently identified as one of the most important behavioral problems affecting performance.

In order assess information overload, it is necessary to incorporate eye tracking cameras into the HMD. This has been initially achieved by SensoMotoric Instruments (SMI), a manufacturer of eye tracking equipment. The integration of the SMI Eye Tracking Glasses with Oculus Rift DK1 was presented at the 2014 Augmented World Expo. Since this initial showing, SMI has offered their eye tracking glasses as an optional upgrade (Sensomotoric Instruments, 2014). In addition, the FOVE Corporation (Fove, 2015) has developed an innovative solution which incorporates eye tracking as an integral part of virtual reality HMD. Several research groups have showed that information about eye movement and eye location can be used in virtual stereoscopic environments to correct the geometry of generated objects (Jones, et al., 2015), and to reduce motion or simulator sickness of the subject (Stengel et al. 2015). The latter factor is especially important when considering a professional simulation environment, since simulator sickness is a common problem affecting HMD (Moss & Muth, 2011).

Conclusions

The use of AV methods in a multi-purpose interface for a ship's bridge prototype will create new opportunities and generate innovative approaches to the use of simulation methods in training and scientific research.

The use of proposed solutions in the training process will improve operations and expand the capabilities of current simulation methods in training by increasing the realism of the tasks performed by the officer/operator. This is especially important for effective training in ship maneuvering according to the International Law of Sea Routes and the requirements of international conventions of the IMO and STCW.

The option of adapting and modifying all virtual devices will provide unprecedented opportunities to modify the architecture of the bridge (connecting, disconnecting, modification, learning algorithms and validation of activities performed). Thanks to such methods, trainees will have the opportunity to broaden their knowledge of the operation and maintenance of ship devices, an impossibility on real consoles due to the cost of electronic devices. These new training methods and associated validation procedures will increased the effectiveness of staff training, using the most up-to-date and non-autonomous simulation methods.

Innovative solutions applied in the prototype will offer globally unique individual training methods. It will create a new possibility of adapting and arranging the layout of the devices in a simulated room, exactly as it is on the bridge of a ship, where a trainee can perform real-life tasks. This is not possible with commercial simulators built using traditional technologies.

The innovative functionalities of the prototype described above can be used in the design and setup of a ship's interior, as well as the field of nautical device ergonomics. The production stage of prototypes can be preceded by prototype testing using a virtual model of the exact shape, with the same software and location in the room. Modern simulation along with the interaction of the operator/officer, gives the opportunity to carry out research into the ergonomics of individual devices, and to integrate entire ship systems in the room, along with the possibility of simultaneous modifications. This eliminates the need to implement improvements on expensive real prototypes.

Integration of all systems gives the opportunity to register movement parameters of the officer/operator during ship operation. Such unique statistical data for maritime operations can be used to analyze the impact of the task on the behavior of the officer/operator. Currently no studies in this field have been conducted in Poland.

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