Concepts and Applications of Eye Tracking Technology in Maritime Shipboard Operation with Pilot Case Study

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Abstract: Despite advanced technologies on modern ships, accidents are nevertheless influenced by human factors [1]. Several key characteristics have been recognised as significant contributors to events, specifically fatigue, inadequate communication, inadequate maintenance practises, insufficient training, improper situation assessment, high mental workload, limited situational awareness, and high stress levels [2,3,4]. In order to investigate the risk analysis pertaining to human factors in marine accidents, it is essential to examine and assess variables that pose challenges in quantification within accident reports. These variables include mental workload and situational awareness. Eye-tracking technology has been widely utilised across several disciplines for a range of objectives. In a broad sense, eye-tracking technologies offer a method to collect a diverse range of eye movements that serve as indicators of various cognitive, emotional, and physiological states in humans, all in real-time. This technology can facilitate a more comprehensive comprehension of the human brain across a range of settings. Eye-tracking technology, an objective measurement, is a recently developed methodology within the marine industry. The present study offers a valuable chance to enhance comprehension of eye-tracking applications within the marine sector by conducting a pilot experiment in a bridge simulator. The pilot research findings and the subsequent analysis of ideas and applications of the eye tracker make a valuable contribution to the ongoing development and exploration of eye movement studies as an objective indicator in maritime operations.

1. Introduction

The significance of the human factor is crucial within industries characterised by high levels of risk, such as the maritime, aviation, and nuclear sectors. This is primarily due to the potential for human errors to result in severe consequences that endanger safety, the environment, and human lives [5]. These industries encompass complex and advanced systems, with human beings playing a crucial role in various capacities, such as operators, pilots, crew members, or engineers. Human variables may considerably influence the functioning and interaction of these systems, hence playing a crucial role in managing risks.

In maritime operations, accidents are commonly related to human error, which is often identified as the primary cause. Factors including fatigue, inadequate training, and breakdowns in communication are widely recognised as significant contributors to these incidents [3]. Similarly, within the aviation industry, pilot error frequently emerges as a significant contributing element in accidents. Similarly, in the context of nuclear power plants, human errors possess the potential to result in safety breaches and accidents with grave consequences. Hence, it is essential to consider the human element in risk management, including factors such as human behaviour, cognition, decision-making, communication, and training [6]. By comprehending and acknowledging the influence of human factors inside these industries, it is possible to reduce risks and improve safety measures.

Maritime operations rely significantly on human performance and decision-making; hence, understanding the various factors that impact crew members' behaviour during shipboard operations is crucial. Eye-tracking has emerged as a promising technique in studying human behaviour and cognition in recent years. Eye-tracking technology can provide valuable insights into crew members' visual attention, workload, and decision-making during shipboard operations. This technology allows researchers to identify possible safety hazards and chances for optimisation and get a better knowledge of human reactions [7].

This research aims to investigate the theoretical foundations and practical implementations of eye-tracking technology within the context of marine shipboard operations. A case study example is presented to demonstrate the potential of eye-tracking technology to enhance maritime safety and performance. First, the fundamental principles of eye tracking and its significance in maritime operations are investigated in depth. Next, different applications of eye tracking in the maritime industry, including training methods, apparatus design enhancements, and safety analysis activities, are examined in detail. In addition, a case study demonstrates how eye monitoring can be used to evaluate the performance of crew members during shipboard duties. This study examines the potential benefits of eye tracking in maritime operations, enhancing safety and efficiency. It also provides a comprehensive framework for future research in this discipline.

2. Eye Tracking Technology

The origins of eye-tracking technology stem from the "eye mind" concept proposed by Just and Carpenter in 1976. This hypothesis states that a direct link exists between where someone is looking and their concurrent thoughts. Eye tracking technology can record and analyze eye movements, transforming them into data streams. These data encompass various metrics, including pupil size, gaze direction, and specific fixation areas. Bojko and Tatler et al. assert that eye movements provide crucial insights into human behaviour due to two primary factors [7,8]. Initially, the locations that we opt to concentrate our attention on provide insights into our behavioural requirements for a particular moment.

2.1 The methodology behind the eye tracker's functioning.

Understanding the structure and function of the eye is crucial in capturing this phenomenon [9]. The photoreceptor cells in the retina, namely the rods and cones, are responsible for the absorption of light reaching the eye through the pupil. Subsequently, these cells transfer the visual information they capture to the brain. Cones facilitate the perception of high-resolution and colour vision, mainly concentrated inside the fovea region, which is characterised by its superior acuity. In addition to the fovea, the region of highest visual acuity, peripheral vision exhibits diminished clarity, necessitating ocular motion to acquire precise visual data [9]. Eye tracking commonly uses pupil-centre corneal reflection. Illuminators are used for capturing the pupil centre and corneal reflections [10]. Gaze calculation requires exact pupil locations and reflections. Given the possible difference between self-reported data and real-life activity, eye-tracking technology provides a reliable and unbiased way to examine gaze patterns [8].

2.2 Types of eye trackers

Researchers utilise various eye-tracking devices, such as wearable eye trackers and screen-based eye trackers. A screen-based eye tracker is most appropriate for the purpose of presenting stimuli on a monitor, projector, or TV screen within the context of an eye-tracking investigation. This particular eye tracker can be mounted in front of the display using a tripod, or alternatively, it may be secured to the lower portion of the display via a magnet. Nevertheless, due to its confinement of human behaviours within the screen, it is deemed unsuitable for examining naturalistic watching. In contrast, wearable eye-trackers enable participants to navigate their realistic surroundings without constraints, rendering them well-suited for capturing eye movements in authentic, real-world settings. Hence, the choice of a suitable eye tracker is contingent upon the research objectives. The development of mobile eye-tracking devices has facilitated the ability of researchers to capture eye movements during unregulated and authentic tasks. Technological progress has yielded valuable information on the correlation between visual perception and motor behaviour [11].

In a specific experimental study, the Tobii Glasses 3 facilitated the participants' engagement in a real-time bridge simulator. The participants were required to operate the simulator utilising realistic electrical navigation equipment, concurrently monitoring several screens, and physically moving inside the simulated environment. The Tobii Glasses eye tracker is a non-invasive video-based eye identification and monitoring device. It has a sampling rate of 50 Hz and a frame interval of 20 milliseconds. Based on the provided description, the Tobii 3 device is outfitted with eight Infrared illuminators, which serve the purpose of illuminating the eyes and assisting the eye-tracking sensors (Figure 1).

Figure 1. Tobii Glasses 3 (retrieved from https://www.tobii.com/products/eye-trackers/wearables/tobii-pro-glasses-3).

2.1 Types of eye movement

Researchers have employed numerous measures to investigate the phenomenon of eye tracking. However, ascertaining the most effective metre for assessing situational awareness, attention, and effort poses a considerable challenge. The interpretation of data is subject to variation depending on the task at hand and the researcher's perspective [11-17].

- Pupil size variation reflects changes in lighting, attention, and cognitive load. Pupil size measures workload, attention, and mental state in both lab and real-world settings [11]. Greater pupil diameter changes occur during visually demanding planning tasks versus verbal working memory tasks [12]. However, lighting changes also affect pupil size [13].

- Blink rate, or blinks per minute, indicates when data may be affected by blinking—blink rate and duration decrease during high visual workload, measuring mental workload [14,15]. Blink frequency drops during demanding prolonged tasks [16]. Air traffic control and flight simulations also show lower blink rates with higher visual demands [17].

- Fixation duration, the time viewing a point before moving the eyes, indicates interest in a stimulus [12]. Dwell time is similar but includes pre-fixation. It decreases with increased flight task demands [12]. After high cognitive load, prolonged blinks may occur until decisions are made [13].

- The fixation rate, or fixations per minute, reflects interest in a stimulus [14]. The saccade rate, the number of rapid eye movements per minute, drops as task difficulty or fatigue increases [15,16].

In summary, many metrics provide insight, but interpretation depends on the task and researcher. Awareness of these factors aids in utilizing eye-tracking data.

3. Eye tracker in Maritime Studies

The use of eye-tracking technology has the potential to provide significant contributions to the maritime industry. This technology enables the measurement of crew members' visual attention and perception throughout various activities, hence offering important insights [17-20]. The utilisation of this data has the potential to discern potential safety hazards and enhance the efficacy of training programmes and the design of equipment. Identifying and analysing key applications in determining the human reaction is crucial in understanding and studying this phenomenon. The assessment of attention and workload may be conducted by tracking eye movements, which enables the identification of locations that get the highest level of focus. This method also detects distractions and high workload instances [17]. The utilisation of eye response models has demonstrated the potential to accurately forecast mental effort in many jobs, including the management of naval engines. The identification of exhaustion can be facilitated by observing the occurrence of prolonged fixation and decreased blinking, as both behaviours are commonly associated with fatigue. The utilisation of real-time eye-tracking equipment enables the identification of fatigue symptoms in crew members [18]. Using eye tracking to measure attention and performance during training reveals specific areas that require development for enhancing the training [19]. It facilitates increased trainee involvement with the subject matter.Another study aims to improve equipment design by assessing visual attention patterns to bridge, cargo, and engine control room layouts and displays. The study identifies modifications in design to enhance performance and ensure safety [20].

In conclusion, eye-tracking technology in maritime operations offers a means of obtaining unbiased observations of human reactions to various jobs and activities. The primary advantages are improved safety measures, expanded training programmes, and optimisation of equipment design.

4. Pilot Case Study

Human factors and crew response plays a crucial role in mitigating maritime accidents. An experiment was undertaken in bridge simulators and eye-tracking technology to examine the behaviours of crew members and their eye movements in simulated emergencies. This facilitated the identification of potential consequences and the enhancement of safety practices. The participants were adequately informed, provided their consent, and completed training in accordance with the ethical requirements for the study. The experiment participants were informed about the study, and their compliance with the EU's General Data Protection Regulation (GDPR) was ensured.The scenarios were designed to be adaptable in order to elicit a range of responses. The calibration of eye tracking preceded the simulations. Areas of focus were established for critical bridge equipment. The first findings indicated that radar displays received the highest level of visual attention. Participants consented and were briefed on the experiment, including ethical considerations. They were trained on operating the bridge equipment and eye tracker. Simulations began with participants alone on the bridge. Before starting, participants received scenario instructions and training. Eye tracker calibration and synchronization preceded the simulations. The 20-minute scenarios had a 3-minute baseline before introducing targets, whose timing depended on reactions. Scenarios were flexible to elicit varied responses. Areas of interest (AOIs) were defined on critical bridge equipment for quantitative eye-tracking analysis. AOIs outlined features for calculating gaze metrics over time. This evaluated officers' overall visual patterns following good seamanship principles, Figure 2 illustrates the AOIs that represent critical equipment on the bridge.

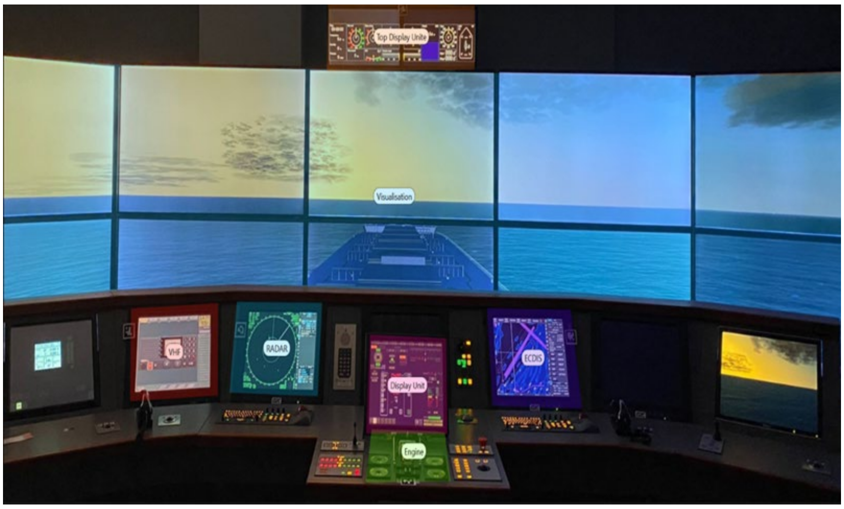

Figure 2. Areas of Interest (AOIs) in the bridge system.

In this particular context, mixed-methods user research was done utilising a bridge simulator and eye-tracking technology. A total of thirteen participants were engaged in the experimental procedures, and the outcomes obtained from these studies are displayed in Table 1. To analyse the metrics, the average pupil size, number of fixations, average time of fixation, number of saccades, average time of saccades, and number of blinks, a comparative approach will be employed within a hypothesis-driven framework. Statistical analyses will be carried out to examine the differences between the two groups. Hence, this study encompasses an initial assessment pertaining to the frequency of impacts on the bridge apparatus, namely the Areas of Interest (AOIs).

Table 1. Results of the eye tracker metrics

Characteristic	Pilot Experiment N = 13
Average pupil size	0.51
Number of fixation	2,470
Average time of fixation	1,663
Number of saccades	270
Average time of saccades	50
Number of blinks	96
Display unit	***157***
ECDIS	**130**
Engine	24
RADAR	**1,034**
Top Display unit	*27*
VHF	13
Visualisations	***415***

The number of hits for Areas of Interest (AOIs) on the bridge was normalized by scenario duration and averaged. The results of the simulator study indicated that participants directed their attention primarily to the radar equipment, followed by visual displays, and finally to the upper display unit.

5. Conclusion

Human factors play a crucial role in ensuring the safety and effectiveness of maritime operations. Integrating eye-tracking technology into maritime activities provides promise for gaining insight into seafarers' visual attention, perception, and mental workload. By implementing eye tracking, businesses can identify hazards, improve training and design, and boost overall performance and safety. To integrate eye tracking, choose a device that meets the requirements of the operation. Then, combine it with existing vessel monitoring systems to analyse seafarers' attention and workload in real-time. Additionally, eye tracking should be incorporated into training programmes to enhance efficiency and evaluate crew performance. Eye tracking provides valuable insights into seafarers' visual attention and mental workload, improving safety, training, and equipment design.

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