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EEG-based Mental Workload and Stress Recognition of Crew Members in Maritime Virtual Simulator: A Case Study

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***Abstract*— Many studies have shown that the majority of maritime accidents/incidents are attributed to human errors as the initiating cause. Efforts have been made to study human factors that can result in a safer maritime transportation. Among all techniques, Electroencephalogram (EEG) has the advantages such as high time resolution, possibility to continuously monitor brain states with high accuracy, recognition of human mental workload, emotion, stress, vigilance, etc. In this paper, we designed and carried out an experiment to collect the EEG signals to study stress and sharing of the mental workload among crew members during collaboration tasks performance on the ship's bridge virtual simulator. Four maritime trainees were monitored in the experiment. Each of them had a role such as an officer on watch, captain, pilot, or steersman. The results show that the captain had the highest stress and workload. However, the other three trainees experienced low workload and stress due to shared work and responsibility. The EEG is a promising evaluation tool to be used in the human factors study in the maritime domain.**

Keywords- EEG; human factors; neuroergonomics; maritime simulator; mental workload; stress; emotion; brain computer interfaces

I. INTRODUCTION

With the fast developing technology and innovation, maritime transportation is constantly advancing throughout the years to accommodate globalization and human needs, improving efficiency and productivity of the work flow while reducing the accident rate. Despite the continuous efforts to improve safety standards, accidents persist to happen [1].

Over the years, various methods and techniques have been established to address the issue of human factors and safety. Apart from the conventional way such as statistical analysis of accident data, biosignals can be considered to evaluate human factors. Electroencephalogram (EEG) has several advantages over other biosignals as the signal has high time-resolution and the adequate accuracy. Mental workload, emotion and stress of the maritime trainees can be monitored using EEG when they perform tasks in the simulators. Then, the cause and effect of human errors can be studied.

In this paper, we conducted an experiment with 4 maritime trainees forming the crew on the bridge in a ship's bridge virtual simulator. Each trainee had a role as an officer on watch, captain, pilot, or steersman in a navigation task performing. EEG signals of trainees were recorded. Workload, and stress levels of the trainees were recognized from the EEG signals. The results show that the workload and stress levels were shared among trainees as follows. Most of them had experienced low workload and stress except the trainee who acted as a captain.

The paper is structured as follows. Section II reviews the human factors in maritime domain. Section III describes the experiment. Section IV introduces the EEG-based brain recognition algorithms, and Section V presents the experiment results. Finally Section VI concludes the paper.

II. HUMAN FACTORS IN MARITIME

Human factors in maritime industry are considered to be one of the main contributing causes among accidents despite improvement of ship equipment and systems [2]. A study by the U.S. Coast Guard R&D Centre has shown that the human factors attributed to a bulk of maritime accidents from 75% to 96% [3]. There is a need to improve safety and reduce number of accidents. Thus, experiments have to be carried out to identify the types of human errors which are related to accidents.

The performance and routine of an individual person can be easily affected by one or many causes. In this paper, we aim to assess and evaluate emotion, workload, and stress during the tasks performance to study the impact on the crew performance that may help prevent future accidents caused by human factors.

A. *Workload*

The workload can be classified into physiological workload, cognitive workload and subjective workload. In our research, we refer to the term 'workload' as cognitive workload. Workload can be defined as the resources to process the needed information to complete the task [4]. Lack of manpower and sophistication of the automation onboard are among the reasons that would cause an increase in the ship's crew workload level. Moreover, studies have shown that the increasing of the workload levels have prompted several auxiliary impacts. For example, exhaustion and the lack of situational mindfulness, both of which have been appeared to be significant reasons for causing accidents at sea [5, 6]. In [7], it is stated that the advancement of automation on-board do not reduce the workload of the crew. Instead, overreliance on the automated systems has created more faults and errors to troubleshoot and hence gave a rise to more complicated problems. [8] supports this view by emphasizing on the consequences of being constantly exposed to high workload level. Undoubtedly, it may cause inter-links of factors such as high stress level, low situational awareness, fatigue, over-reliance on automation and other issues that can be disastrous in maritime operations.

B. *Stress*

Stress, as often discussed by academics and scholars, also has various definitions. It is being brought up that stress correlates itself as a mental conscious and emotion within a person that exceeds the achievable capability [9].

Studies have shown that individuals working on the maritime business faces a higher level of stress as of compared to those normal working individual population inland [10]. Such higher level of stress plays a crucial part in influencing the individual performance and decision making. In [11, 12], a study was done where experiment with maritime students was carried out to prove that bad decisions and mistakes was indirectly caused by the high stress. Further studies have discovered the correlation pertaining to individual performances, stress and related mental workload. These factors have shown that higher stress level contributes to anxiety and may be the underlying factor of bad decisions and decline in the work output and results, provoking a decline in expectations and performances [13]. As different individuals react differently towards stress level, certain people have higher and/or lower stress acceptance level, and thus, the level of stress may vary accordingly.

C. *Traditional Methodologies in Maritime Human Factors Study*

Many studies were conducted by analysing available reports and databases. These databases are usually a joint effort from the marine organization and government safety department. The data of these case studies are often used to identify underlying common factors [14].

However, researchers face a major challenge as there is no standardized system to classify the type of accidents. Accidents are usually happened due to multiple factors, and it could be difficult to categorize them in order to have a better comparison of the result and meaningful insight. One of the major problems to be overcome is to identify the common factors of human errors. The underlying human factors can be from the interaction between environment, people and technology. The preliminary findings have shown that human errors can be due to poor performance or lack of situational awareness as a whole. Therefore, the complex result about the possible factors could be insignificant to identify the actual error [8, 14].

D. *Bio-signal based Methodologies in Maritime Human Factors Study*

To overcome the problems encountered by traditional methods in human factors study, different types of bio-signals can be considered to be applied in this area.

1) Electrodermal activity: electrodermal activity measures how much changes in skin conductance happened during non-invasive observation [15]. Usually, a low constant voltage is being applied, and the skin's reaction in perspiration is observed. Sweat production is associated with the amount of stress that an individual encounters when it is given a task with the expectation to fulfil it within the given time frame or up to a certain mark of expectation. The higher the workload and stress, the more amount of perspiration is expected to be produced.

2) Electrocardiography: The electrocardiography is a method where it records the electric motion of the heart over a certain fixed period using electrodes which are placed on the human. The electrodes serve to detect minuscule electrical differences on the skin that comes within the heart muscle thumping during each heartbeat. The heartbeat of the human during some conditions is associated with the level of stress they experience at that moment [16].

3) Electroencephalography: Electroencephalography (EEG) is an electrophysiological observing method that reflects the electrical activity within the human brain. This method is noninvasive and using the same technology as the ECG but the electrodes are placed on the scalp. In addition, high precision of time measurement can be obtained by using the EEG device with higher sampling rate. The EEG mainly concentrates on reading the neuron undulations, commonly known as "brain waves".

In our work, we monitor the workload and stress level of the maritime trainee using EEG signal. The aim of our research is to study the relationship between the trainees' workload and stress level, and the maritime tasks performance.

III. EXPERIMENT

We carried out an experiment using EEG tools to study the relationship between maritime trainees' mental workload and stress levels, and their task performance when they had different roles on the bridge.

A. Simulator

The experiments were conducted within SMA's Integrated Simulation Centre (ISC), which houses five full mission ship's bridge simulators. Each simulator contains high-tech equipment such as True Motion radar, Automatic Radar Plotting Aid (ARPA), navigation controls, and electronic navigational aids display (Fig. 1). A 180-degree field of view is provided by large-screen monitors, simulating a highly realistic environment.

Figure 1. Simulator at SMA.

B. Subject

The experiment was carried out with 4 maritime trainees in the same simulator. Each of them took up a different role to simulate actual bridge watch-keeping duties.

Their respective roles are as follows:

Trainee 1 - Officer On Watch (OOW)

Trainee 2 - Steersman

Trainee 3 - Captain

Trainee 4 - Pilot

The OOW was assigned with the duties of watch keeping and navigation on the ship's bridge. He was also the representative of the ship's master and had the total responsibility of safe and smooth navigation of the ship. Steersman was the one who steered the ship. Captain was in charge of the safe navigation of the ship while giving instructions to the rest of the crew. Meanwhile, pilot was the mariner who was experienced in the maneuvering of the vessel in a congested area or harbor and gave advices to the captain about navigation in that particular area. In Fig. 2, OOW, captain and pilot are navigating in the simulator during the experiment. EEG devices were mounted on their heads.

Figure 2. OOW, captain, and pilot in the simulator during the experiment.

C. Experiment Procedure

Before the start of the experiment, the subject was required to fill in an intake questionnaire. Next, the calibrations for subject-dependent emotion and workload recognition were done. To evoke different emotions, sound clips from IADS database [17] were used. For workload, the Stroop Colour word test was conducted in which it had 4 different workload levels in ascending order, each of the levels needs more mental effort than the previous one. The Emotiv [18] device was used to record the raw EEG data when the maritime trainees were exposed to the stimuli. The obtained EEG data were used to train the classifier as described in Section IV.

After calibration, the trainees were required to navigate the vessel in the simulator under scenarios that were determined by the captain at the control room. Details of the vessel type and destination of voyage were given prior to the start of the exercise.

The EEG data and video footage in the simulator were recorded in order to label the timelines of the EEG data with the corresponding significant events that happened during the navigation.

IV. EEG-based Brain States Monitoring

A. Emotion

In our previous work [19], we proposed a subject-dependent algorithm for emotion recognition. It uses the combination of the fractal dimension feature and statistical features as the input to train the Support Vector Machine (SVM) classifier. Once the classifier model is obtained, it can be used to identify the emotional state of the subject. All 14 channels are used in the algorithm, and the features are extracted using a sliding window of 4 seconds with 75% overlap. We showed in [19] that up to 8 emotions can be recognized with accuracy 69.53%.

In this work, 3 emotions including positive, neutral, and negative one are targeted. The emotion labels and the corresponding numerical number are presented in Table I.

TABLE I. Emotional States

Emotion Level	State
0	Positive
1	Neutral
2	Negative

B. Workload

Similar to emotion recognition, the combination of the FD and statistical features are extracted and SVM classifier is used. The algorithm was verified in [20] with an average accuracy of 80.09% for four levels of workload recognition.

In Table II, it shows that the values: 0, 1, 2 and 3 corresponds to no workload, minimal workload, moderate workload and high workload respectively.

TABLE II. Workload States

Workload Level	State
0	No
1	Minimal
2	Moderate
3	High

C. Stress

Stress has always being associated with one's emotional state and the workload level as it is directly or indirectly influenced by both of them. Significant correlation has been found in [21].

Following the algorithm proposed in work [21], we combine the recognized emotional state and workload state to get stress level, as shown in Table III.

TABLE III. STRESS STATES

Emotion Level	Workload Level	Stress Level	State
0	0	0	Low
1	0	0	Low
2	0	0.5	Medium Low
0	1	1	Moderate Low
1	1	1	Moderate Low
2	1	1.5	Medium
0	2	2	Medium High
1	2	2	Medium High
2	2	2.5	Moderate High
0	3	3	High
1	3	3	High
2	3	3.5	Very High

V. RESULTS

From the video footage, we observed that three significant events happened during the exercise: 1) at the 14 second, the pilot gave instructions to the captain and asked to reduce the engine speed. The ship was trying to navigate away from a stationary vessel. All trainees were alerted. 2) At the 847 second, OOW identified a nearby ro-ro vessel and cruise ship speed was identified as 6 knots. 3) At the 1106s, the trainees were discussing the voyage details. The emotion, workload, and stress recognized from EEG signals for these three events are described and discussed in this section.

A. EEG-based Emotion Recognition

1) Comparison of the emotional states of trainees for Event 1: At the start of the exercise, the trainees headed to their respective positions for duties. The traffic condition was congested, and high awareness was needed to manoeuvre the ship out of the area. The OOW, captain and pilot's emotional states were at level 1 which means a neutral state, and the steersman was in a positive state. The average emotional states for the first 33 second of the OOW, steersman, captain, and pilot were mostly neutral and positive. The details are listed in Table IV.

TABLE IV. EMOTAONAL STATES FOR EVENT 1

Event 1	Activity during the event	Emotion Level at 14s	Average Emotion Level (1- 33 second)
OOW	Maintain watch-keeping duty and report to the pilot.	1	1.03
Steersman	On the helms. Reduce speed of ship, navigate away from the stationary vessel.	0	0
Captain	Receiving instructions from the pilot	1	1
Pilot	Giving orders and direction to the captain and OOW.	1	0.57

2) Comparison of the emotional states of trainees for Event 2: At the 847s, the OOW identified the cruising speed of the nearby vessel. The emotional states of the crew members are similar to the states during Event 1 whereby only the steersman had emotion level of 0 which means positive state. The average emotion level also showed positive and neutral emotional state of all trainees throughout this event as shown in Table V.

TABLE V. EMOTAONAL STATES FOR EVENT 2

Event 2	Activity during the event	Emotion Level at 847s	Average Emotion Level (837-857 second)
OOW	OOW identified the nearby ro-ro vessel and cruise ship speed as 6 knots.	1	1
Steersman	On standby to navigate the ship.	0	0
Captain	Receiving instructions from the pilot.	1	1
Pilot	Giving orders and direction to the captain and OOW.	1	0.714

3) Comparison of the emotional states of trainees for Event 3: In this particular event, the pilot at the 1106s appeared to feel negative as he was giving out orders to overtake one of the vessels ahead safely (Table VI). The steersman emotion level still remained at 0 level, which means positive state throughout the whole event. The highest average emotion level was recorded at 1.035 for the OOW while the lowest average emotion level obtained was 0.035 for the steersman. The pilot and captain's average emotion level was recorded at 0.614 and 1 correspondingly, which means the positive and neutral state.

TABLE VI. EMOTAONAL STATES FOR EVENT 3

Event 3	Activity during the event	Emotion Level at 1106s	Average Emotion Level (1080- 1136 second)
OOW	Officer discussing the voyage details as they overtake one of the vessel along the route.	1	1.035
Steersman	On standby to navigate the ship.	0	0.035
Captain	Discussing the route with the pilot.	1	1
Pilot	Giving orders and direction to the captain and OOW.	2	0.614

4) Overall emotional state: The overall emotional state of the trainees for the entire exercise is shown in Fig. 3. The OOW had a neutral but slightly negative emotion at 1.08 while the steersman was mostly positive with overall emotion level at 0.11. It can be understood that the OOW was busy planning the route and maintained watch-keeping at all time which caused a slightly negative emotional state beyond the neutral state. The steersman generally had only one job to do being in charge of the steering, so he felt positive. For captain and pilot, the average emotion level was 1.01 and 0.63 respectively.

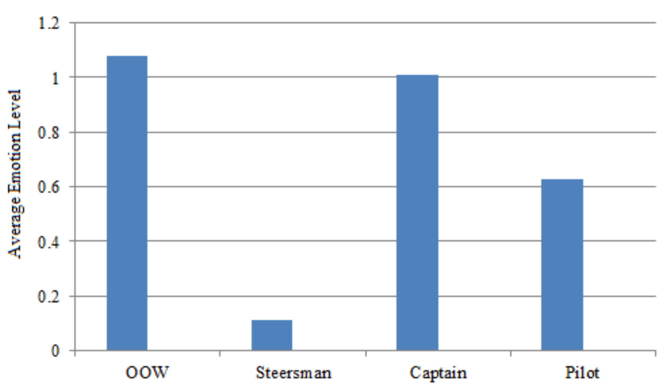

Figure 3. Overall emotional state for the entire exercise.

B. EEG-based Workload Recognition

1) Comparison of the workload levels of trainees for Event 1: High attention can be observed from the 2s after the exercise started. The captain and pilot had experienced the greatest degree of workload level while the steerman had 0 workload level throughout this event. The captain and pilot had a huge amount of responsibility to navigate the ship out of the congested area. Thus, the average workload level of the captain was the highest as 1.63, which was moderate workload level in contrast to the rest of the crew members who had minimal workload levels. The results are summarized in Table VII.

TABLE VII. WORKLOAD LEVEL FOR EVENT 1

Event 1	Activity during the event	Workload level at 14s	Average workload level (1- 33 second)
OOW	Maintain watch-keeping duty and report to the pilot.	0	0.27
Steersman	On the helms. Reduce speed of ship, navigate away from the stationary vessel.	0	0
Captain	Receiving instructions from the pilot	1	1.63
Pilot	Giving orders and direction to the captain and OOW.	0	0.50

2) Comparison of the workload levels of trainees for Event 2: The OOW reported the cruising speed of the nearby vessel to the pilot and captain after checking the navigation panel. From Table VIII, we can see that the workload level of the steersman and OOW appeared to be at 0 most of the time indicating that there is almost no workload for them. In contrary, the pilot and captain experienced moderate to high level of workload. At 847s, the captain workload level was 3, indicating that he was having a high workload level when receiving instructions from the captain-instructor by phone. Meanwhile we noticed that the workload level of pilot was only at high level from the 837s to the 850s when he was giving out orders. Thus, the average workload level of the pilot obtained was 1.286 which was at the low to moderate workload level while the captain had the highest average workload level at 2.571 among all trainees.

TABLE VIII. WORKLOAD LEVEL FOR EVENT 2

Event 2	Activity during the event	Workload level at 847s	Average workload level (837- 857 second)
OOW	OOW identified the nearby Ro-ro vessel and cruise ship speed as 6 knots.	0	0.048
Steersman	Standby to navigate the ship.	0	0
Captain	Receiving instructions from the pilot.	3	2.571
Pilot	Giving orders and direction to the captain and OOW.	0	1.286

3) Comparison of the workload levels of trainees for Event 3: At the 1106s, the OOW informed the captain and pilot about the route to be taken to navigate the vessel ahead. From Table IX, it can be seen that the workload level was 3 for OOW which could be due to high complexity information needed to ensure save voyage. The pilot was giving out advices to the captain after discussing the route to overtake the vessel. His average workload level remained minimal at 0.211. However, it is shown in Table IX that the captain had the highest workload level compared to the rest of the crew at this particular time frame. The average workload level of the captain was 1.404 which is around minimal to moderate workload level.

TABLE IX. WORKLOAD LEVEL FOR EVENT 3

Event 3	Activity during the event	Workload Level at 1106s	Average workload level (1080-1136 second)
OOW	Activity during the event	3	0.351
Steersman	Officer discussing the voyage details as they overtake one of the vessel along the route.	0	0
Captain	On standby to navigate the ship.	3	1.404
Pilot	Discussing the route with the pilot.	0	0.211

4) Overall workload levels of trainees: To summarize the workload levels experienced by the trainees, the average workload levels are calculated through the whole experiment session. During all three events the captain had the highest average workload for the whole experiment session which is 1.71 as shown in the Fig. 4. Meanwhile, the rest of the crew had low workload levels, namely 0.45 for OOW, 0.01 for steersman, and 0.82 for pilot.. The captain had the highest workload as he needed to give out orders to the crew and felt responsible for the ship. As expected, the steersman, who had the easiest work to do among others, experienced the lowest workload level.

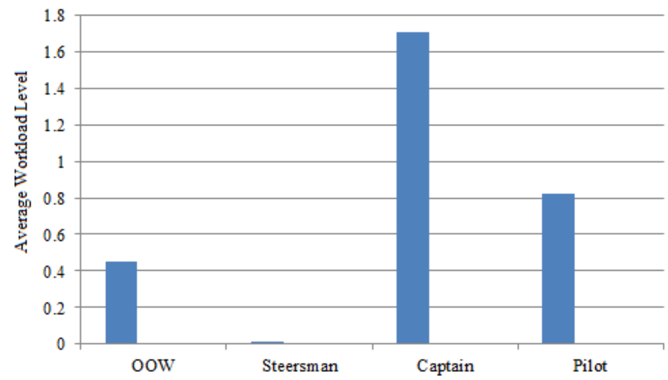

Figure 4. Overall workload level for the entire exercise.

C. EEG-based Stress Recognition

1) Comparison of the stress levels of trainees for Event 1: As given in Table X, the captain and pilot had the highest stress level while the steersman had 0 stress level throughout this event. The captain's average stress level was 1.63, which means low moderate stress level in contrast to the rest of the trainee who had low stress level.

TABLE X. STRESS LEVEL FOR EVENT 1

Event 1	Activity during the event	Stress Level at 14s	Average Stress Level (1- 33 second)
OOW	Maintain watch-keeping duty and report to the pilot.	0	0.28
Steersman	On the helms. Reduce speed of ship, navigate away from the	0	0

	stationary vessel.		
Captain	Receiving instructions from the pilot	1	1.63
Pilot	Giving orders and direction to the captain and OOW.	0	0.55

2) Comparison of the stress levels of trainees for Event 2: The results for Event 2 are presented in Table XI. It shows that the steersman and OOW had almost no stress throughout this event. At the 847s, the captain stress level was 3, indicating that he had high stress when receiving instructions from the captain - instructor. Meanwhile, it can be seen that the stress level of the pilot was only at high level from the 837s to 850s when he was giving out orders. The pilot average stress level obtained was 1.333 which means that he had the moderate stress while the captain had the highest average stress level at 2.571.

TABLE XI. STRESS LEVEL FOR EVENT 2

Event 2	**Activity during the event**	**Stress Level at 847s**	**Average Stress Level (837- 857 second)**
OOW	OOW identified the nearby Ro-ro vessel and cruise ship speed as 6 knots.	0	0.048
Steersman	On standby to navigate the ship.	0	0
Captain	Receiving instructions from the pilot.	3	2.571
Pilot	Giving orders and direction to the captain and OOW.	0	1.333

3) Comparison of the stress levels of trainees for Event 3: At the 1106s, the OOW and captain had high stress at level 3 as shown in Table XII. While the pilot was giving out advices to the captain to overtake the vessel, his average stress level remained minimal at 0.360. Same as OOW, the captain had the highest stress level as 3 at this particular time frame. By comparing the average stress levels, the captain had the highest stress level as 1.404 which means medium stress level.

TABLE XII. STRESS LEVEL FOR EVENT 3

Event 3	**Activity during the event**	**Stress Level at 1106s**	**Average Stress Level(1080-1136 second)**
OOW	Activity during the event	3	0.368
Steersman	Officer discussing the voyage details as they overtake one of the vessel along the route.	0	0
Captain	On standby to navigate the ship.	3	1.404
Pilot	Discussing the route with the pilot.	0	0.360

4) Overall stress level: The captain and pilot had the highest average stress during the whole session which was 1.097 and 0.918 respectively as shown in Fig. 5. Meanwhile, the rest of the crew had lower stress levels, namely 0.493 for OOW and 0.023 for steersman. The reason of higher stress is that the captain needed to give out orders to the crew at most of the time, and both the captain and pilot had higher responsibility. Among all trainees, the steersman had the lowest stress level at 0.023 as he just followed the orders.

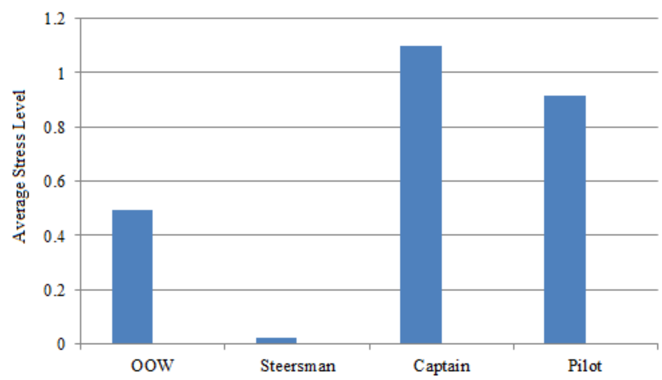

Figure 5. Overall stress state for the entire exercise.

D. Discussion

From the results presented in the above sections, we can conclude that the emotional state of all trainees were positive throughout the exercise except for the OOW who had a neutral emotion with slight negativity. The mean workload during the entire exercise was mostly at a low level as the trainees were doing the exercise together, and the workload was being shared. Among all trainees, the captain had the highest average workload and stress level as he held the greater responsibilities during the entire exercise. In contrast, the steersman showed the lowest workload and no stress which is consistent with the fact that his duties were the easiest among other crew members' jobs.

VI. Conclusion

In this paper, we presented a case study to investigate workload and stress of crew members during performing collaborative tasks on the bridge of virtual maritime simulator. We designed and carried out an experiment to collect the EEG signals to study stress and shared mental workload among crew members. The results show that the trainee who played the role of captain experienced the highest workload and stress levels compared with the others, while the steersman had the lowest workload and stress. This finding is consistent with fact of the complexity level of their roles. It also supports the use of the EEG signals in monitoring the brain states of the maritime trainees. In the next step of our project, the proposed experiment design will be implemented with real crews of maritime companies.

The proposed approach can be applied far beyond the maritime domain. The EEG-based human factors evaluation tools can be used for human-machine interaction assessment in automotive industry, air-traffic control systems, user interfaces, game industry, neuromarketing, etc.

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