HUMAN FACTOR STUDY FOR MARITIME SIMULATOR-BASED ASSESSMENT OF CADETS

Yisi Liu
Fruanhofer IDM@NTU,
Nanyang Technological University, Singapore
LIUYS@ntu.edu.sg

Xiyuan Hou
Fruanhofer IDM@NTU,
Nanyang Technological University, Singapore
HOUXY@ntu.edu.sg

Olga Sourina
Fruanhofer IDM@NTU,
Nanyang Technological University, Singapore
EOSourina@ntu.edu.sg

Dimitrios Konovessis
School of Mechanical and Aerospace Engineering,
Nanyang Technological University, Singapore
DKonovessis@ntu.edu.sg

Gopala Krishnan
Maritime Institute@Singapore Polytechnic, Singapore
GOPAL@sp.edu.sg

ABSTRACT

Maritime accident statistics show that the majority of accidents/incidents are attributed to human errors as the initiating cause. Some studies put this as high as 95% of all accidents (collision, grounding, fire, occupational accidents, etc). The traditional way to investigate human factors in maritime industry is the statistical analysis of accident data. Although this analysis can provide key findings, it cannot capture the causal relationship between performance shaping factors and human performance in the everyday routine work, and is not suitable to be used in the individual assessment of cadets.

To reveal the effects of human factors in maritime and assess the performance of cadets, a full-mission simulator is widely used. Different scenarios such as bad weather, day and night environment, different traffic load, etc. can be simulated. The fine details of the cadet performance can be recorded in the simulator during the assessment. As a result, other than performance failure, the near misses can also be detected. Additionally, a number of cadets can go through the same scenarios at the same time and between-subjects comparison is enabled.

Besides the operations recording provided by the simulator, biosignal-based tools can additionally help in the human factors study in maritime. The existing methods include palmer perspiration, electrocardiography, etc. However, the psychophysiological states that can be recognized by these methods are limited. Electroencephalogram (EEG) biosignals can be used to directly assess the "inner" mental states of subjects. Nowadays, since the EEG devices become portable, easy to setup, and affordable in price, EEG-based tools can be used to assess psychophysiological state of subjects. Using the sensors during performing the task we can recognize the cadet/captain's emotions, attentiveness/concentration, mental workload, and stress level in real time. In this work, we propose a real-time brain state recognition system using EEG biosignals to monitor mental workload and stress of cadets during simulator-based assessment. Currently, the proposed and implemented system includes stress and mental workload recognition algorithms. The EEG-based mental state monitoring can reflect the true "inner" feelings, stress level and workload of the cadets during the simulator-aided assessment. The time resolution is up to 0.03 second. As a result, we can analyze the recognized brain states and the corresponding performance and behavior recorded by the simulator to study how human factors affect the subject's performance. For example, we can check is there any correlation of the cadet's stress level and performance results. Finally, the proposed EEG-based system allows us to assess whether a cadet is ready to perform tasks on the bridge or needs more training in the simulator even if he/she navigated with few errors during the assessment.

INTRODUCTION

The majority of maritime accidents are usually attributed to human errors. Different studies indicate that from 80% to 95% of serious accidents and disasters at sea including collisions, groundings, fire/explosions, etc. are due to human failures (1). The most common causes mentioned are error of judgment, improper lookout or watchkeeping, and failure to comply with regulations. Constant exposure of crew to ship motion, noise, vibration, fumes, lighting and temperature composes a potential environment for human performance failure, which evidently leads to errors in navigation, ship maintenance, etc.

Marine officers need to carry out different cognitive tasks during signal selection, situation recognition and make general judgment during ship operation. For example, the recognition of ships approaching to their own ship by radars or by naked eyes needs perceptual ability. The determination of the scale of the heading of the bow to avoid collisions needs the decision-making ability (2). Electroencephalogram (EEG) signals can be used for human psychophysiological monitoring and for measuring such cognitive abilities. EEG-based tools can be used to select the suitable crew during recruitment or to evaluate cognitive performance of marine officers before they go on duty or during the duty. It is more reliable since it can recognize the internal mental activity of human. Different brain states such as emotions, attention, workload, stress levels can be identified and based on the recognition results, it is possible to give alarm to guarantee a safe sail. For example, in (3), EEG is used to detect the change of mental activity, stress level, and situation awareness level in the marine full mission simulator experiments.

In this paper, we considered the human cognitive states related to stress, and workload which could contribute to human performance failure. We propose tools to recognize mental workload and stress levels from EEG to monitor cadets during the simulator-based assessment. We design a simulator-based experiment to record EEG signals of cadets, recognize from EEG changes of their workload and stress during the task performance in the simulator and to analyze relationship between mental workload, stress and the task performance. Finally, EEG-enabled simulator-based system to assess cadet performance will be proposed. Different from the traditional human factors study such as survey or interview, the proposed EEG-based approach allows real-time crew members/captain brain state and performance monitoring during crew member/captain's assessment.

RELATED WORK

HUMAN FACTORS STUDY IN MARITIME

Human factors play an important role in maritime operations. Many researches in human factors on maritime operations involve statistical analysis of accident data by categorization of the causal factors, in depth analysis of specific accidents, analysis of work and safety cultures and focus group studies. Meanwhile, outside the maritime industry, researchers have also conducted experiments in simulated environments to further analyze the causes of human error.

Experimental work in the simulator. The advantage of the maritime simulator is that 1) the environment is fully controllable. Different scenarios can be given based on the needs of experiments. For example, weather and visibility can be adjusted to assess the performance of cadets under high workload; 2) every fine detail of the operation can be recorded, which enables the expert to analyze the behavior of cadets. It is also possible to record video, audio, or even biosignals in the simulator to get a deeper understanding of the effects of human factors in maritime work (4).

Case studies of maritime work. Case studies can provide us with information about what issues could possibly be observed on board due to human factors or other contributing factors. In case studies, the issues can be analyzed if we have the chance to observe them on board. However, there are also phenomena we may be overlooked or we haven't experienced them so far. We cannot get a general conclusion about how likely an observed phenomenon is, and it is also hard to study the quantitative relationships or correlations between different variables such as traffic density, human factors, etc (4).

Quasi-experimental study. As different variables such as weather and visibility have natural variation, this kind of study is considered as quasi-experimental. The work of the crew is observed, and correlation with their performance is studied. However, this kind of study is time-consuming as the natural variation may be observed over a extremely long period (4).

In our work, the simulator is used in the experiment to study the human factors in maritime, and we propose a simulator-based assessment of cadets using EEG as the tools. As a result, we can record all operations of the cadet and correlate these operations with the recognized brain states during the simulator-based assessment to have a deeper understanding of human factors effect in maritime.

BISOSIGNALS-BASED HUMAN FACTOR STUDY

Recently, biosignals were used in human factor study. In (5), the workload-induced stress is identified from the human voice. The voice is considered as an indicator of stress as it is directly related with respiration and heart activity via the blood. There are also other biosignals such as galvanic skin response, electrocardiogram, heart rate variability, electromyography, muscle tension, electroencephalographic activity, eye/eyelid movement, pupillary dilation, respiration analysis, and body fluid analysis which are related with workload (6, 7). In (5-7), it was shown that the biosignals can be used in human factors study in maritime research.

However, the psychophysiological states that can be recognized by these methods are limited. To directly assess the "inner" mental state of subjects, EEG (Electroencephalogram) biosignals can be used. Nowadays, the EEG devices become portable, easy to setup, and affordable in price, which makes it possible to assess psychophysiological state of subjects using EEG-based technology.

BRAIN STATE RECOGNITION

In this work, we implement a comprehensive brain state recognition system with mental workload and stress level recognition. With this system, we can monitor the brain states of cadets during the simulator-based assessment.

EEG DEVICE

The Emotiv device (8) is used to capture the users' EEG signals. The device is easy to set up and it is wireless. It has 14 channels locating at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 as shown in Fig. 1.

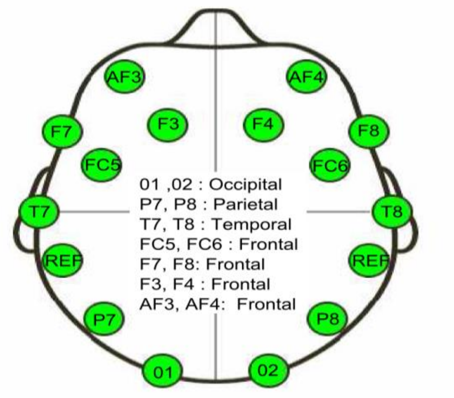

Fig. 1. Location of 14 electrodes of Emotiv EEG device.

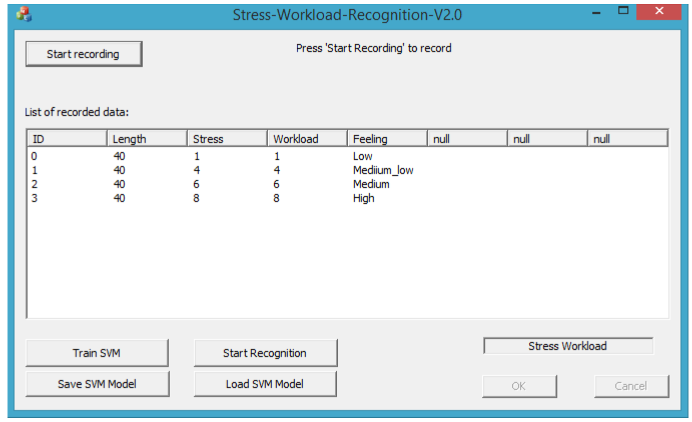

Fig. 2. Screenshot of the training interface.

MENTAL WORKLOAD AND STRESS RECOGNITION

The method proposed in our previous work (9) is used to recognize mental workload. The algorithm consists of two parts: feature extraction and classification. Fractal dimension (10) and statistical features (11) are combined as features, and Support Vector Machine (SVM) is employed as the classifier. All 14 channels from Emotiv device are used in the algorithm. The best accuracy is obtained as 90.39% for 2 levels of mental workload recognition and 80.09% for 4 levels of mental workload recognition.

To recognize stress levels, we apply an algorithm proposed in (12). By using the combination of fractal dimension and statistical features and applying the Support Vector Machine (SVM) classifier, four levels of stress can be recognized with the average accuracy of 67.07%.

Both workload and stress recognition algorithms are subject-dependent, thus a classifier needs to be trained before it can be used in real time.

A training programme is implemented. To induce different levels of workload and stress, the Stroop color-word stress test is used. The EEG data are recorded while the subject is doing the Stroop test, and the data are rated by the subjects after that. Screenshot of the training interface is shown in Fig. 2. When the “Start recording” button is pressed, the programme begins to record the EEG signals. After each Stroop color-word test and when the user is clicking on the “Stop recording” button another window is pop-up for the subject to rate his/her workload and stress levels during the test, ranging from 1 to 9, while 1 represents the lowest level and 9 indicates the highest level. The subject also needs to describe his/her experienced workload and stress level with the word such as high, low, or medium. Then this information about the recorded EEG data is shown in the training interface. For example, in Fig. 2, the first recording with ID 0 lasts for 40 seconds, the numeric rating for stress given by the subject is 1 and for workload is 1.

COGNIMETER

To monitor and visualize the recognized mental workload and stress level, a CogniMeter system is implemented.

The recognized mental workload is displayed on a meter as shown in Fig. 3. The pointer moves from left to right with the color changing from green, yellow to red. The color of the pointer indicates the workload level changing from low workload to high workload.

The recognized stress level is visualized on a meter as shown in Fig. 4. When the pointer is green, it means the recognized stress level is low or medium-low; when the pointer is yellow, it means the current stress level is medium; when the pointer is red, it means the recognized stress level is high.

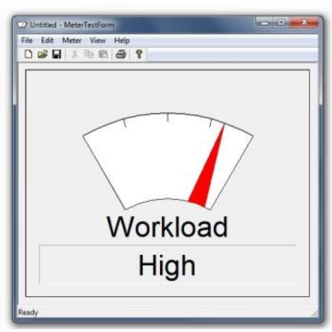

Fig. 3. The workload meter shows that the current worklaod level is high.

Fig. 4. The stress meter shows that the current stress level is medium-low.

A report is generated as a txt file (Fig. 5) to draw the conclusion on the subject's mental workload and stress level during performing the tasks. The report includes the date, exact time, length of the monitoring, and the percentage of different levels of workload and stress of the subject during the assessment. The bars plots visualizing workload and stress levels are generated as shown in Fig. 6.

```
------------- EEG Report -------------
Date & Time:       Mon Dec 08 13:38:47 2014


Workload:
-----Low:               70%
-----Medium_low:        20%
-----Medium:            8%
-----High:              2%

Stress:
-----Low:               52%
-----Medium_low:        27%
-----Medium:            14%
-----High:              7%
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Fig. 5. Summary of workload and stress levels during the monitoring.

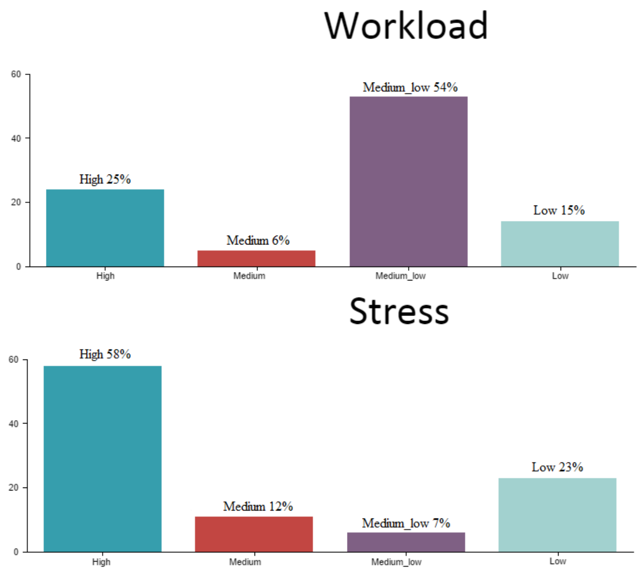


Fig. 6. Bar plot of the workload and stress levels.

EXPERIMENT DESIGN

We design an experiment to propose a system to assess whether a cadet is ready to perform tasks on the bridge or needs more training time in the simulator. The experiment uses the implemented CogniMeter system that allows recognize mental workload and stress levels. The experiment consists of two parts:

1) calibration, and

2) simulator-based assessment Exercise.

In the first part, a classifier needs to be trained as the EEG-based algorithms are subject-dependent. In the second part, the cadets work on the designed tasks in the simulator, and their EEG signals are recorded during the simulator-based assessment.

The details of the experiment are listed as follows.

Number of subjects: 8 subjects.

Number of Exercises: 4.

Length of each Exercise: 30 minutes.

Calibration. To train the classifier for workload and stress recognition, a Stroop color-word test (13) is used. To induce low workload/stress, the subject doesn't need to do anything and just maintain a relax status (Rest). To induce medium-low workload/stress, the word's meaning shown on the screen is the same with the word's font color (Congruent Section). To induce medium workload/stress, the word's meaning shown on the screen is not the same with the word's font color (Incongruent Section 1). To increase workload/stress to a higher level, the subject needs to react to the incongruent word within the limited time (Incongruent Section 2). The EEG data are recorded at the same time when the subjects perform the Stroop test, and the data are labeled with different levels of workload/stress by self-assessment rating of the subjects. The detailed procedure of the calibration is illustrated in Fig. 7. In the "Introduction" section, the subjects are briefly explained about the Stroop color-word test and get familiar with it. In the "Rest" section, the subjects are in the relaxed state, and the EEG is recorded. Then, the subjects perform the Stroop test with three sections as described above. The self assessment is done at the end of each section. The EEG data recorded in each section are labeled using the numerical score given by the subject. In Fig. 8 and Fig. 9, the questionnaire to rate correspondingly mental workload and stress level are shown.

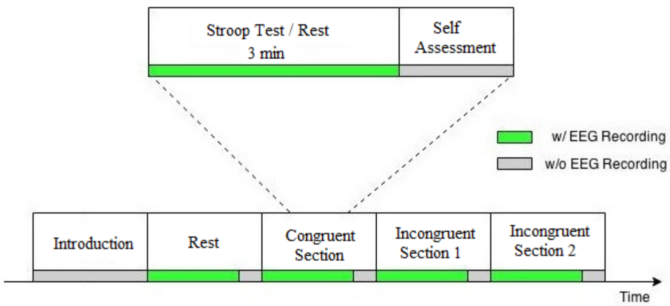
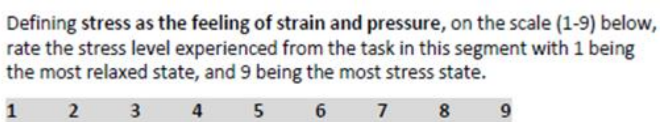


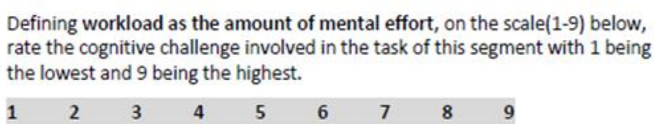
Fig. 7. The procedure of the calibration.

The labeled EEG data are fed into the classifier, and the trained model is used to identify the mental workload and stress levels during the simulator-based assessment.


Defining **stress as the feeling of strain and pressure,** on the scale (1-9) below, rate the stress level experienced from the task in this segment with 1 being the most relaxed state, and 9 being the most stress state.

1	2	3	4	5	6	7	8	9

Fig. 8. Rating of workload.


Defining **workload as the amount of mental effort,** on the scale(1-9) below, rate the cognitive challenge involved in the task of this segment with 1 being the lowest and 9 being the highest.

1	2	3	4	5	6	7	8	9

Fig. 9. Rating of stress.

Simulator-based Assessment. During each Exercise the stress is continuously increased by adding more difficult tasks using different scenarios in the simulator. The difficulty level is increasing from the first to the forth Exercise. We assume the stress level of cadet keeps increasing from one exercise to another as well.

Based on the cadet's stress and mental workload levels and their performance during the simulator-based assessment, the subjects are graded into 3 classes: excellent, more training needed, and failed.

The procedure of each Exercise is illustrated in Fig. 10. At the beginning of each experimental session, the subject experiences the normal cruise in the simulator. An internal failure of the equipment appears when the time reaches 5 minutes. A weather influence (visibility, wind, etc) appears when the time reaches 15 minutes. The combination of both weather and failure of equipment occurs at 25 minutes. During the whole 30 minutes, the EEG of the subject is recorded.

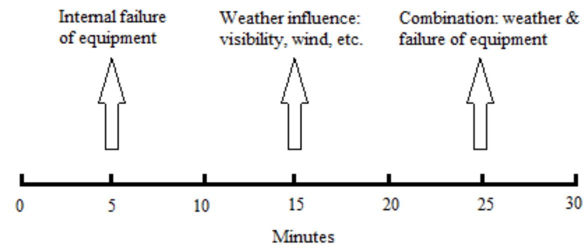


Fig. 10. The procedure of the simulator-based Exercise.

The ground truth of the subject's performance in the exercises is the subject assessment by experienced experts. The rating given by the subjects during the calibration part is used as ground truth of workload and stress level of the subject.

The experiment environment of the EEG-based cadet assessment in the simulator is shown in Fig. 11. As the EEG device mounted on the head is wireless, the cadet can move freely in the simulator room without additional disturbance. The brain states can be monitored in real time and recorded for further analysis and comparison between different cadets.

Fig. 11. The EEG-based human factors study experiment.

CONCLUSION

In this work, we introduce an EEG-based human factors study system for simulator-based assessment of cadets. The brain states such as workload and stress are monitored in real time. The proposed system can help the assessor to get deeper understanding of the performance of cadets. We also design a novel EEG-based human factors study experiment in maritime simulator to improve assessment of cadets with the proposed EEG-based system. In the next step, we plan to analyze the experimental data and reveal the relationship between the mental workload, stress and the performance of cadets.

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