Emotional State Evaluation during Collision Avoidance Operations of Seafarers Using Ship Bridge Simulator and Wearable EEG

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***Abstract*—Seafarers' emotional states (e.g., pleasure, displeasure, excitement, and stress) has been proved as a critical factor that affects their performance during collision avoidance operations. The emotion can be quantified using an electroencephalogram (EEG) sensor to reflect its correlations with human performance. Given the advantages of wearable EEG (portable, wireless and high resolutions), it provides an effective method for non-intrusive emotion measurement. This study conducted experiments to measure the emotional states of the seafarers. Firstly, two encounter situations based on the ship bridge simulator were formulated for the test. During the experiments, the participants were required to wear an EEG that measures brain activity reflecting the emotional states of seafarers while operating using the ship bridge simulator. At the same time, the trajectories of vessel movement were recorded accordingly. Next, a bipolar dimensional emotion model consisting of valence (from displeasure to pleasure) and arousal (from relaxation to excitement) dimensions, was generated to identify seafarers' emotional states. Integrated with vessel trajectory data (such as rudder angle, ship speed, etc.), the correlation analysis was conducted to explore the patterns of seafarers' emotion during collision avoidance operations. The results show that the emotional states of seafarers varied in different ship encounter situations and were closely related to the vessel trajectory. Also, it demonstrated the applicability of wearable EEG technology in emotional state evaluations for seafarers.**

Keywords—maritime transportation; maritime safety, electroencephalogram; emotion; ship bridge simulator

I. INTRODUCTION

With the development of world economy and increasing global trade in recent years, there is a growing demand for the shipping. However, such increasing demand exposes quite a few maritime risks in the shipping, including human errors, vessel failure, and environmental factors. According to the 2017 annual report on marine casualties and incidents published by the European Maritime Safety Agency, 71% of the accidents were caused by human errors, with navigation environmental factors accounting for 19%, and vessel failure for 5%. Although there were a few accidents caused by bad weather or mechanical failure with the statistical analysis, the majority of them were associated with human factors [1]. Therefore, human factors are one of the dominant factors affecting the safety of ship navigation. The emotional changes of the seafarer during the navigation will affect their work efficiency and job satisfaction, thus affecting the human performance during the navigation.

Due to the important role of seafarers in daily duty and ship maneuvering during the navigation, their emotional states (e.g., pleasure, displeasure, excitement, and relaxation) which influence human performances cannot be ignored. The emotion states of seafarers will have impacts on (1) cognitive status (e.g., attention and motivation), (2) decision making and behaviors (e.g., risk-taking behaviors affecting unsafe actions), and (3) mental and physical health (e.g., stress, sleep disorder, and headache) [2]. Therefore, emotional states generating negative impacts on before-mentioned aspects will affect the seafarers' operation and reflect on vessels dynamic trajectories.

The emotion of seafarers is a critical factor for the navigation safety, however, there is rarely research on the emotional evaluation during collision avoidance operations in maritime transportation. Because of the emotional states of human are hard to be measured and quantified, which makes it difficult to be analyzed with other behavior data. Although several psychological methods have been widely applied to measure the emotions, most of them collected data based on the questionnaire survey, which only reflected subjective feelings by answering the questionnaire. During the process, it distracted the attention of participants from manoeuvring missions, which introduced irrelevant interference. Therefore, aforementioned method is not applicable for the emotional evaluation of seafarers when operating the ships.

To measure the emotion with effective technologies, some researchers have attempted to measure human emotions utilizing physiological responses (e.g., electrochemical activity (EDA), heart rate (HR), and electroencephalogram (EEG) to study the correlations with physiological activities.

Among them, EEG which measures brain waves signals, has advantages in measuring emotions compared with other sensors. EEG directly detects brain waves from the central nervous system activities (i.e., brain activities), whereas other responses (e.g., EDA and HR) are originated from peripheral nervous system activities [3]. To be specific, the emotion can be described within several dimensions. The central nervous system activities are associated with two dimensions of the emotion, e.g., valence (from displeasure to pleasure), and arousal (from relaxation to excitement), while the peripheral nervous system activities are associated with arousal and relaxation. With regards to comprehensive measurement, EEG is selected to evaluate the emotional states of seafarers during maritime operations.

II. Literature Review

In the maritime field, about 75-96% of marine accidents are caused by human errors [5]. Human errors is usually caused by a variety of reasons, including mis-operations, inattention, fatigue, organizational factors and so on [6-8]. Statistics show that nearly 62% of marine pollution and accidents are related to human errors [9]. Among them, 30% of deck officer's mistakes, 7% of shore based officer's mistakes, 2% of engine room officer's mistakes, and 8% of pilot's mistakes. Compared to shore based workers, seafarers have higher probability to be involved in accidents during navigation.

Traditional research on human factors is usually based on the maritime accident investigation. This type of investigation has advantages in obtaining statistical characteristics, identifying the in-depth causation of the accidents. However, when the amount of data is not small, and each accident report contains limited information depth, it is difficult to quantify some human factors in detail. Moreover, such approaches cannot reflect personnel's psychological and physiological factors and lack of real-time data sources. Therefore, more experimental methods and data are necessary to support the reliability of the research. For example, Hou and Lan [10-11] used the vessel handling simulator, combined with brain functional imaging techniques to carry out experiments on a vessel driving emotion recognition. The study indicated its feasibility in performing research on navigation safety impact. Combined with marine Hydro-meteorological Information, driving behavior simulation, complex scenes and extreme weather simulation construction, we can use advanced sensors to monitor and collect personnel's psychological data and behavior data. It is a trend to study the human factors affecting maritime safety. Brain functional imaging technologies, such as EEG and functional near-infrared spectroscopy (fNIRS), have been widely applied in clinical, neuroscience and other fields. They have also been applied to the research of human cognitive load in road traffic and aviation fields. Therefore, it provides an effective tool and observation index for the study of maritime human factors, and also has potentials in the research of human errors of seafarers. The vessel watch-keeping environment has the characteristics of narrow working space and insufficient information sources, which are easy to cause destructive emotions of the crew, which is mainly manifested in irritability, tension, instability, depression and burnout, and presents periodic changes. A multi-dimensional model can put abstract emotions in a multi-dimensional space for quantitative expression of emotions that cannot be expressed by specific language. According to the three-dimensional theory of emotion [13], it can be measured in three dimensions: pleasant, relaxed excited and tense. Each emotion is in different positions between the two poles of the three dimensions. The two-dimensional classification model can describe emotion from the two-dimensional coordinate system. The ordinate represents the excitement degree of the state, which gradually transits from depression to excitement. The abscissa represents the pleasure degree of mood, which gradually transits from never like to like. The description of emotion lays a foundation for the study of emotional behavior mechanism.

Emotional analysis and recognition of vessel pilots are an important interdisciplinary field among transportation engineering, psychology, cognitive science, neuroscience and artificial intelligence. There is no quantitative research on the influence of emotional problems of seafarers' operational behavior and human errors. It is of significance to improve the behavior of seafarers and to reduce human errors, and investigates the relationship between their emotions and human factors.

III. Collision Avoidance Decision and Emotion Analysis

A. Ship Bridge Simulator and EEG Data

1) Ship bridge simulator

In order to improve navigation safety and the life safety of the crew, the crew needs to carry out vessel handling training in a safe environment, especially for the ability of the vessel pilot. The vessel simulator can be utilized to study the berthing and disembarking scheme of vessels, the tracking recovery after the collision avoidance operations, and the safety guarantee of navigation in crowded waters. Ship bridge simulator can interact with the system simply through the human-computer interface, the operators and the system, which are generally recognized in terms of reliability and system stability. Vessel simulator system and equipment are also used in various levels of crew training, which can meet the requirements of training flexibility. In the research of vessel mooring safety, the simulator can ensure that the test results are consistent with the real situations and reduce the cost and optimize the mooring scheme.

Fig.1. Ship bridge simulator

In this study, the vessel collision avoidance operation simulation experiment is carried out in the large ship bridge simulator in Wuhan University of technology, as showed in Fig. 1. The facility uses the TRANSAS system. The main functions include (1) Group cooperation and vessel safety navigation simulations; (2) Hydrological and meteorological characteristics and object landscape simulation of ports and waterways; (3) Pilotage and maneuvering of vessels in ports, narrow channels, inland rivers and open sea areas; (4) Bridge resource management with maritime search and rescue training, vessel maneuverability research, port channel design demonstration and pilotage test, maritime accident analysis, etc. This study utilizes ship bridge simulator to design scenarios for collision avoidance, which is safe and efficient tool to evaluate emotions in the manoeuvring.

2) EEG data collection

With the penetration of interdisciplinary in the field of traffic safety, we can explore the driver's driving behavior by measuring the driver's brain activity. Although EEG signal is weak in the process of acquisition and interfered by other noise, it has good performance in time resolution. As a widely used non-interference brain imaging method, it has been applied in road transportation, aviation transportation, railway transportation and other fields to quantify the physiological changes of drivers and identify its relationship with driving behaviors. EEG brain wave data extraction and analysis have a particular foundation in human emotion research, so it is selected as the main technology of vessel pilot emotion quantification in this study.

EEG is a fragile physiological signal, which is easily interfered by the external environment and blinking or facial muscle movement. EEG can also be interfered by the external environment and blinking or facial muscle movement. Therefore, it is necessary to preprocess the EEG data to eliminate the artifact noise. In this study, a 14-channel Emotiv mobile EEG head-mounted device, as showed in Fig. 2, is used to collect brain wave signals of test objects. It is a universal 14 channels (electrode) device with a sampling rate of 128Hz. It has the characteristics of viewing real-time data stream, frequency data, and this kind of brain wave instrument has been reprocessed while collecting the data.

Fig.2. 14-channel Emotiv EEG sensor

B. Experiment Design

1) Experiment objective

Referring to related researches in the field of traffic, quantitative data in the field of maritime safety can be collected by sensors such as EEG, ECG, EMG, blood volume pulse, skin electrical response and eye movement, which can be used for quantitative research on human factors of seafarers. Research methods of driver emotion mainly include the social support rating scale. Eysenck Personality Questionnaire, symptom Checklist-90 and so on. In road traffic safety, experts have pointed out that some driving behavior patterns, such as positive driving and delayed reaction, may be affected by the strong emotions of drivers. For instance, it was evident that increasing driving speed and acceleration is associated with anger induced by emotional events. Anxiety and contempt have the same negative effect as anger, but the effect is weak. Panic can cause emergency braking and low speed driving. In addition, negative emotions change periodically and are related to irritability, tension, unstable emotions, depression and burnout. Although relevant research has been carried out in the field of road traffic safety, the relationship between seafarers' emotion and driving behavior has not been fully elaborated.

Therefore, the objective of this study is to identify the emotion of the vessel pilot through the combination of emotion theory, psychology and EEG, and it is of great significance for the safety of vessel driving and the identification of the direct causes of human errors and accidents.

2) Encounter situation formulation

In this study, each experiment is designed in advance, so the scene of each experiment is consistent. Each experiment lasted about 5-10 minutes, and several fixed events occurred in the scene. Collect experimental data and record corresponding fixed types of scene events, which are mainly divided into the following two types:

Two ship encounter situation:

Scenario 1: Tug 1 is downstream, and the main tug is crossing the Yangtze River. The two ships encounter each other at a wide waterway with good visibility.

Multi-ship encounter situation:

Scenario 2: Add tug 2 and go upstream, opposite tug 1. The main tugs leave the berth and cross the Yangtze River. They meet tug 1 and tug 2 in turning. They are sailing in a wide waterway with good visibility.

3) Emotion collection method

During the whole process of the experiment,participants wear the EEG sensor. EEG data from the participants are collecting at the sampling frequency of 128Hz. In the meantime, ship trajectories and the maneuvering parameters, including rudder angle and speed, are recorded by the simulator.

Fig.3. The participants in ship bridge simulator

EEG data of about 5-10 minutes were collected in each experiment. Fig. 4 presents a sample of 10 seconds from the 14 channels.

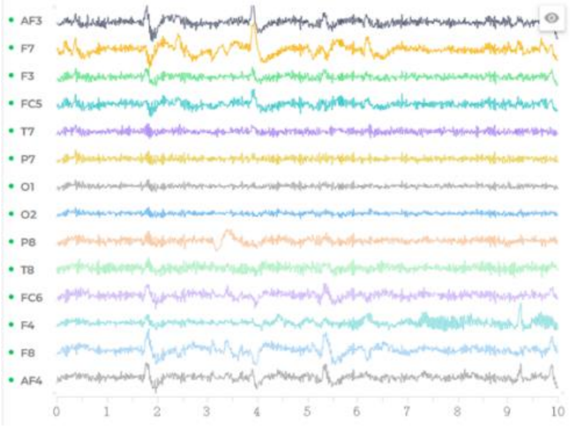


Fig.4. The raw EEG data

4) *EEG data analysis*

The power density spectra of δ wave, θ wave, α wave, β wave and γ wave are obtained by extracting EEG features. The δ wave (0.5Hz to 4Hz), θ wave (4Hz to 8Hz), α wave (8Hz to 13Hz), β wave (13Hz to 30Hz) and γ wave (30Hz to 60Hz) is related to different mental states. For instance, the δ frequency is predominant during deep sleep, and the θ frequency is related to states including drowsiness, creative inspiration, and meditation. The α frequency is linked to relax states, whereas the β frequency is predominant during the alert, active, and busy states or anxious thinking, and the γ frequency is related to high mental activity and information processing.

Due to the complexity of emotions, many researchers classified emotions from a multidimensional perspective. Specifically, a person's emotions can be classified based on a valence-arousal-dominance model (VAD), that is, from restlessness to pleasure, from arousal to excitement. It is generally accepted that the two-dimensional model valence and arousal is enough to classify most emotional states. Through the quantitative analysis of emotion, the model can also reflect the intensity of emotion.

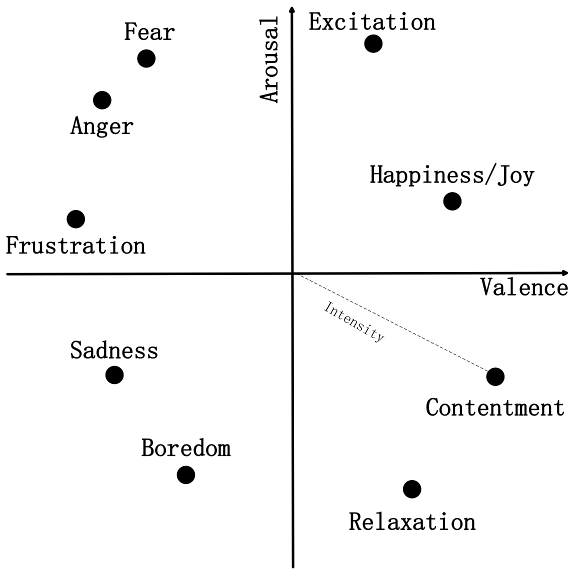


Fig.5. Two dimensional emotion model

The negative and positive emotions of the seafarers can be described in three dimensions: valence, arousal and dominance. Through the power density spectrum of the EEG and the following formula, it can quantitatively calculate the participants' pleasure and arousal emotional state as follows:

$$Valence = \frac{\alpha(F4)}{\beta(F4)} - \frac{\alpha(F3)}{\beta(F3)} \tag{1}$$

$$Arousal = \frac{\alpha(AF3 + AF4 + F3 + F4)}{\beta(AF3 + AF4 + F3 + F4)} \tag{2}$$

The power density of α wave and β wave can be directly measured by EEG. Then according to the VAD model emotional state of the crew can be determined.

In this study, in order to more clearly understand the change of emotional value,the emotions of vessel pilots are mainly divided into two categories: negative emotions and positive emotions. Here, emotional value = valence + arousal. The average value of emotion in a period of time is used to describe the emotional state. The average of emotion can be divided into two categories: (0, 1) negative emotion and (1, 2) positive emotion.

C. *Result Analysis*

1) *Analysis of emotion*

The correlation analysis is performed in this section between the emotional value of the vessel pilot based on EEG data and the collision avoidance operations. The two scenarios are shown in Fig. 6, by taking the trajectory of one of the participants as an example.

Scenario 1 can be divided into two stages, which were before and after the collision, respectively. The red section is the track before the collision, and the blue section is the track after the collision avoidance operations. Scenario 2 is divided into three stages, the red section is ready for the first encounter, the blue section is ready for the second encounter, and the green section is after the encounter. Through statistical calculation, the following shows the real-time relationship between the emotion of the vessel pilot based on EEG data before and after the vessel encounter.

Fig.6. Scene 1 vessel trajectory

Since the sampling frequency of the EEG is 128Hz, the average value of emotional value in every minute is selected to describe the emotional state. In the vessel encounter scenarios, the participants may have negative or positive emotions. In the same test, the participants may show two different emotional trends in the two vessel encounter situations. In scenario 1, the frequency of positive emotions before the encounter is significantly lower than that of negative emotions, and the frequency of positive emotions rises and exceeds that of negative emotions after the encounter. In the second scenario, the frequency of positive emotions is lower than that of negative emotions before the encounter. However, with the success of the first encounter, the frequency of positive emotions gradually increases and exceeds that of negative emotions after the second encounter. According to the tendencies of emotional values, although participant 1 had a relatively stable emotion in Scenario 1, the emotional value also decreased when preparing for the second encounter in Scenario 2, and it did not become stable until the second encounter was completed. In both scenarios, participant 2 showed a downward trend in the first encounter and an upward trend in the second encounter.

Fig.7. Vessel trajectories under scenario 2

It can be seen that the tendencies of the crew's emotion have a close relationship with the events generated by the ship bridge simulator, and different emotional changes can be produced by creating different experimental situations.

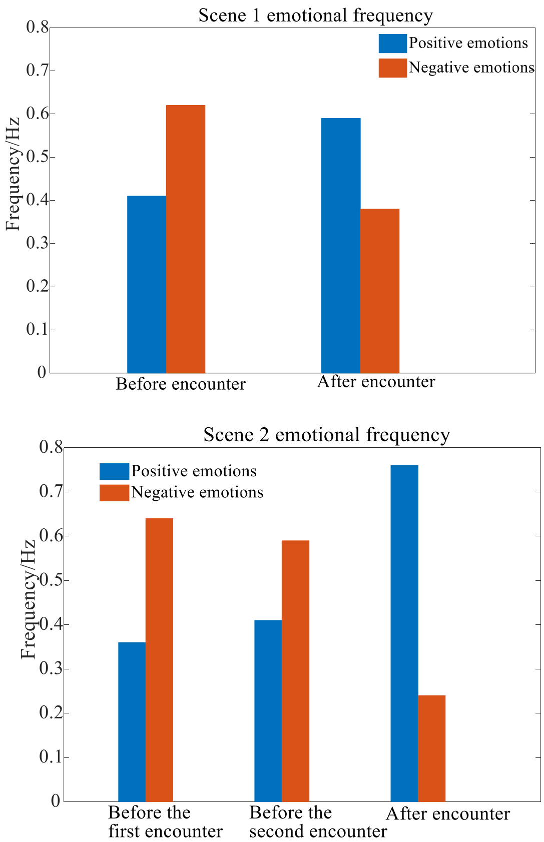


Fig.8. Distribution of emotion frequency

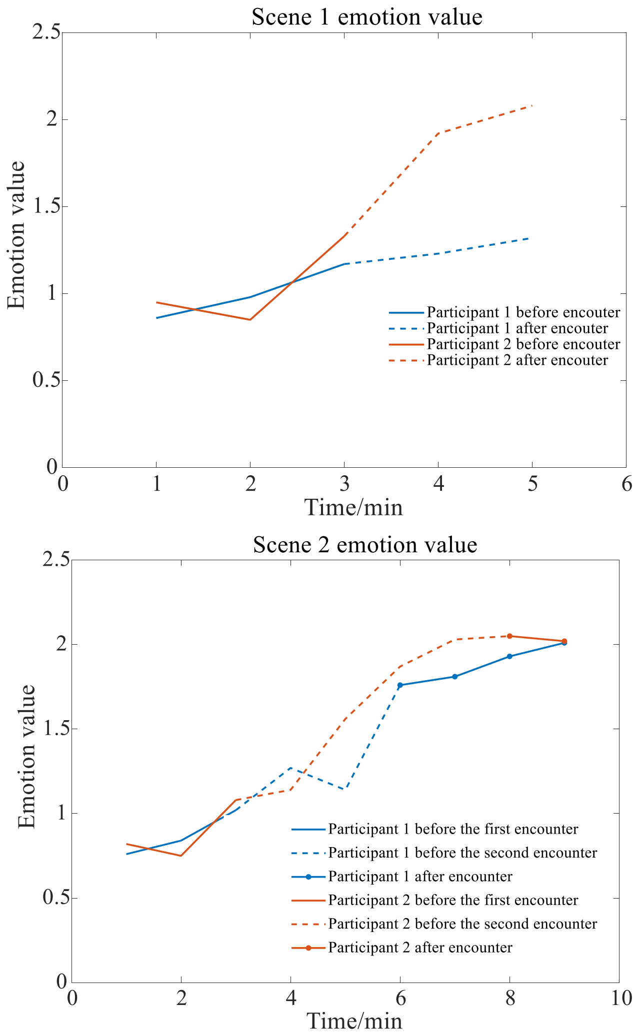


Fig.9. Change of emotional value

2) Analysis of crew's emotional and vessel's trajectory

Real-time emotional values calculated based on EEG data are also calibrated with the vessel trajectories. We compare and analyze the vessel trajectories from the two participants, as showed in Fig. 10.

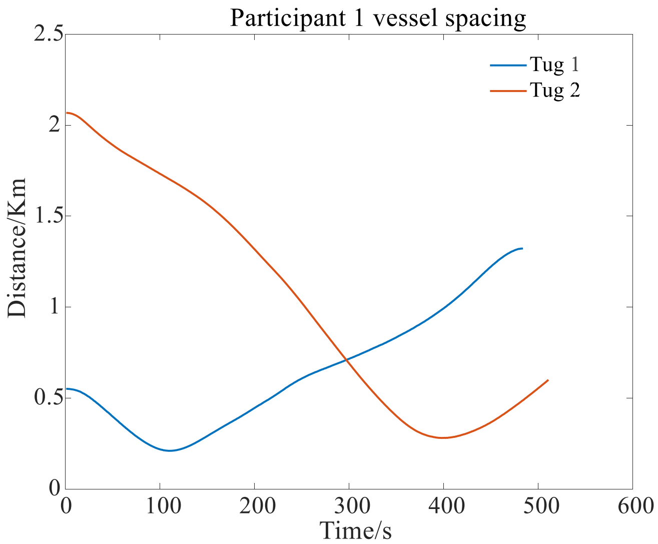
Fig.10. Trajectory comparison of Scenario 1

Among them, the blue trajectory is the track from participant 1, and red is the track of participant 2. Because Scenario 1 is relatively simple, the tracks of the two participants are similar. With respect to scenario 2, when two vessels encounters, after the first encounter, the two participants make completely different decisions. Participant 1 believes that there is a risk of collision when continuing to sail, and then decides to turn starboard to avoid collision with vessel 2, while participant 2 determines to keep straight sailing. As can be seen from Fig. 6, when participant 1 was preparing for the second encounter, although the emotional value rises as a whole, it fluctuated more apparent compared with participant 1, while participant 2 chose to continue sailing and successfully completed the boat encounter 2, and the emotional value continued to rise and the track was relatively stable.

Fig.11. Trajectory comparison in scenario 2

The distance between the vessel and the background vessel in scenario 2 is present in Fig. 12. Two participants select different routes after the first encounter. Participant 1's emotion fluctuated greatly when preparing for the second encounter. It took him only 400 seconds to complete the second encounter, nearly 100 seconds faster than participant 2. This means participant 1 is out of the wood earlier. Although the emotion of participant 2 has been relatively stable, but there is a high risk of collision.

Under these circumstances, the emotional state of seafarers reflects different patterns with regard to the ship trajectory. The fluctuation and change of seafarers' emotions during the navigation may affect their attention, judgment and decision-making, so as to be reflected in the vessel's trajectory.



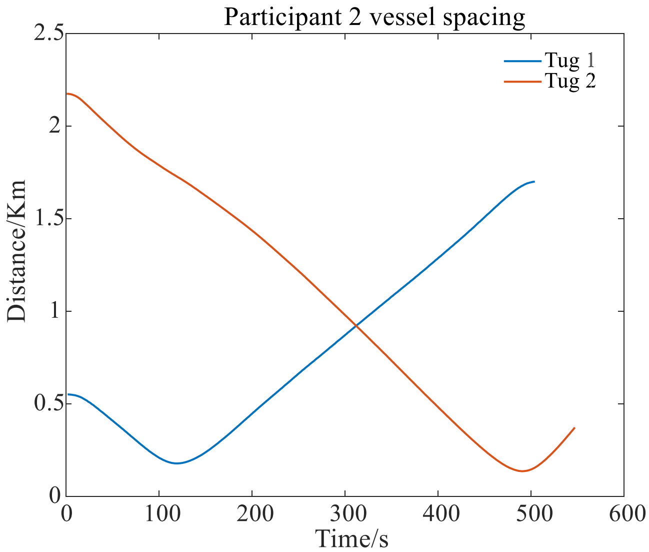


Fig.12. Distance between ships under scenario 2

3) *Correlation analysis*

Correlation analysis is a statistical analysis method mainly used to study the correlation between different parameters. This method can clarify the relationship between two or more random variables in the same position, and quantify the strength of the correlation through appropriate statistical indicators. Calculating the correlation coefficient is the most common method in correlation analysis. The commonly used correlation coefficients include Pearson correlation coefficient, Spearman rank correlation coefficient and Kendall π-correlation coefficient. Pearson correlation coefficient is mainly used to quantify the linear correlation of numerical variables, and its calculation method is as follows.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

In the above formula, *r* is the correlation coefficient in the range of [-1, 1]. N is the sample size, x_i and y_i is the variable value of two variables. In this experiment, Pearson correlation analysis is used to calculate the correlation coefficient between emotional value and vessel distance. Then it is divided according to the track segment, and the correlation coefficient of different track segments is further calculated. After comparison, the most relevant track segment with emotion is obtained.

Based on the Pearson correlation coefficient, the relationship between the emotional value and the driving behavior is discussed in the process of operation, focusing on the emotional value, the distance between ships and different experimental scenarios. It can be seen from table 1 and table 2 that during the normal operation period, there is a certain correlation between the emotional value of the pilot and the distance between the vessels. In scenario 1, the correlation before the vessel encounter(participant 1: 0.164, participant 2: 0.203)was higher than that after the encounter (participant 1: 0.132, participant 2: 0.157). In scenario 2, the two parameters have the highest correlation (participant 1: 0.351, participant 2: 0.458) when preparing for the second encounter. Thus, when the scenario is relatively complex, emotion has a higher impact on the vessel.

TABLE I. CORRELATION COEFFICIENT UNDER DIFFERENT TRAJECTORY SEGMENTS IN SCENARIO 1

Participant	Trajectory segment	Time (s)	Correlation coefficient (r)
1	Before encounter	153	0.164
1	After encounter	127	0.132
2	Before encounter	154	0.203
2	After encounter	152	0.157

TABLE II. CORRELATION COEFFICIENT UNDER DIFFERENT TRAJECTORY SEGMENTS IN SCENARIO 2

Participant	Trajectory segment	Time (*s*)	Correlation coefficient (*r*)
1	Before the first encounter	112	0.179
1	Before the second encounter	288	0.351
1	After encounter	113	0.208
2	Before the first encounter	119	0.304
2	Before the second encounter	374	0.458
2	After encounter	76	0.287

Ship collision avoidance operations are complex task, which requires the pilot to perceive, perceive, decision-making, responds and operates properly. Therefore, driving activities need the coordination of all aspects, and seafarers' emotions have a certain impact on the success of collision avoidance. However, due to the variety of emotional features and driving behavior features extraction, it is difficult to find the in-depth relationship between emotional value and operations, and more operational driving features such as heading and speed can be added accordingly.

IV. CONCLUSION

Based on the human factors of marine accidents, this study designed related experiments to quantitatively analyze the EEG data of pilots and explore the influence of emotion on vessel navigation. It is found that the emotion is closely related to encounter scenes and vessel trajectories. When the encounter is over, emotional value will rise, which will effectively promote the navigation. When the emotional value fluctuates, the pilot will carry out operations to avoid the collision, so as to save the encounter time of two ships and reduce collision risks.

In future research, more scenarios can be designed according to different hydrometeorological characteristics and more participants to study the impact of fatigue and workload on vessel running.

V. ACKNOWLEDGEMENTS

This work was supported by International S&T Cooperation Program of China (2019YFE0104600), National Natural Science Foundation of China (52071247), Technical Innovation Project of Jiangsu Province (2020Z02), Innovation and entrepreneurship team import project of Shaoguan city (201208176230693), European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie SAFEMODE (814961) and ENHANCE (823904).

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