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Fatigue Driving Detection and Early Warning System based on EEG Signals

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Abstract

The fatigue driving detection and warning system based on EEG signals aims to use EEG technology to monitor the mental state of drivers in real time, so as to identify and warn fatigue driving behavior in time, so as to improve road safety. The design of the system is based on a deep understanding of the connection between EEG signals and the fatigue state, by analyzing the changes in frequency bands such as α wave, β wave, θ wave and δ wave, which are closely related to the alert state and fatigue in humans. The development of the system first considers the main factors induced by fatigue, such as sleep deprivation, long work hours and environmental monotony, which can significantly affect the activity of brain waves. From these physiological and environmental factors, the system requirements analysis emphasizes the need for real-time data processing and high accuracy, as well as a user interface design that provides clear and intuitive feedback to users (drivers and regulators). In terms of implementation, the system integrates EEG monitoring equipment for data acquisition, uses advanced signal processing algorithm to extract fatigue-related features, and uses machine learning model for real-time analysis and fatigue state determination. In addition, the system design includes an emergency response mechanism, once signs of fatigue are detected, it can automatically trigger an alarm, issue a warning to the driver, and if necessary through the vehicle control system to ensure driving safety. This comprehensive system not only improves driving safety, but also provides strong data support for traffic management departments.

Keywords

EEG Signal; Datigue Driving Detection; Fatigue Driving Warning.

1. Introduction

1.1. Research Methods for Fatigue Driving Detection

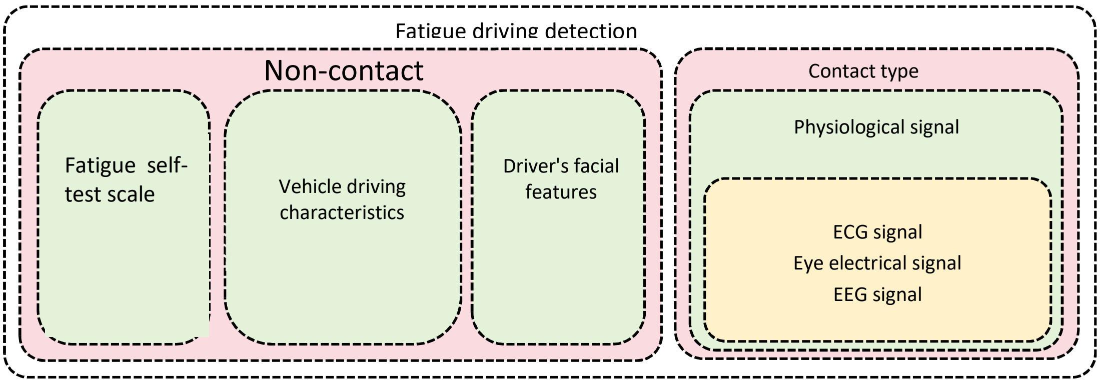

Figure 1. Classification of fatigue driving detection

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The classification of fatigue driving detection can be divided from different technical and methodological perspectives, as shown in Figure 1. It mainly includes the following four mainstream categories:

1.1.1. Test Method based on the Self-measuring Table of Fatigue Assessment:

The test method based on the fatigue assessment self-measurement meter is a simple and inexpensive fatigue driving test method. Their own fatigue can be assessed by asking drivers to fill in their fatigue assessment form. This method is suitable for preliminary screening or fatigue research field, which can help drivers to realize their fatigue level and take action accordingly.

However, relying on the subjective feelings of individuals can be influenced by the degree of individual honesty and self-perception. Some drivers exaggerate or underestimate their fatigue, affecting the accuracy of the assessment results. There are some limitations in objectivity, because this method cannot provide real-time and objective monitoring of fatigue status, but depends on the time point and the emotional state. In order to improve the accuracy and objectivity of the detection methods based on self-measurement tables for fatigue assessment, other detection methods, such as physiological signals or vehicle driving characteristics, can be considered for comprehensive evaluation. Training and education can also be provided to help drivers better understand the harm of fatigue driving, so as to improve their understanding and their ability to assess their own fatigue state[1].

1.1.2. Detection Method based on Driver Facial Features:

The detection method based on the driver's facial features is a very practical and effective fatigue driving detection technology. The camera captures the driver's face images and uses computer vision technology to analyze the facial features to determine the fatigue degree of the driver. The advantage of this method is that it is non-contact, causes no inconvenience to the driver, and is relatively easy to be accepted by the driver. It is more sensitive to ambient light and other visual occlusion, which affects the accuracy of detection. In cases of insufficient light or shelter, the algorithm is unable to accurately identify facial features. Individual differences and expression changes also affect the accuracy of detection. Different drivers have different facial features and expression habits. In order to overcome these limitations, a comprehensive analysis can be combined with other physiological signals or vehicle driving characteristics to improve the accuracy and reliability of fatigue driving detection. With the continuous development and progress of computer vision technology, it is believed that the detection methods based on the driver's facial features will become more accurate and reliable in the future[2].

1.1.3. Detection Method based on Vehicle Driving Characteristics:

The fatigue driving detection method based on the vehicle driving characteristics is a real-time monitoring method to determine whether the driver is in the fatigue state by analyzing the driving behavior and the vehicle dynamic characteristics. The main indicators of this method include steering wheel operation frequency, lane departure, acceleration and braking mode. The steering wheel operation frequency can reflect the degree of the driver controlling the vehicle. During fatigue driving, the driver may be slow or unstable, resulting in a change in the operation frequency of the steering wheel. Lane departure is whether a vehicle frequently deviates from the lane while driving. Fatigue driving causes the driver to pay less attention to the road, which increases the risk of the vehicle getting off the lane. The ation and braking mode can also reflect the driver's driving state. When driving with fatigue, the driver may accelerate or brake sharply, thus affecting the stability and safety of the vehicle. By analyzing the driving characteristics of these vehicles, the fatigue driving detection system can monitor the state of the driver in real time and issue an early warning in time to reduce the safety risks caused by fatigue driving. However, the performance of this method may be influenced by the driving

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environment and the condition of the vehicle, and thus it needs to be fully considered and evaluated in practical application[3].

1.1.4. Detection Method based on Physiological Signals:

The fatigue driving detection method based on physiological signals is an important and effective technical approach. By collecting the physiological signals such as ECG, electric eye and EEG during driving, and then analyzing these signals through the algorithm, the accurate identification of the driver fatigue state can be realized. The ECG signal is a common physiological signal that can reflect the heartbeat of the human body. Fatigue driving can cause heart rate changes, so monitoring the ECG signals can indirectly reflect the fatigue level of the driver. Eye electrical signal refers to the electrical activity signal of the eye, mainly reflecting eye movements and eyelid movements. Fatigue driving leads to changes in eye movement characteristics, such as decreased blink frequency and increased eye closure time, so that the monitoring of the fatigue state of the driver can be achieved by monitoring the eye electrical signals. EEG signals refer to the electrical activity signal of neurons in the cerebral cortex, which can reflect the working state of the brain. Fatigue driving leads to changes in the EEG signals, such as changes in spectral characteristics and abnormal waveforms, so the monitoring of the driver fatigue status can be achieved by monitoring the EEG signals. By collecting and analyzing these physiological signals, the fatigue driving detection system can realize accurate judgment of the driver's fatigue state and timely warning, so as to effectively reduce the safety risks caused by fatigue driving. However, since this approach requires direct contact with the driver, it may cause some driver discomfort, so attention is needed to balance the relationship between the monitoring effect and user experience[4].

1.2. Theoretical Overview of the EEG Signals

The brain is made up of the left and right hemispheres that are connected by transverse nerve fibres (mainly the corpus callosum), allowing information to be transmitted between the two hemispheres. The outer layer of each cerebral hemisphere is covered by gray matter, forming the so-called cerebral cortex, composed mainly of the cell bodies of nerve cells. The cerebral cortex is the outermost part of the brain, responsible for processing advanced brain functions, such as perception, thinking, and language, as well as advanced motor control. It is a key region for cognitive and emotional responses in humans, and is also involved in regulating the balance of the body with the external environment.

The surface of the cerebral cortex is separated by many sulci and subdivisions, as shown in Figure 2, which help divide the cerebral hemisphere into different parts, each with a unique function: the frontal lobe (Frontal lobe). Located in the anterior part of the brain, it is mainly responsible for executive function, decision-making, problem solving, control of speech and voluntary movements. Second, the parietal lobe (Parietal lobe). Located in the upper part of the brain, it mainly processes sensory information such as touch, stress, pain, as well as spatial positioning and navigation. Third, the occipital lobe (Occipital lobe). Located in the posterior part of the brain, is the center of visual processing responsible for receiving and interpreting visual information from the eye. The fourth is the temporal lobe (Temporal lobe). Located in the side of the brain, mainly involving the processing of auditory information, memory storage, and part of the language function[5].

Electroencephalogram (EEG, Electroencephalography) is a detection method that records the electrical activity of brain neurons by placing electrodes on the surface of the scalp. This technique can capture and record the potential changes generated by the synchronous firing of large numbers of neurons, providing a non-invasive means to study brain function.

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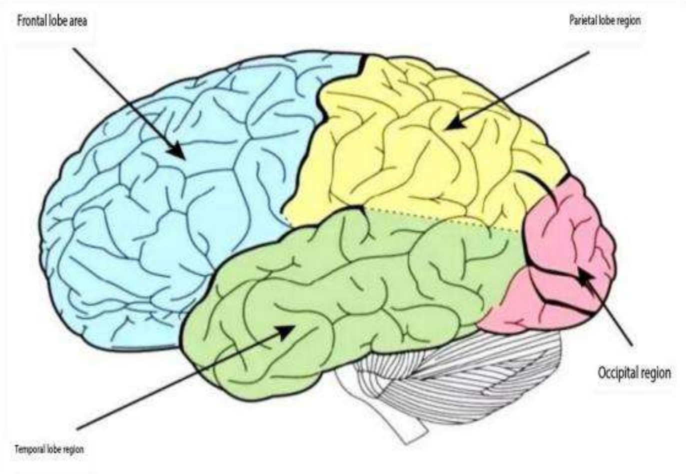

Figure 2. Distribution of brain regions

There are three properties of EEG signals. One is spontaneity. The EEG signal arises spontaneously and can be recorded without external stimuli. Second, non-stationary randomness. The statistical properties of EEG signals, such as the mean and variance, change with time, exhibit non-stationary properties[6]. The third is the nonlinearity. The electrical activity of the brain exhibits a high degree of nonlinearity, reflecting the complex and dynamic behavior of the neuronal networks[7]. EEG signals are often divided into several basic rhythms based on frequency, each related to different functional states of the brain. The frequency partition of the EEG is shown in Table 1.

Table 1. Frequency partition of the EEG

Rhythm	Frequency Range	Characteristic
δ -Wave (Delta wave)	The frequency range is approximately 0.5-4 Hz	Usually present during deep sleep
θ -Wave (Theta wave)	The frequency range is approximately 4 – 8 Hz	Associated with emotional responses, deep relaxation, and memory formation
α -Wave (Alpha wave)	The frequency range is approximately 8 – 13 Hz	Present in relaxed and eyes closed resting states, often associated with a relaxed arousal state
β -Wave (Beta wave)	The frequency range is approximately 13 – 30 Hz	Associated with states of vigilance, positive thinking, and concentration
γ -Wave (Gamma wave)	Frequency above 30 Hz	Associated with sensory processing, learning, and advanced information processing activities

1.3. Early Warning Overview of Fatigue Driving Detection

The early warning method of fatigue driving detection is to monitor and respond to the changes of alertness status, aiming to remind drivers to keep alert and ensure the driving safety[8]. Its specific early-warning methods include the following aspects: One is no intervention in good condition. When the system monitors that the high-speed rail driver is in good mental state, no intervention, the feedback of good mental state signal, and the white lights remain normal. Second, the red light reminds the lighting under the fatigue condition. When the system continuously detects the fatigue signal of the high-speed rail driver for more than 4 seconds, the driver is determined to be in a state of fatigue, and the lights in the cockpit turn to red lighting to remind the driver to pay attention[8]. The third is the treatment after the recovery of the fatigue state. If the fatigue signal is not detected within 6 seconds, the system determines that the driver's alertness state returns to normal, the red lighting turns to white normal, and the driver should keep attention at all times. Fourth, the fatigue state. If the fatigue signal is still

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detected within 6 seconds after the red light, the driver's mental state is very poor, the driving is dangerous, the lighting starts to flash, the system reports to the train dispatching console and notifies the crew to implement response measures. Five is the fatigue state of recovery but no longer driving[9]. If the awake state signal is detected within 6 seconds after the fatigue red lighting starts to flash, it indicates that the driver's attention has recovered, but should not continue to drive. The standby driver should be deployed to substitute driving, and the driver should be recorded and investigated[10].

Fatigue driving detection and early warning monitors the physiological state of the drivers, identifies the fatigue degree, and reminds the drivers through early warning measures, so as to effectively reduce the traffic accidents caused by fatigue driving and ensure driving safety[11].

2. Current Situation of Similar Research at Home and Abroad

Fatigue driving is one of the important causes of traffic accidents, which poses a serious threat to the life safety and traffic safety. Studies have shown that fatigue driving can affect the driver's attention, response speed and decision-making ability, increasing the risk of traffic accidents. Therefore, the research of fatigue driving detection and early warning system is particularly important.

In the United States, research work has started early and achieved remarkable results[12]. The US began exploring fatigue driving as early as the 1930s, but the real substantive research work began in the 1980s. Early research is mainly divided into two directions: one is to study the mechanism of fatigue, and the other is to warn of fatigue by detecting the fatigue degree of the human body. With the development of electronic application technology, the fatigue driving warning system has made great development[13].

Representative fatigue driving warning systems include DDMS fatigue detection system, SAM direction monitoring system, PVT reaction tester, DD550 products from Attention Technologies, and AntiSleep fatigue prevention and sleepiness system from SmartEye in Sweden. These systems monitor and warn the driver's condition in different ways, such as Doppler radar, steering wheel motion, reaction speed, etc[614].

In contrast, the research on fatigue driving warning system in China started late, and there is a certain gap compared with the United States and other countries. Chinese research is mainly conducted in some universities and research institutes, such as Tsinghua University and Peking University. At present, the relatively mature product is the gogo85 fatigue driving warning system developed by Tsinghua University, Southeast University and Nanjing Yuanguang Technology Co., LTD. The principle is to effectively identify the fatigue state of the driver through the closure degree of the human eye and the recognition of the pupil[15].

In recent years, China has begun to use EEG signals to identify fatigue, and analyzed the time-frequency characteristics of EEG signals to analyze the fatigue state of the human body. These studies have provided new ideas and methods for the detection of fatigue driving[16]. Although China's research lags behind the United States and other countries, with the continuous development of technology and the in-depth of research, China's fatigue driving detection technology is expected to gradually catch up with the level of foreign countries[17].

3. Analysis of the Induction of Fatigue States and the Demand of EEG Platforms

3.1. Induction of the Fatigue State

3.1.1. Lack of Sleep and Insufficient Quality

Lack of sleep and insufficient quality are one of the main causes of the fatigue state. Sleep deprivation leads to increased synchronized activity in the brain, which is usually manifested

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as more slow-wave activity in electroencephalography (EEG). Specifically, specific bands such as the θ and α waves can change during sleep deprivation[18]. The θ wave is a low frequency brain wave, usually in mild sleep and awakening; the α wave is a higher frequency brain wave, usually in a relaxed but still awake state. Fatigue detection systems can detect the effects of sleep deprivation by analyzing the activity of these bands. By monitoring changes in these specific bands, the system can assist in determining whether the driver is in fatigue state. The advantage of this method is that information can be obtained in a non-invasive way without driver intervention, and has certain objectivity and science.

3.1.2. Long-time and High-intensity Work

Long and high work can have an impact on brain activity, especially changes in the β frequency band. The β wave is a high-frequency brain wave that usually occurs with the brain in a state of high alert and cognitive load. Proprolonged work results in increased β -wave activity, reflecting the brain in a highly active and focused state. As fatigue accumulates, β activity may decrease, while α and θ activity may increase. The α wave is a brain wave with low frequency and usually occurs in relaxed states, while the θ waves are common in sleep and relaxation states. With increasing working hours and increasing working intensity, the activity rhythm of the brain may change, gradually shifting from high frequency β wave to lower frequency α and θ waves, reflecting the emergence of fatigue state.

3.1.3. Monotonic Working Environment

Long time in the monotonous and repetitive working environment can lead to the fatigue state of the drivers. In this case, the pattern of EEG activity changes, especially in the α -wave frequency band.α Wave usually occur when people are relaxed, but decrease when they need to concentrate. When the driver is in a monotonous environment, the increase in α waves may indicate a decreased attention level, in a relaxed state that affects its focus on the driving task. During driving, the driver needs to maintain a certain level of alertness and concentration to deal with emergencies and ensure safe driving. A long, monotonous driving environment will reduce the driver's focus, thus increasing the risk of fatigue driving. For drivers with high concentration requirements, such as long-term highway driving or long-distance driving, special attention needs to be paid to the fatigue state of drivers, and to take corresponding monitoring and prevention measures.

3.1.4. Driver's Concentration Requirements

During driving, the driver needs high attention to cope with complex driving tasks and changing road conditions. High concentration is usually shown in EEG signals as an increase in γ -wave activity. The γ -wave is closely related to cognitive processing and attention, and its increase reflects effective communication and coordination between brain regions, helping to maintain attention concentration and rapid response. When the driver is in fatigue, γ wave activity decreases, leading in reduced synchronization between brain regions. Leading to a prolonged response time, decreased attention, and reduced sensitivity to the surrounding environment. During long periods of driving or requiring long periods of high concentration, the driver's fatigue state can affect his γ -wave activity, thus affecting his ability to perform driving tasks.

3.1.5. The Monoicity of Driving Environment

In driving environments lacking stimulation and change, drivers experience monotony and boredom, leading to fatigue and decreased attention. The monotonic driving environment leads to brain relaxation, as reflected in the increase in α -wave activity in the EEG signal.α Wave are usually present in relaxed and closed eye states, and are usually reduced in tasks that require attention. If the driving environment is too monotonous, the driver will appear the "driving hypnosis" phenomenon, which is similar to the sleep state, but the driver can still continue to drive. In the EEG, this state would appear as an increase in the α and θ waves.θ Wave are usually associated with light sleep and relaxation states, and the appearance of such waveform during

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driving tasks can cause the driver's less attention to the surrounding environment and increase the risk of driving accidents.

3.2. Demand Analysis of the EEG Signal Platform

3.2.1. Driving Safety Requirements of Drivers

The system needs to be able to monitor the driver's electrical activity in real time and identify signs of fatigue. The EEG equipment is required to be highly sensitive and able to work stably in a variety of driving environments. Once a fatigue state is detected, the system should quickly notify the driver, allowing them to take action before the fatigue excessively affects the driving ability, such as taking rest or changing the driver. The interface should be simple and intuitive, and should not increase the driver's operation burden or distract his attention. Important warnings and messages should be clearly presented visually and auditory.

The installation and use of the equipment should not interfere with the normal driving operation, and the EEG headset should be comfortable, light and easy to wear.

3.2.2. Supervision Requirements of Traffic Management Departments

The system shall be able to automatically record all the fatigue events and the driver's response, and the data is extremely important for accident investigation and driving safety analysis. Provide adequate data storage and backup to ensure the security and integrity of critical information. The traffic management department shall be able to access the system in real time and remotely monitor the fatigue state of the drivers. This requires the system to support secure network connections and data transmission. The system must comply with both national and international safety standards and regulations. In addition, all devices and algorithms need to be rigorously tested to ensure their accuracy and reliability. The system shall have an interface with emergency services (e. g. ambulances and police vehicles) to quickly initiate rescue procedures in dangerous situations. Provide powerful data analysis tools to help traffic management departments conduct long-term safety trend analysis, optimize road safety policies and driver health management.

4. Construction and Design of the Online EEG Fatigue Detection and Early Warning System Platform

4.1. Design Idea of EEG Fatigue Driving Detection System

The network structure of an EEG fatigue driving detection system that combines a convolutional neural network (CNN) and a long and short-term memory network (LSTM) is shown. Hybrid network structure is a common method in the field of deep learning for processing and identifying sequence data of EEG signals.

The system first collects 3 consecutive seconds of EEG signal data from the driver's scalp. The collected raw EEG data underwent preprocessing steps such as noise filtering and artifact removal to ensure the quality of the input data. Local features in the time-series data are extracted by using a one-dimensional convolutional layer. In the figure, (18,64,2) represents the number, size, and step size of the convolution kernel. Used to increase the network nonlinearity and help the model to learn more complex features. Reduce the data dimension, extract the most important features, and improve the generalization ability of the model. Random disconnecting of neuronal connections reduces overfitting. Process the time-series data to learn the long-term dependencies in the EEG signal. The LSTM layer is able to remember and use the information in the time series, which is particularly important for fatigue detection. The SE module, also known as Squeeze-and-Excitation module, is used to learn the relationship between feature channels and strengthen useful and inhibition-independent features through adaptive recalibration, thus improving the representation ability of the network. The feature vectors of the output of the LSTM were converted into probability distributions of fatigue and non-fatigue states by the Softmax layer for classification judgments. Finally, the system output includes both fatigue and non-fatigue states, to help monitor and warn the driver's fatigue state. Overall, the design idea of this system uses the ability of CNN to extract features in space and the characteristics of LSTM to capture dynamic changes in time series analysis, and the ability of attention mechanism to highlight important features, so as to jointly construct an efficient network structure that can accurately detect the fatigue state in EEG signals.

4.2. Design Idea of Online EEG Fatigue Early Warning System

The figure represents the database design of a driver fatigue driving warning system, showing how the data related to fatigue driving detection is stored and managed. This design contains three main entities, driver, fatigue record and alarm, and demonstrates the relationship between them.

First, data collection and management. Record basic information of the driver, such as driver ID, license number and other personal information in order to track and link fatigue events. Each fatigue record contains multiple parameters associated with fatigue, such as PERCLOSE (percent eye closure), and other physiological and behavioral indicators that affect the fatigue state. Includes generation and notification of alarms, and recording of any subsequent actions.

Second, real-time monitoring and analysis. Driver EEG signals were collected in real time by EEG wave monitoring equipment, and relevant features were extracted using signal processing techniques, such as α wave, β wave, θ wave and δ wave. EEG data were analyzed in real time using deep learning or machine learning models to identify signs of fatigue. When the analysis determines that the driver is in a state of fatigue, the system will trigger an early warning to alert the driver through the onboard system to prompt him to take measures, such as rest or stop. In more severe cases, the system can interact with the vehicle's autopilot assistance system to guide the vehicle to safely slow down or park.

Third, information feedback and supervision. The early warning information will be recorded and fed back to the relevant regulatory authorities, such as the traffic management departments, for the follow-up data analysis and driving behavior supervision. This system provides a back-end database for supervisors to query, generate reports and provide decision support.

4.3. The MATLAB Simulation Design of the Return Fatigue Value of the EEG Fatigue Driving Detection

During this MATLAB simulation, a class named FatigueDetection was created to simulate the fatigue value calculation process in the EEG fatigue driving detection system. The class contains a property, fatigueValue, which stores the calculated fatigue values. In the constructor, we initialize the fatigueValue to 0. The process of processing the input data using the kNN algorithm was simulated using the detectFatigue method. In the MATLAB simulation design of returning the fatigue value, this paper simplifies the processing process and directly generates a random number as the fatigue value. This simulation design example shows how to create a simple class to simulate the calculation of fatigue values using MATLAB. In practical applications, the detectFatigue method can be modified according to the actual requirements, using real EEG signal data, and implementing more complex fatigue calculation algorithms.

5. Conclusion

With the increase of road traffic density, fatigue driving has become an important factor affecting road safety. The research and implementation of fatigue driving detection and early warning system based on EEG signals provides a practical solution to prevent accidents caused by fatigue driving by monitoring and analyzing the physiological state of drivers in real time. This study not only expounds the theoretical basis and technical path of the system, but also shows the construction process of the system and the effect of simulated practical application,

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and verifies its effectiveness in improving driving safety and auxiliary traffic supervision. With further development of technology and enhanced data analysis capabilities, it is expected that this physiological signal-based monitoring system can assess the status of drivers more accurately, achieving earlier warning and more effective interventions. It is hoped that the popularization of the system will provide scientific and technological support for road traffic safety management, and make an important contribution to reducing traffic accidents and protecting the life safety of drivers.

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