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Multi-modal Safe Driving System for New Energy Vehicles based on Microcontrollers

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Abstract

This paper presents a multimodal intelligent safety driving system for new energy vehicles, developed based on STM32 microcontrollers and multimodal visual algorithms. The system integrates real-time dynamic monitoring of the A-pillar blind spot, fatigue driving detection, and battery spontaneous combustion detection. Through optimized distortion correction algorithms, dynamic display solutions, fatigue detection models, and the construction of spontaneous combustion sensors with information transmission systems, it achieves multidimensional safety monitoring. The system innovatively employs object detection and Zhang Dingyou calibration for dynamic A-pillar blind spot monitoring, combines deep learning for fatigue driving detection, and implements battery spontaneous combustion risk warnings through dual data module feedback. In practical application, it reduces the risk of accidents caused by blind spots and fatigue driving, decreases the probability of battery spontaneous combustion, and provides technical support for intelligent cockpits, assisted driving, and new energy vehicle safety, demonstrating broad potential for in-vehicle applications.

Keywords

New Energy Vehicles; Multimodal Safety Driving System; A-pillar Blind Spot Monitoring; Fatigue Driving Detection; Visual Algorithms.

1. Introduction

With the advancement of the times, automobiles have become the most vital means of transport in our daily lives. Multimodal interaction design and the introduction of numerous features have made driving safer and more comfortable, while drivers must also interact with various in-vehicle systems and devices while performing primary driving tasks[1]. With the rapid advancement of the new energy vehicle industry, its safety performance has become a core issue constraining the sector's sustainable development. Analysis of driver behaviour indicates that over 80% of information is derived from visual sources[2]. The closer a pillar is to the driver, the greater the obstruction it causes to their field of vision, with the A-pillar being the primary obstruction to forward sightlines. In real-world driving scenarios, blind spots frequently cause misjudgements of pedestrians, vehicles, and other obstacles. At the same time, the fatigue driving, as one of the main causes of traffic accidents, greatly increases the danger because of its latent and instantaneous characteristics. In addition, the repeated occurrence of the phenomenon of spontaneous combustion of batteries in new energy vehicles has increased the worries of users about the safety of vehicles. These problems not only endanger the lives of the occupants, but also restrict the practical application of intelligent cockpit and driver assistant systems and other technologies, which are imminent challenges for the new energy vehicle industry. The current methods for dealing with the A-pillar blind spot mainly include redesigning the structure of

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the A-pillar and developing auxiliary equipment to eliminate the blind spot. The former cannot provide a complete solution, and the latter often has poor real-time performance and high cost, making it difficult to promote widely. In order to solve these problems, this paper proposed a multi-modal intelligent safe driving system for new energy vehicles based on STM32 and multi-modal visual algorithms. The system combines three core functions to provide a complete solution. Firstly, using Zhang Dingyou calibration and target detection technology to optimize image distortion correction algorithms and develop dynamic display solutions, real-time dynamic monitoring of A-pillar blind spots is realized to eliminate the hazards of line-of-sight obstruction; Secondly, a fatigue detection model is built using deep learning, and the drivers status is recognized and real-time reminders are provided through facial feature extraction and behavior analysis; Thirdly, an integrated battery self-ignition risk warning system is established by integrating an MQ-7 carbon monoxide sensor and a DS18B20 temperature sensor with a dual-data module feedback mechanism and an ESP8266 WiFi transmission system. By the combined use of multi-modal technologies, the system aims to improve the safety of new energy vehicles in three aspects: blind spot monitoring, driver condition management, and battery safety protection, so as to provide technical support for the development of intelligent driving technologies.

2. Design on System Architecture

2.1 System Block Diagram

The multimodal intelligent safety driving system for new energy vehicles under investigation comprised an environmental factor acquisition module, a main control module, a control execution module, and a display and warning module.

Environmental factor acquisition module, real-time acquisition of driving-related data through various types of sensors. In particular, the K210 and K230 vision processors acquired images of the A-pillar blind spot of the vehicle and the drivers facial expression respectively, supplying visual data for the blind spot monitoring and fatigue detection; The steering wheel angle sensor acquired the vehicle steering angle information so that the displayed blind spot image area can be dynamically adjusted; The MQ-7 carbon monoxide sensor and DS18B20 temperature sensor acquired the carbon monoxide concentration and battery temperature around the battery pack respectively, supplying data support for the battery self-ignition early warning.

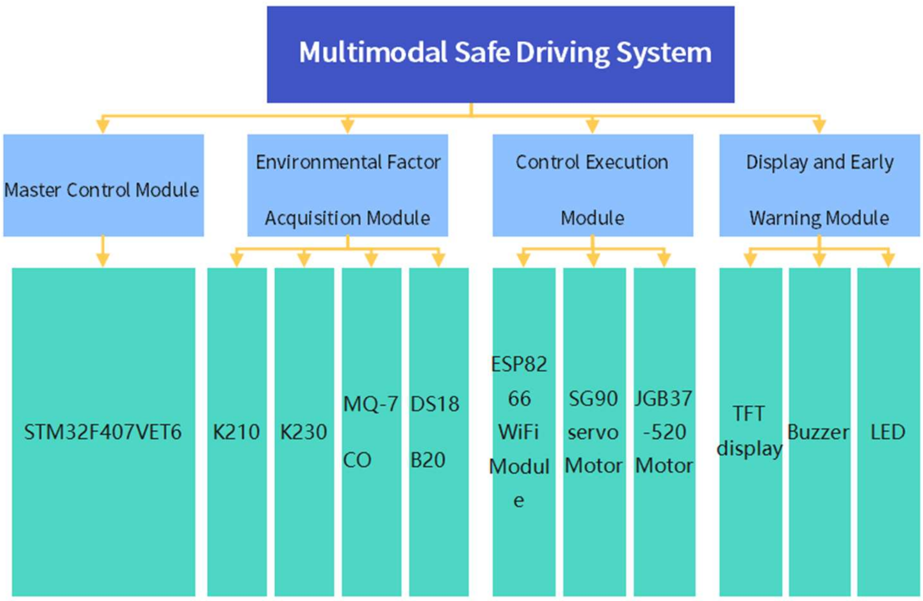

Figure 1. Overall System Block Diagram

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Main Control Module, employing an STM32F407VET6 microcontroller as the core for data acquisition and system control. This module received diverse data streams from environmental factor sensors, performing filtering, conversion, and computational processing. It compared battery-related sensor readings against preset thresholds while coordinating the operation of all subsystems.

Control execution module, it performed actions as per the instructions of the main control module. In case of A-pillar blind spot monitoring, it changed the area of image display dynamically by controlling the SG90 servo motor based on the steering wheel angle information. In case of fatigue driving detection, it activated the warning device whenever the driver is found to be fatigued. In case of battery self-ignition alerts, if the monitored data crossed the threshold values then the alarm mechanism was activated and the information was sent through the ESP8266 communication module to the TFT display. The whole system was provided with a JGB37-520 Hall effect encoder motor for movement.

Display and Warning Module, including a dynamic display screen and warning device. The dynamic displayed screen displayed the processed A-pillar blind spot images and battery status information in real-time. When fatigue driving or battery abnormality is detected, the warning device gave alarm through the buzzer and LED lights to warn the driver about the safety issues.

System modules communicate via SPI, UART and other protocols. Processed data from the main control module facilitates internal information exchanged through designated mechanisms, ensuring coordinated module operation. This enabled real-time, accurate implementation of A-pillar blind spot monitoring, fatigue driving detection and battery self-ignition alerts, thereby safeguarding new energy vehicle driving safety.

2.2 System Hardware Design

This design used an STM32 microcontroller as the main processor core, which coordinated data interaction and command execution between modules, and supported multiple sensor interfaces and high-speed data processing. The main board included communication interfaces for the K210 and K230. The OV5642 camera connected to the K210 was used to capture the A-pillar blind spot, while the K230 was used for acquiring the drivers facial image. The K210s built-in NPU was used to accelerate the inference of visual algorithms such as distortion correction and object detection. The built-in sensor interfaces included: the MQ-7 carbon monoxide sensor was used to detect the CO concentration in the battery compartment; The DS18B20 temperature sensor collected the real-time battery temperature; the steering wheel angle sensor collects the vehicle steering information, which was used to adjust the A-pillar camera display area dynamically. The built-in communication module used the ESP8266 WiFi module to transmit the real-time data from various sensors to the smart display of the vehicle, such as the CO concentration and temperature. It also transmits the alarm message when abnormality is detected. The built-in display module had a dynamic display screen to show the real-time A-pillar blind spot image after processing, the battery status and warning messages to provide intuitive feedback to the driver. The auxiliary modules included the TB6612 driver, the 520-encoded motor and the TPS54360 power step-down module. The power module provided stable electricity to the whole system to ensure the normal operation of the relevant devices; the drivers and motors assisted in realizing certain functions of the system execution.

2.3 System Software Design

2.3.1 Programme Function Description

Real-time image distortion correction algorithm for the A-pillar blind spot dynamic monitoring system software[3]. Optimization: Employing Zhang Dingyou 's calibration method[3] to achieve high-precision calibration of the camera detecting the vehicle A-pillar blind spot. With wide-angle lenses, the straight image from the distortion center curves. By capturing a chessboard pattern[5], the camera's intrinsic parameter matrix and distortion coefficients were determined, providing data for subsequent distortion correction. Combined with the K210's distortion correction algorithm, the lens_corr() function remaps distorted input images, translating each pixel from its distorted position to its

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corrected location. Concurrently, optimized calibration parameters and a dynamic remapping compensation mechanism enhance correction accuracy in both stationary and steering scenarios.

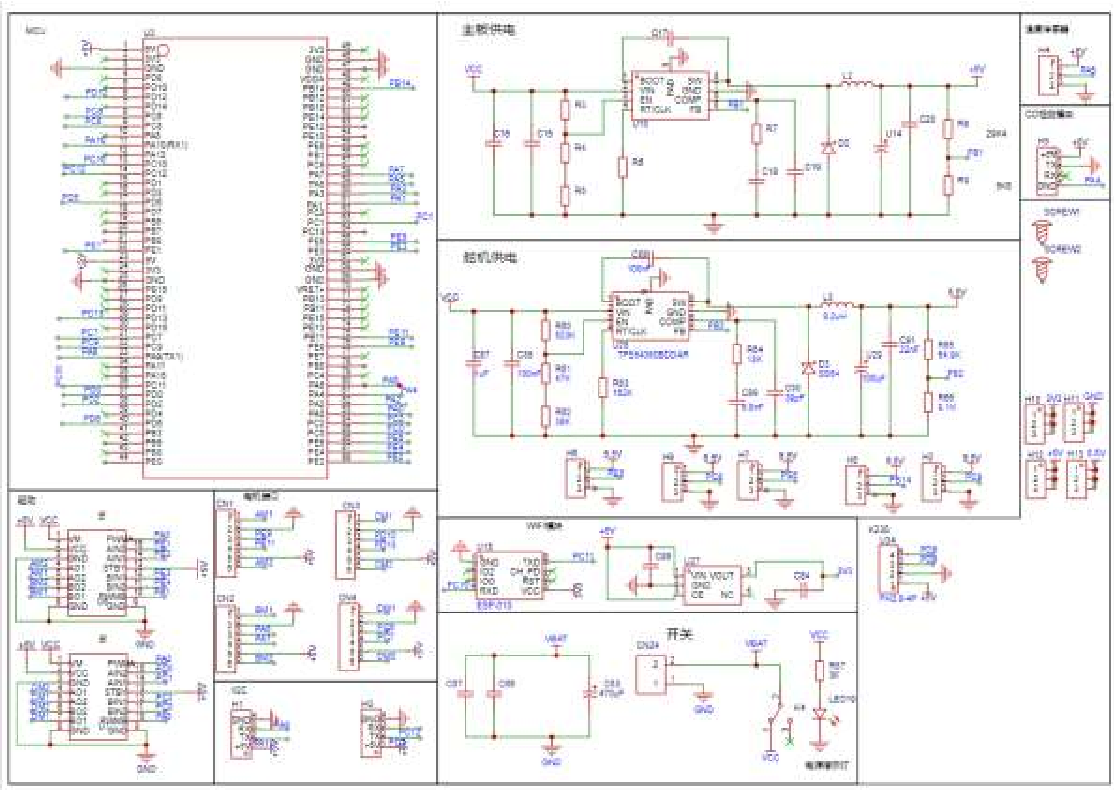

Figure 2. System Schematic Diagram

Software implementation for the dynamic image displayed scheme tracking vehicle movement: Integrates the YOLOv5 object detection model to located the steering wheel angle in real time. YOLOv5 was an innovative model based on YOLOv3 and YOLOv4 models, which was characterized by small model and fast speed and was suitable for mobile terminals[6]. Combining this with vehicle steering angle sensor data established an angle-to-display-region mapping relationship. The YOLO algorithm rapidly identified the steering wheel position by partitioning the camera feed into grids and predicting bounding boxes. Sensor data was then used to correct detection errors, ensuring angle detection accuracy within $\pm 2°$. By dynamically adjusting the A-pillar camera's display area, it achieved image tracking functionality: centring during straight driving, left-bias for left turns, and right-bias for right turns. Image switching latency is $\leq$30ms. Furthermore, multimodal data fusion (visual + sensor) and adaptive filtering algorithms optimized detection robustness under complex lighting conditions.

The Haar transform was the simplest of all wavelet transforms, however, it was very appealing for digital image feature extraction[7]. The driver fatigue detection system directly utilized the K230 processor's deeply optimized facial detection model to efficiently achieve rapid and precise localization of the driver's facial region. This approach circumvented the performance limitations inherent in traditional Haar cascade methods ,significantly enhancing robustness and real-time detection capabilities under complex driving conditions such as varying illumination and robust detection performance in complex driving conditions involving pose shifts. Leveraging the K230 chip's substantial computational power and dedicated NPU acceleration, the system immediately executed the Dlib 68-point facial feature detection algorithm[8], reliably locating key feature points such as eyes and mouth. By calculating real-time Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR), combined with dynamic threshold adjustment and multi-frame temporal analysis (e.g.,

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duration of consecutive closed eyes, yawn frequency per unit time), it comprehensively assessed fatigue states, providing effective safeguards for driving safety.

New Energy Vehicle Battery Self-Ignition Early Warning system[9] software, processes data collected from MQ-7 carbon monoxide sensors and DS18B20 temperature sensors. Compares recorded carbon monoxide concentration and temperature readings against predefined safety thresholds to determine whether an alarm stage has been reached. - Software configuration of the vehicle's built-in ESP8266 WiFi module enables real-time transmission of CO concentration and temperature data to the automotive smart display. Upon detecting anomalies, it concurrently send alarm notifications alongside data transmission.

System integration and collaborative software implementation established communication protocols between the STM32F407VET6 core board and hardware modules (cameras, sensors, WiFi modules, etc.), ensuring seamless and accurate data transmission[10]. Optimization of deep learning models, including the YOLOv5 object detection model and fatigue driving detection model, ensures low latency and minimal memory consumption during operation on the embedded platform, thereby enhancing overall system efficiency and stability.

2.3.2 Programme Flowchart

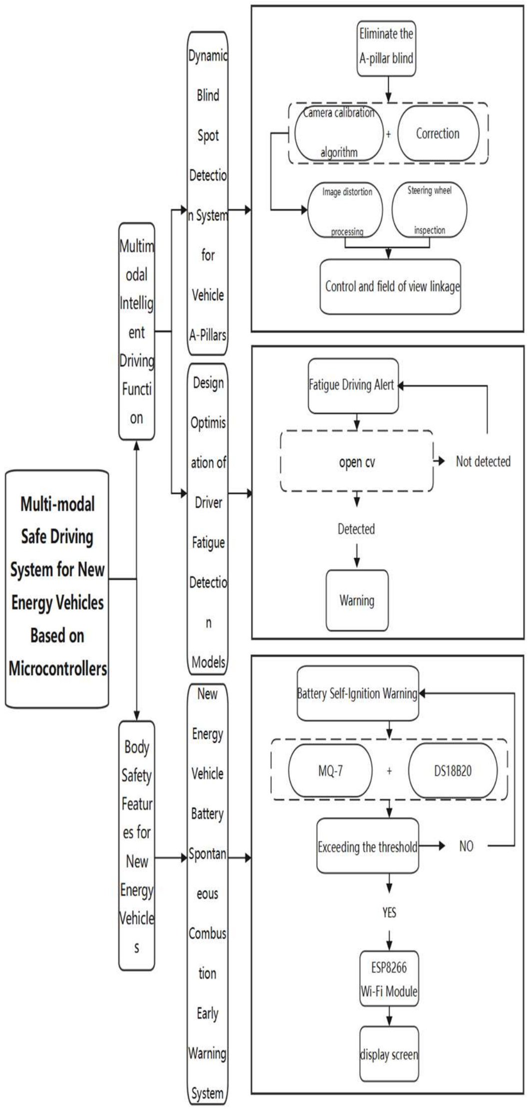

Figure 3. Program Flowchart

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3. System Testing and Analysis

3.1 Distortion Correction

Figure 4. Checkerboard image prior to distortion correction

Distortion correction design based on the "Zhang Dingyou calibration method + k210lens-corr() function", using a chessboard pattern as the calibration target. Raw distorted images from the A-pillar blind spot were captured via the K210 vision processor (corresponding to Figure 4, where chessboard lines appear twisted and grid misalignment occurs); Subsequently, the calibration algorithm was invoked to solve for the intrinsic parameter matrix and distortion coefficients. Combined with the lens-corr() function, pixel remapping was completed, outputting the corrected image (corresponding to Figure 5, where the chessboard grid is regular, lines show no offset, and edge pixels are accurately positioned). Test results validated the effectiveness of the "dynamic remapping compensation mechanism", meeting the requirement for clear display of A-pillar blind spot images.

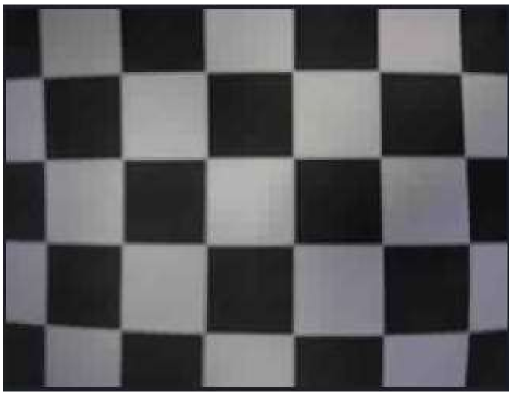

Figure 5. Chessboard grid image after distortion correction

3.2 Fatigued Driving Detection

Based on the design of "K230 facial detection + Dlib 68-point feature extraction + EAR/MAR temporal judgement", the K230 captured the driver's facial image and run feature detection algorithms in real time:

During open-mouth states (as per Figure 6), the system calculates MAR values (e.g., 0.675–0.888) and timestamps them. When exceeding 2 seconds continuously, the display triggered the alert: "Fatigued driving! Yawning has persisted for X.XX seconds." Single-frame detection duration is <80ms.

During eye closure (as per Figure 7), the system calculates the EAR valued (e.g., 0.659–0.780) and initiated timing. Should closure persist beyond 5 seconds, it outputted the alert "Fatigued driving! Eyes closed for X.XX seconds", with the code logic (the eye closure duration determination segment in Figure 7) accurately executing threshold assessments. Test data (real-time EAR/MAR output and

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prompt warning response) validated the system's detection robustness and real-time performance in complex driving scenarios.

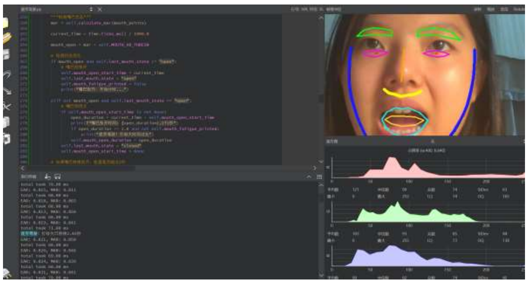

Figure 6. Debugging cumulative open-mouth duration

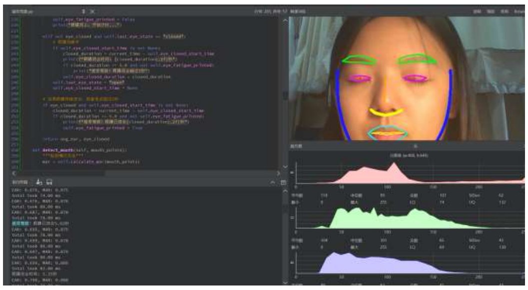

Figure 7. Debugging cumulative closed-eye duration

3.3 Temperature and CO Test Results

Tests were conducted based on the hardware design comprising an MQ-7 carbon monoxide sensor, DS18B20 temperature sensor, and ESP8266 transmission module, alongside software logic employing threshold comparisons (Normal: $CO \leq 0.01 \times 1000$ ppm, temperature < 200°C; Alarm: Exceeded thresholds).

Initialization Test: Data acquisition aligns with preset initialization range ($CO = 0.009 \times 1000$ppm, temperature 24-35°C), corresponding to Table 1 initialization data, verifying minimal sensor zero drift error.

Operational Simulation Test: Under normal conditions, data stabilized within normal thresholds. When simulating battery malfunction ($CO = 0.12 \times 1000$PPM, temperature= 210°C), the system triggered audible and visual alarms. The ESP8266 transmitted data in real-time to the vehicle's smart display (corresponding to abnormal data records in Table 1). Test results validated the reliability of dual-sensor coordination and the data transmission system, achieving battery self-ignition risk early warning.

3.3.1 Project Parameters

Table 1. CO/Temperature Project Parameters

	Carbon monoxide (unit): 1000 ppm	Temperature (unit): Celsius
Initialization Data	0.009	24–35
Normal Data	Below 0.01	Below 200
Alarm data	>0.1	>200

3.3.2 Test Results

Test initialization (data)

Reading sequence: CO, temperature

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CO: 9 ppm T: 27 ° C
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Figure 8. CO concentration and Temperature Data Acquisition Table

4. Conclusion

This study successfully developed a multimodal intelligent safety driving system for new energy vehicles based on STM32 and multimodal visual algorithms, achieving three core functions namely dynamic real-time monitoring of A-pillar blind spots, fatigue driving detection, and battery self-ignition early warning. By optimizing the distortion correction algorithm (combining Zhang Dingyou calibration with K210 real-time remapping), the A-pillar field-of-view obstruction issue was effectively resolved. The deep learning-based fatigue detection model (integrating Dlib feature extraction with dynamic thresholding) provided an efficient solution for driver state monitoring. The dual-data module battery warning system (combining MQ-7 carbon monoxide sensor and DS18B20 temperature sensor), utilizing ESP8266 WiFi module for real-time data transmission and anomaly alerts, significantly enhanced the reliability of new energy vehicle battery safety monitoring. The system's innovative valued manifested in three aspects Firstly, it integrated target detection with dynamic display, overcoming the static limitations of conventional A-pillar blind spot monitoring; Secondly, it employed lightweight deep learning models to balance fatigue detection accuracy with real-time performance; Thirdly, its dual-parameter fusion battery warning mechanism enhanced the comprehensiveness of spontaneous combustion risk identification. Practical application demonstrates the system's efficacy in reducing blind spot incidents, fatigue-related driving risks, and battery spontaneous combustion probability. It provided critical support for intelligent cockpits and driver assistance technologies, exhibiting broad potential for in-vehicle applications. Nevertheless, certain limitations remain algorithm robustness under complex lighting and extreme road conditions requires further validation, while hardware cost control and mass production adaptation demand deeper exploration. Future advancement will focus on three areas Firstly, introducing multi-sensor fusion (such as millimetre-wave radar and visual synergy) to enhance detection stability in adverse conditions; Secondly, optimizing computational resource utilization on the STM32 platform through model pruning and quantization techniques to reduce hardware costs; Thirdly, conducting real-vehicle testing in collaboration with automotive manufacturers to drive technological standardization and industrial implementation, thereby providing more robust technical safeguards for new energy vehicle safety systems and intelligent transport development.

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