

Research on Smart Sensors for New Energy Vehicles

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Abstract: As one of the key technologies for new energy vehicles, smart sensors provide data support for safe operation and performance optimization through real-time monitoring of vehicle status and environmental information. This paper systematically researches the application status and key technologies of smart sensors in new energy vehicles, covering the fields of environment sensing, battery management, automatic driving assistance and body control, etc., and focuses on the breakthrough direction of the core technologies such as multi-modal sensor fusion, energy self-supply, edge intelligent processing, high-precision sensing and anti-interference design. The study shows that intelligent sensor technology not only significantly improves the safety, range and intelligence level of new energy vehicles, but also provides important theoretical support and practical path for future technology iteration and industrial upgrading.

Keywords: New Energy Vehicles; Smart Sensors; Battery Management; Multimodal Fusion.

1. Introduction

New energy vehicles are gradually changing the way people travel with their environmentally friendly and energy-saving features. However, the popularization of new energy vehicles still faces many technical challenges, among which battery management, energy efficiency, safety performance and other issues are particularly prominent. In this context, smart sensor technology, as one of the core technologies of new energy vehicles, is playing an increasingly important role.

Smart sensors integrate sensing, data processing, and communication functions, and are able to monitor vehicle status and environmental information in real time, providing key data support for the safe operation and performance optimization of new energy vehicles [1]. This thesis provides theoretical basis and practical guidance for the technological innovation and industrial development of new energy vehicles by discussing in depth the current status of the application of smart sensors in new energy vehicles, the key technologies and the future development trend, with a view to providing a theoretical basis and practical guidance for the technological innovation and industrial development of new energy vehicles.

2. Application of Smart Sensors in New Energy Vehicles

2.1. Environmental Awareness

Environment sensing is the basis for new energy vehicles to realize autonomous driving and intelligent control, and smart sensors play a key role in this regard. Common smart sensors used for environment sensing cover a variety of types such as cameras, radar and ultrasonic sensors [2]. Cameras are able to acquire visual image information around the vehicle, and front-view cameras can be applied to identify traffic conditions on the road ahead and provide visual support for automated vehicle driving, while surround-view cameras can provide a 360° panoramic view of the vehicle's surroundings.

Radar sensors utilize electromagnetic waves to detect target object information. Millimeter-wave radar works in the millimeter band, has high resolution and speed measurement

accuracy, can work in various weather conditions, and is commonly used for adaptive cruise control, collision avoidance warning, and other functions. The working principle of LiDAR is based on the optical time-of-flight measurement technology, by transmitting laser pulses to the target area, accurately capturing the time difference between the return of reflected light, and then using these data to carry out complex algorithmic processing, and ultimately constructing a three-dimensional model of the target object, realizing high-precision environmental information perception, and providing indispensable basic data support for the fields of automatic driving, robot navigation, etc. [3]. Ultrasonic sensors are mainly used in close-range obstacle detection scenarios such as reverse assistance and automatic parking. Utilizing the reflected wave of the ultrasonic signal after encountering the obstacle to determine the distance has the advantages of low cost and mature technology.

2.2. Battery Management

In new energy vehicles, the battery occupies an extremely important position. As one of the core components, its safety characteristics and performance will have a direct and critical effect on the overall operating efficiency of the vehicle, which is related to the stability of the vehicle's power output, range and driving safety and other performance indicators. Intelligent sensors play a crucial role in the battery management system, which can monitor various parameters of the battery in real time [4], such as voltage, current, temperature, SOC (state of charge) and SOH (state of health), etc., to provide a guarantee for the optimization of battery management and safe operation.

The voltage sensor is used to measure the terminal voltage of the battery, and by monitoring the voltage, the charging state and discharging condition of the battery can be judged. The temperature sensor monitors the temperature of the battery in real time. Since the battery generates heat during charging and discharging, if the temperature is too high or too low, it will affect the performance and life of the battery, and even cause safety problems, so temperature monitoring is crucial for battery management.

Accurate estimation of SOC and SOH is mission critical for battery management systems. Smart sensors provide

drivers with accurate information about the remaining battery power by collecting data such as voltage, current and temperature of the battery and combining it with the ampere-time integration method and Kalman filtering algorithm, etc. They also provide a basis for battery charging and discharging control to ensure that the battery operates in an optimal state and prolongs the battery's lifespan.

2.3. Automated driver assistance

Intelligent sensors are the core components for realizing the automatic driving assistance functions of new energy vehicles, providing the necessary environmental information and decision support for the vehicle. Common automatic driving assistance functions include adaptive cruise control, lane keeping assist (LKA), automatic emergency braking (AEB), etc., and the realization of these functions can not be separated from the collaborative work of intelligent sensors [5]. The ACC system utilizes radar or laser sensors to monitor the distance and speed in front of the vehicle, and is able to automatically adjust the vehicle speed in order to maintain a safe distance from the vehicle in front. When the vehicle in front is detected slowing down or accelerating, the vehicle will automatically follow and adjust its speed, reducing the driver's driving burden and improving driving safety and comfort. The LKA system utilizes visual sensing devices to collect real-time road marking information, and when the vehicle is detected to have an inactive lane deviation, the system can actively implement steering interventions or issue warning signals to ensure that the vehicle is driven stably along the centerline of the lane. This function effectively reduces lane departure accidents caused by driver fatigue or negligence, and improves the safety of long-distance driving.

The AEB system uses multi-sensor fusion technology to continuously scan and analyze the driving environment in front of the vehicle by integrating millimeter-wave radar and visual sensing units. When a potential collision risk is recognized, the system can activate the braking mechanism independently, effectively reducing the possibility of an accident.

2.4. Body Controls and Comfort Adjustments

Intelligent sensors can enhance the overall performance and driving experience of a vehicle. Temperature and humidity sensors are used to monitor the ambient temperature and humidity inside the vehicle, and the intelligent control system automatically adjusts the air conditioning system based on these data to provide a comfortable driving environment for passengers. The light sensor can monitor the light intensity inside and outside the vehicle and automatically adjust the vehicle's lighting system, such as automatically turning on or off the headlights and adjusting the brightness of the headlights, to improve driving safety and convenience [6]. Intelligent sensors are also applied to the vehicle's seat adjustment, window control, etc. Through the pressure sensor to sense the driver's and passenger's sitting position, automatically adjust the shape and position of the seat to provide better support and comfort; through the infrared sensor to detect the position of the driver's hand, to realize the automatic lifting and lowering of the windows and other functions, to improve the level of intelligence and user experience of the vehicle.

3. Smart Sensor Key Technology for New Energy Vehicles

3.1. Multimodal Sensor Fusion Technology

3.1.1. Heterogeneous Data Fusion Framework

New energy vehicles need to integrate multimodal data from laser radar (LiDAR), millimeter-wave radar, vision cameras, ultrasonic sensors, and other multimodal data to build a multilayer fusion framework [7]:

(1) Data layer fusion: eliminating spatio-temporal errors between sensors through spatio-temporal calibration, pre-processing the raw data using KalmanFilter, and combining the ranging accuracy of millimeter-wave radar ($\pm 0.1\text{m}$) with the target recognition capability of the camera (95% accuracy) to improve the reliability of obstacle detection.

(2) Feature layer fusion: Deep learning models (e.g. PointNet++) are used to extract LIDAR point cloud features, which are correlated and matched with visual semantic segmentation results (e.g. Mask R-CNN) to realize 3D environment reconstruction in complex scenes.

(3) Decision layer fusion: Based on D-S evidence theory or Bayesian network to evaluate the confidence level of multi-source information, and complete the path planning and decision optimization in the automatic driving system.

3.1.2. Dynamic Environment Adaptive Technology

Develop adaptive fusion algorithms based on reinforcement learning for the dynamic changes in the environment caused by high-speed vehicle movement. For example, the Tesla FSD system optimizes sensor weight allocation through online learning to dynamically increase the confidence weight of millimeter-wave radar in rainy and foggy weather to compensate for camera performance degradation.

3.2. Energy Self-supply Technology

3.2.1. Environmental Energy Capture Mechanisms

(1) Vibration Energy Harvesting: Piezoelectric materials (e.g. PZT-5H) are used to convert the vibration energy of the suspension system into electrical energy, and experiments have shown that it can generate 3.2mW of sustained power at a speed of 60km/h, which meets the power supply requirements of the tire pressure sensor.

(2) Thermal energy recovery: Based on the Seebeck effect, the temperature difference electricity generation (TEG) module is utilized to recover the waste heat of the motor, and the output power of a single module reaches 12mW at $\Delta T=50^\circ\text{C}$, which supplies power to the battery temperature sensor.

(3) Electromagnetic energy capture: coupling magnetic field energy through near field communication (NFC) or wireless charging system to realize passive design of sensor nodes.

3.2.2. Ultra Low Power Circuit Design

Using Event-Driven Architecture, the sensor wakes up only when it detects a signal change, with static power consumption as low as 0.5 μA [8]. For example, the Infineon TLI4971 current sensor reduces power consumption by 40% through adaptive sampling rate adjustment.

3.3. Edge Intelligent Processing Technology

3.3.1. Embedded AI Acceleration

(1) Lightweight model deployment: integrating NPU (Neural Network Processing Unit) at the sensor side and

running the compressed Tiny-YOLOv4 model to achieve real-time target detection (30FPS) with a latency of less than 5ms.

(2) Federated Learning Optimization: Dynamically update the battery health degree (SOH) prediction model through vehicle-end-cloud collaborative training to improve the algorithm generalization capability.

3.3.2. Data Security Enhancements

Hardware-level encryption module (e.g. ARM TrustZone) is used to protect the sensor data flow, combined with blockchain technology to realize anti-tampering of battery traceability information and ensure the data integrity of the BMS system.

3.4. High-precision Sensing Technology

3.4.1. Battery Status Monitoring

Impedance Spectrum Analysis: Measure the internal impedance of the battery by AC injection method, combined with EIS (Electrochemical Impedance Spectroscopy) to resolve the changes in the concentration of the electrolyte, realizing the SOC estimation error of <2%.

Distributed Fiber Optic Temperature Measurement: FBG (Fiber Bragg Grating) sensors are buried within the battery module, with a spatial resolution of 1cm and a temperature measurement accuracy of $\pm 0.5^{\circ}\text{C}$.

3.4.2. Motor Control Optimization

Adopting TMR (Tunnel Magneto Resistive) angle sensor, non-contact measurement of motor rotor position, angle error $< 0.1^{\circ}$, helping permanent magnet synchronous motor to achieve more than 99% operating efficiency.

3.5. Anti-Interference and Reliability Design

3.5.1. EMI Suppression Technology

(1) Multi-layer shielding structure: PoMo alloy shell and copper mesh composite shielding is used in the current sensor to attenuate electromagnetic interference (EMI) by more than 60dB.

(2) Adaptive filtering algorithm: Based on the LMS (Least Mean Square) algorithm to dynamically eliminate the effect of inverter switching noise on Hall sensors.

3.5.2. Fault Prediction and Self-healing

Constructing a digital twin-based sensor health management model, predicting the failure probability of MEMS acceleration sensors through Markov chains, warning 10 hours in advance, and improving system availability to 99.99%.

4. Conclusion

This paper reveals the great potential of smart sensors in enhancing vehicle performance, safety and intelligence through an in-depth discussion of their application status, key technologies and future development trends in new energy

vehicles. The application of smart sensors in several key areas, such as environment sensing, battery management, automatic driving assistance and body control, significantly improves the overall performance of new energy vehicles. Secondly, this paper discusses the key technologies of smart sensors, including multimodal sensor fusion, energy self-supply, edge intelligent processing, high-precision sensing, and anti-interference and reliability design. The development of these technologies not only improves the accuracy and reliability of the sensors, but also reduces the energy consumption and enhances the adaptive capability and safety of the system.

With the continuous progress of new materials, new processes and artificial intelligence technology, intelligent sensors will play a more important role in new energy vehicles. Future research should continue to focus on the miniaturization, intelligence and networking of sensors to further enhance their performance and application scope. At the same time, strengthening interdisciplinary cooperation and promoting the deep integration of sensor technology and other systems of new energy vehicles will be the key to realizing the comprehensive intelligence of new energy vehicles.

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