Smart Internet of Vehicles: An Integrated Comprehensive System for Human-Vehicle Safety

-- Making Dangers Nowhere to Hide and Ensuring Safe Travels

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Abstract

This paper conducts in-depth research on the integrated comprehensive system for human-vehicle safety in the smart Internet of Vehicles. It elaborates on the architecture design, core functional modules, and key technologies of this system, including vehicle networking communication, dangerous behavior monitoring and early warning, automatic assisted driving, emergency response, and traffic congestion alleviation. Through the synergy of these technologies, the system can effectively respond to dangers such as natural disasters, vehicle malfunctions, traffic accidents, and criminal acts, improve traffic safety levels, optimize traffic flow, and provide comprehensive guarantees for modern transportation. Through practical case analysis and performance evaluation, the remarkable advantages and broad application prospects of this system in ensuring human-vehicle safety and improving traffic efficiency have been verified.

Keywords

Smart Internet of Vehicles, human-vehicle safety, dangerous monitoring and early warning, emergency response, traffic congestion alleviation.

1. Introduction

In today's society, the safety and efficiency of transportation are the focuses of people's attention. With the sharp increase in the number of vehicles, the traffic environment has become increasingly complex. Traffic accidents, vehicle breakdowns, criminal acts, and natural disasters have had a more and more serious impact on the transportation system, and traffic congestion has also become an important issue restricting urban development. The rise of smart Internet of Vehicles technology has brought new opportunities to solve these problems. The integrated comprehensive system for human-vehicle safety, as an important application of it, aims to build an intelligent, efficient, and safe transportation ecological environment. As Zhao Jun reviewed in his paper [1], the development of Internet of Vehicles technology has a wide range of impacts on transportation.

2. Architecture of the Integrated Comprehensive System for Human-Vehicle Safety in the Smart Internet of Vehicles

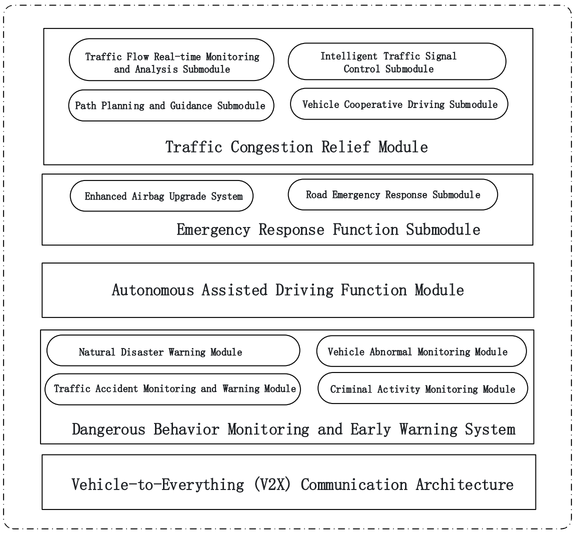

Figure 1. Integrated Overall System Architecture of Intelligent Vehicle-to-Vehicle and Vehicle-to-Infrastructure Safety for Humans and Vehicles

2.1. Vehicle Networking Communication Architecture

As shown in Figure 1, the core of the integrated comprehensive system for human-vehicle safety in the smart Internet of Vehicles is a powerful vehicle networking communication architecture. Based on advanced wireless communication technologies such as 5G and LTE-V2X, it constructs a large-scale, high-reliability mesh network to achieve all-round, real-time communication among vehicles (V2V), between vehicles and infrastructure (V2I), and between vehicles and people (V2P). The vehicle networking wireless relay technology is widely used to enhance network coverage and signal strength, especially in areas with serious signal occlusion or interference, such as urban streets with high-rise buildings and mountain tunnels. Through the intelligent deployment of relay nodes and signal forwarding mechanisms, the stability of the communication links between vehicles and between vehicles and the background system is ensured, laying a solid communication foundation for the realization of system functions.

2.2. Dangerous Behavior Monitoring and Early Warning System

1) Natural Disaster Early Warning Module

This module integrates multiple types of sensors and data sources. By installing high-precision meteorological sensors (such as temperature sensors, humidity sensors, air pressure sensors, etc.) on vehicles and interacting with the external meteorological monitoring network in real time, the system can obtain weather change information in real time. At the same time, it uses geological sensors (such as accelerometers, inclinometers, etc.) to monitor the geological conditions of roads. Based on these data, combined with big data analysis and machine learning algorithms, accurate predictions and early warnings for natural disasters can be made. For example, in heavy rain weather, when the system detects a rising trend in water levels and the risk of road flooding, it will promptly issue flood warnings to nearby vehicles, reminding drivers to avoid dangerous sections. For high-risk natural disasters such as earthquakes and landslides, when abnormal crustal movements or changes in mountain structures are detected, alarms can also be quickly issued to guide vehicles to move to safe areas.

2) Vehicle Malfunction Monitoring Module

The interior of the vehicle is equipped with a complete sensor network, including but not limited to wheel speed sensors, brake pressure sensors, engine oil temperature sensors, battery status sensors, etc. These sensors collect the operating parameters of various key systems of the vehicle in real time. Through the built-in intelligent diagnostic algorithm, the mechanical components, electronic systems, and power systems of the vehicle are monitored in real time. When abnormal conditions of the vehicle are detected, such as abnormal wheel speed (which may indicate a flat tire or transmission system failure), abnormal brake pressure (brake system failure), excessive engine oil temperature (engine overheating), or abnormal battery power (electrical system problems), the system immediately activates the alarm mechanism. The alarm information is sent to the driver, the remote monitoring center of the vehicle manufacturer, and nearby maintenance service stations through the vehicle networking. At the same time, detailed fault data and vehicle location information are also transmitted together to facilitate quick response and repair. The data fusion technology in this process, as studied by Li Lijun, Li Hongying, and Liu Jiming in "Research on Data Fusion Technology in the Internet of Vehicles" [6], helps in accurately detecting and diagnosing vehicle malfunctions.

3) Traffic Accident Monitoring and Early Warning Module

Multi-modal sensors such as millimeter-wave radars, laser radars, and high-definition cameras installed around the vehicle are used to construct a real-time perception model of the vehicle's surrounding environment. The millimeter-wave radar can accurately measure the distance, speed, and angle between the vehicle and surrounding objects. The laser radar provides high-resolution three-dimensional environmental information, and the high-definition camera is used to identify road signs, traffic signals, and the characteristics of other vehicles and pedestrians. Through sensor fusion technology and advanced image recognition algorithms, the system can judge in real time whether the distance between vehicles is safe, whether the vehicle deviates from the lane, whether there are sudden obstacles in front, etc. Once a possible traffic accident, such as a rear-end collision, collision, or scratch, is predicted, the system will send multi-dimensional early warning information such as visual, auditory, and tactile (such as seat vibration) to the driver within a very short time. At the same time, the accident risk information will be broadcast to surrounding vehicles to guide them to take evasive or braking measures in advance, thereby effectively reducing the occurrence and loss of traffic accidents. As Zhang, K., Mao, Y., Leng, S., & Fadlullah, Z. M. discussed in "Vehicle-to-Everything (V2X) Communication for Intelligent Transportation Systems: A Survey" [7], V2X communication plays an important role in such traffic accident prevention scenarios.

4) Personnel Crime Monitoring Module

Inside the vehicle, high-definition cameras and microphones are combined with advanced artificial intelligence behavior analysis algorithms to monitor the behaviors and expressions of the people in the vehicle. By analyzing the facial expressions, limb movements, and voice intonations of the driver and passengers in real time, signs of abnormal behaviors such as violence, panic, and coercion can be identified. Outside the vehicle, the sensors and cameras around the vehicle body can detect the approaching, lingering, and attempts to damage the vehicle by suspicious persons. Once suspicious signs of personnel crimes are detected, the system will automatically trigger an alarm, send alarm information to the local police, security agencies, surrounding vehicles, and pedestrians, and at the same time start the vehicle's security protection mechanism, such as automatically locking the doors, activating the anti-theft device, etc., and record video and audio evidence of the crime process to provide strong support for subsequent investigations and handling.

2.3. Automatic Assisted Driving Function Module

The automatic assisted driving module is an important part of the smart Internet of Vehicles system in improving driving safety. In complex road conditions, such as heavy fog, heavy rain, and low visibility at night, the system realizes functions such as adaptive cruise, automatic emergency braking, and lane keeping assistance by comprehensively using technologies such as laser radars, millimeter-wave radars, cameras, and high-precision maps. For example, in foggy weather, laser radars and millimeter-wave radars can penetrate the fog to accurately detect the distance and speed of the vehicles and obstacles in front, and the cameras assist in identifying the boundaries of the road and the lane lines. The system automatically adjusts the vehicle speed, maintains a safe distance, and ensures that the vehicle travels within the lane. Under normal driving conditions, the automatic assisted driving module can also provide reasonable driving suggestions for drivers according to real-time traffic information and road condition changes, such as the optimal vehicle speed and the appropriate lane change time, effectively reducing the driver's driving burden and the risk of accidents caused by human operation errors.

2.4. Emergency Response Function Module

1) Emergency Airbag Upgrade System

The traditional emergency airbag has been innovatively upgraded. On the basis of the original airbag triggering mechanism, power suspension and attitude adjustment functions have been added. When a vehicle collision occurs, the emergency airbag pops out quickly. At the same time, the power suspension system is activated to generate a reverse force by injecting gas or liquid in a specific direction to adjust the attitude of the vehicle at the moment of the collision, reducing the possibility of secondary injuries such as vehicle rollover and sideslip. The attitude adjustment system adjusts the inflation degree and support direction of the airbag in real time according to the angle and force of the collision, providing more precise protection for the people in the vehicle, especially in side collisions and rollover accidents, minimizing the risk of casualties.

2) Road Emergency Handling Sub-module

A sensor network is deployed on the road surface and underground to monitor road conditions in real time. These sensors include road surface pressure sensors, humidity sensors, temperature sensors, and underground structural integrity sensors, etc. When dangerous situations such as potholes, cracks, water accumulation, icing, collapses, or missing manhole covers are detected on the road surface, the system will immediately send danger information to the vehicles approaching this section and report to the road maintenance department at the same time. For vehicles, the system will provide corresponding countermeasures according to the type of danger and the driving state of the vehicle, such as decelerating, avoiding, or stopping. In extreme cases, such as sudden road collapses, the system can also assist the vehicle to start the emergency braking and stability control procedures to avoid the vehicle getting into danger.

2.5. Traffic Congestion Alleviation Module

1) Traffic Flow Real-time Monitoring and Analysis Sub-module

A large number of induction coils, video monitoring devices, and the positioning and communication functions of vehicles themselves are installed at key nodes of the urban road network (such as intersections, viaducts, tunnel entrances and exits, etc.) to achieve all-round, real-time monitoring of traffic flow. The information collected by these devices includes the number of passing vehicles, speed, type, and driving direction. Through big data technology to analyze and process these massive data, a traffic flow model is constructed to accurately grasp the change laws of traffic flow in different sections and at different times. Based on this model, the formation and development trend of traffic congestion can be detected in time, providing data support for subsequent traffic control and optimization. As Wang Yunpeng, Liu Qi, Chu Xiumin, et al. studied in "Research on Traffic Congestion Mitigation Strategies Based on the Internet of Vehicles" [3], traffic flow monitoring is the basis for congestion alleviation strategies.

2) Intelligent Traffic Signal Control Sub-module

According to the traffic flow monitoring data, the intelligent traffic signal control sub-module uses advanced algorithms to dynamically optimize and adjust the duration of traffic lights. During peak hours, the green light time is extended for the direction with a large traffic volume to reduce the waiting time and queue length of vehicles. During off-peak hours, the signal light time is evenly distributed according to the real-time traffic flow to improve the traffic efficiency at intersections. In addition, through vehicle networking communication with vehicles, the system provides recommended vehicle speeds to drivers approaching traffic lights, enabling vehicles to pass through intersections at appropriate speeds, reducing unnecessary stops and starts, and further alleviating intersection congestion. At the same time, the system can also coordinate the traffic lights at adjacent intersections to achieve green wave band control, allowing vehicles to pass through multiple intersections continuously without stopping on a certain driving route, improving the traffic capacity of the entire road network.

3) Route Planning and Guidance Sub-module

Combining real-time traffic flow data and historical traffic data, the route planning and guidance sub-module provides drivers with personalized optimal driving route recommendations. The system takes into account multiple factors, such as the current road congestion situation, estimated travel time, traffic accident information, and road construction information. When traffic accidents, road construction, or other situations causing congestion occur on the road, the system will promptly re-plan the route for the vehicle, guide the vehicle to divert, and avoid a large number of vehicles pouring into congested sections. Through vehicle networking, the route planning information is pushed to the driver in real time, and the estimated arrival time is dynamically displayed in the vehicle navigation system and updated in real time according to road condition changes, helping the driver better plan travel time and routes and improving travel efficiency.

4) Vehicle Cooperative Driving Sub-module

The vehicle cooperative driving sub-module realizes information interaction and cooperative control among vehicles through vehicle networking. In specific scenarios such as highways, the system encourages vehicles to form fleets and maintain a safe and stable distance and speed among them. By sharing driving information such as speed, acceleration, and steering intentions, vehicles can cooperatively adjust their driving states, reducing frequent overtaking and lane changing behaviors. When a vehicle in the fleet needs to decelerate, change lanes, or stop, it sends a signal to other vehicles through vehicle networking, and other vehicles respond in advance to achieve smooth fleet driving. This cooperative driving method not only improves the utilization rate of the road but also effectively alleviates traffic congestion and reduces the incidence of traffic accidents.

3. Key Technology Support

3.1. Advanced Sensor Technology

The system widely applies a variety of advanced sensors, which are the key to obtaining accurate information. For example, high-resolution laser radars can provide precise three-dimensional environmental information. Its working principle is to construct a point cloud map of surrounding objects by emitting laser beams and measuring the time of reflected light. Millimeter-wave radars use electromagnetic waves in the millimeter-wave frequency band to detect and measure the distance of targets, and have the advantage of stable performance in bad weather. New environmental sensors can measure meteorological parameters and geological changes with high precision. Behavior monitoring sensors in the vehicle can accurately capture the details of people's expressions and movements. The high precision, high reliability, and diversity of these sensors provide rich data sources for the functions of dangerous behavior monitoring and automatic assisted driving of the system. As discussed in

Huang Gang, Liu Jun, and Dong Xuewen's work [4], the development of sensor technology is essential for the smart Internet of Vehicles system.

3.2. Sensor Fusion and Data Processing Technology

To make full use of the data obtained by different sensors, sensor fusion technology is essential. Through methods such as data layer fusion, feature layer fusion, and decision layer fusion, the information from different sensors is integrated. For example, in traffic accident monitoring, the distance and speed data of millimeter-wave radars are combined with the image recognition results of cameras to improve the accuracy of accident judgment. At the same time, big data processing technology and cloud computing platforms are used to process massive sensor data. Through distributed storage, parallel computing, and data mining algorithms, the data is analyzed and processed in real time to extract valuable information and provide a basis for the system's decision-making and control.

3.3. Artificial Intelligence and Machine Learning Algorithms

Artificial intelligence and machine learning algorithms are widely used in the system in aspects such as dangerous behavior recognition, traffic flow prediction, and driving behavior analysis. Convolutional neural networks (CNN) in deep learning algorithms are used for image recognition, such as recognizing road signs, vehicles, and pedestrians. Recurrent neural networks (RNN) and their variants (such as long short-term memory networks LSTM) are used to process time series data, such as traffic flow prediction and driver behavior analysis. Through a large amount of training data, these algorithms can learn the patterns of various dangerous behaviors, the change laws of traffic flow, and the characteristics of normal and abnormal driving behaviors of drivers, so as to achieve accurate early warning of dangers and effective optimization of traffic conditions. As Chen Shanzhi, Shi Yan, and Hu Jinling's research [5] shows, artificial intelligence and machine learning algorithms play a crucial role in the smart Internet of Vehicles system.

3.4. Vehicle Networking Communication and Security Technology

Reliable vehicle networking communication technology is the key to realizing information interaction among vehicles and between vehicles and infrastructure. In addition to communication technologies such as 5G and LTE-V2X, it also includes a series of communication protocols and network architecture designs. Meanwhile, to ensure the security of vehicle networking communication, encryption technologies, identity authentication technologies, and access control technologies are adopted. Encryption technology ensures the confidentiality and integrity of data during transmission, preventing data from being stolen or tampered with. Identity authentication technology verifies the identities of both parties in communication to prevent illegal access. Access control technology restricts the access rights of different users and devices to system resources to ensure the safe and stable operation of the system. As Lü Zhiyong, Li Zhihong, and Zhong Ming studied [2], security in vehicle networking communication is a significant aspect that needs to be addressed.

4. System Advantages and Application Case Analysis

4.1. System Advantages

1) All-round Security Guarantee

The integrated comprehensive system for human-vehicle safety in the smart Internet of Vehicles provides all-round security guarantees for drivers, passengers, and pedestrians through comprehensive monitoring and early warning of various dangerous behaviors and powerful emergency response capabilities. Whether it is natural disasters, vehicle malfunctions, traffic accidents, or personnel crimes, the system can respond in a timely manner, reduce security risks, and protect life and property safety.

2) Traffic Efficiency Improvement

The application of the traffic congestion alleviation module has significantly improved the traffic efficiency of roads. Through functions such as intelligent traffic signal control, route planning, and vehicle cooperative driving, the waiting time and driving time of vehicles are reduced, energy consumption and exhaust emissions are decreased, urban traffic congestion is alleviated, and the operation efficiency of the entire traffic system is improved.

3) Intelligent and Personalized Services

The system utilizes advanced artificial intelligence and big data technologies to provide users with intelligent and personalized services. According to factors such as the driving habits, travel time, and destination of drivers, customized driving suggestions and route planning are provided. At the same time, through real-time perception of vehicles and the traffic environment, the system automatically adjusts its functions to adapt to different traffic scenarios and user needs.

4.2. Application Case Analysis

1) Singapore Smart Transportation Project

Singapore is gradually deploying the smart Internet of Vehicles system across the country. Based on its advanced communication infrastructure, high-speed and stable communication among vehicles, traffic management centers, roadside facilities, and other vehicles has been achieved. The high-precision sensor network in its dangerous behavior monitoring and early warning system can monitor road and vehicle conditions in real time. For example, before the rainy season, the geological sensors and meteorological monitoring network work together to predict flooded sections and send warnings to vehicles to guide them to detour. When vehicle malfunctions such as brake system abnormalities are detected, the system can notify the vehicle owner and make appointments with nearby maintenance service stations. The traffic accident monitoring and early warning system uses cameras and radars to perceive the driving state in real time and effectively prevents many rear-end collision accidents. The personnel crime monitoring function also plays a role in key areas to ensure the safety of drivers and passengers. Through the application of this system, Singapore's urban traffic congestion has been significantly improved. The average vehicle speed on main roads during peak hours has increased by about 20%, the incidence of traffic accidents has decreased by nearly 35%, the traffic interruption time caused by vehicle malfunctions and natural disasters has been greatly shortened, the security and smoothness of urban traffic have been greatly improved, and energy waste and exhaust emissions caused by traffic congestion have been reduced, which has strongly promoted the sustainable development of the city.

2) Shanghai Intelligent Connected Vehicle Demonstration Zone

As an important testing and application area for intelligent connected vehicles in China, the Shanghai Intelligent Connected Vehicle Demonstration Zone is making every effort to build a demonstration application of the integrated comprehensive system for human-vehicle safety in the smart Internet of Vehicles. In the automatic assisted driving function module, many vehicle manufacturers conduct tests and verifications on autonomous driving technologies with the help of high-precision maps, laser radars, cameras and other equipment, and successfully enable vehicles to stably realize functions such as adaptive cruise, automatic emergency braking and lane keeping assistance in complex urban road environments. In the emergency response function module, the emergency airbag upgrade system has been applied to some test vehicles, and its power suspension and attitude adjustment functions have effectively reduced the risks of vehicle rollover and secondary injuries during simulated collision tests. The traffic congestion alleviation module dynamically adjusts the duration of traffic lights according to the real-time traffic flow through intelligent traffic signal control, and combines with the vehicle cooperative driving sub-module to encourage vehicles to form fleets, which has increased the traffic volume carrying capacity of specific test sections by about 30%. The application of this demonstration zone not only provides valuable experience and data support for the development of smart Internet of Vehicles technology in China, but also, in terms of safety, due to the effective operation of the automatic assisted driving and dangerous monitoring and early warning functions, the number of traffic accidents in the test area has been significantly reduced, especially the accidents caused by human operation errors have decreased by about 40%. In terms of traffic efficiency, the average waiting time at intersections has been reduced by about 25%, and the road resources have been fully utilized, thus laying a solid foundation for the large-scale construction of future urban smart transportation.

5. Conclusion and Prospects

The integrated comprehensive system for human-vehicle safety in the smart Internet of Vehicles has brought revolutionary changes to modern transportation through innovative architecture design and advanced technology applications. It has shown great advantages and potential in ensuring human-vehicle safety, alleviating traffic congestion and improving traffic efficiency. With the continuous development of related fields such as sensor technology, communication technology and artificial intelligence, this system is expected to be further improved and optimized to achieve wider application and greater social and economic benefits. In the future, we will continue to pay attention to the performance improvement and application promotion of the system, and strive to build a safer, more efficient and intelligent transportation environment. At the same time, it is also necessary to further strengthen cross-industry and cross-field cooperation to jointly promote the in-depth development of smart Internet of Vehicles technology in the transportation field.

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