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An overview of automotive safety and user experience enhancement in the era of the Internet of Vehicles

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Abstract. With the rapid development of Internet of Vehicles (IoV) technologies, the automotive industry is undergoing a profound transformation from traditional mechanical systems to intelligent and connected systems. By integrating technologies such as 5G communication, V2X, edge computing, and artificial intelligence, the IoV has established an intelligent transportation system characterized by vehicle-road-cloud-terminal collaboration. Focusing on the two core topics of automotive safety and user experience in the IoV era, this paper systematically reviews the security challenges and pathways for optimizing user experience, while also exploring future trends in their coordinated development. The study finds that IoV technologies offer significant advantages in enhancing traffic safety, improving traffic flow, and reducing energy consumption. However, they also face risks such as cybersecurity threats, data privacy breaches, and system reliability issues. Measures such as optimizing smart cockpit interaction and expanding full-scenario service ecosystems can effectively enhance both automotive safety and user experience. In the future, as technology continues to advance and supportive policies are further implemented, IoV technologies will drive the automotive industry toward a safer, smarter, and more efficient direction.

Keywords: Internet of Vehicles, automotive safety, user experience, V2X, smart cockpit

1. Introduction

With the rapid advancement of information technology, the Internet of Things (IoT) has become a critical bridge between the physical and digital worlds. In the automotive industry in particular, IoT applications are driving a transformative revolution. Vehicle-to-Everything (V2X), as a key application of IoT, enables the exchange of information between vehicles and their surrounding environment through wireless communication technologies, thereby offering new solutions for improving road safety and reducing traffic congestion [1]. In recent years, the rise of autonomous driving and intelligent connected vehicles has drawn significant attention to V2X technology. Around the world, governments and enterprises have been increasing their investments in this field, accelerating its development [2].

The core objective of V2X is to enhance the overall level of intelligent driving, providing users with safer, more comfortable, smarter, and more efficient driving experiences and mobility services. At the same time, it aims to improve traffic efficiency and promote the intelligent development of transportation systems. From early in-vehicle information systems to today's fully integrated smart connectivity, V2X technology has evolved from a conceptual idea to widespread application. However, its extensive implementation also brings a host of new challenges—particularly the balancing act between automotive safety and user experience, which has become a major research focus. Progress in this area directly influences the direction of innovation and the competitive landscape of the entire industry.

V2X technology significantly increases the frequency of information exchange between vehicles and external systems. While it brings added convenience, it also introduces new cybersecurity threats such as network attacks and data breaches. For instance, hackers may gain remote control of a vehicle by infiltrating its V2X system, posing severe threats to driver and passenger safety [3, 4]. This paper systematically gathers, categorizes, and analyzes the types of security risks faced by vehicles in the V2X era, covering both active and passive safety systems.

V2X endows vehicles with new capabilities such as intelligent interaction and personalized services. However, some current V2X applications still suffer from complex operations, slow responsiveness, and poor service adaptability, which negatively impact user experience. Taking user needs and behaviors as a starting point, this paper systematically identifies the key factors and methods for enhancing user experience in the V2X era. The goal is to provide valuable references for automakers to optimize product design and improve service models, thereby promoting a deeper integration between V2X functions and real user demands. Ultimately, this can increase user acceptance and satisfaction, and help drive upgrades in the automotive consumer market.

In addition, this paper provides a comprehensive overview of the research findings and practical cases related to automotive safety and user experience enhancement. These insights serve as valuable references for technology R&D, standard-setting, and policy planning within the industry. By helping to dismantle industry barriers and promoting cross-sector collaborative innovation, this work contributes to the maturation and refinement of the V2X ecosystem and supports China's automotive industry in gaining a competitive edge during the global transition to intelligent mobility.

Finally, this paper offers a forward-looking analysis of the future direction of automotive safety and user experience enhancement, based on trends in V2X technology development, shifting market demands, and evolving policy and regulatory frameworks. From the perspectives of technological innovation, industrial collaboration, and policy support, it provides targeted suggestions and strategies for automotive enterprises, research institutions, and government agencies, with the aim of continuously optimizing automotive safety and user experience in the V2X era and promoting the healthy, rapid development of the V2X industry.

2. Automotive safety systems

2.1. Active safety systems

Active safety systems refer to those that take preventive measures before an accident occurs, aiming to avoid or mitigate collisions. With real-time data collection and intelligent decision-making enabled by IoT technology, the effectiveness of these systems has been significantly enhanced.

2.1.1. Collision warning system

The collision warning system utilizes onboard sensors—such as radar, LiDAR, and cameras—to monitor obstacles ahead. When a potential collision is detected, the system issues warning signals to alert the driver to take corrective action. Data collected by the sensors is transmitted in real time via onboard units and roadside units, then rapidly processed and analyzed using edge computing and cloud computing technologies. Artificial intelligence algorithms are employed to identify potential hazards and issue timely alerts.

2.1.2. Automatic Emergency Braking

The Automatic Emergency Braking (AEB) system activates when the collision warning system alerts the driver but no action is taken in time. It automatically engages the brakes to reduce the severity of a collision or avoid it altogether. The AEB system relies on high-precision sensors—such as radar, LiDAR, and cameras—and rapid data processing capabilities. Edge computing allows for swift, localized decision-making within the vehicle, ensuring braking is initiated within milliseconds.

2.1.3. Lane Departure Warning

The Lane Departure Warning (LDW) system uses cameras to monitor lane markings and alerts the driver when the vehicle unintentionally departs from its lane. The images captured by the cameras are analyzed using image processing algorithms to recognize lane boundaries and the vehicle's position. Edge computing enables real-time data processing and triggers alerts when necessary.

2.2. Passive safety systems

Passive safety systems refer to those that help mitigate the consequences after an accident has occurred. With real-time monitoring and rapid response capabilities, V2X technology has improved the performance of these systems.

2.2.1. Post-collision rapid response mechanism

After a collision, the system can automatically send a distress signal, providing the vehicle's location and accident details to enable rescue personnel to arrive quickly. Onboard sensors—such as accelerometers and airbag sensors—detect collision events, and once a crash is identified, the system triggers an emergency call and transmits incident information via cellular networks (such as C-V2X). Vehicle location is accurately determined using GPS or the BeiDou Navigation Satellite System.

2.2.2. Intelligent airbag system

The intelligent airbag system conducts real-time monitoring through multiple sensors, including pressure and acceleration sensors. Upon collision, edge and cloud computing technologies are used to quickly analyze the severity of the crash and the position of occupants. This information determines how the airbags deploy, ensuring optimal protection for passengers [5].

3. User experience optimization pathways

User experience is a key driving force behind the development of Internet of Vehicles (IoV) technologies. Efforts should be guided by scenario-based demands to construct a triadic service system characterized by “safety, convenience, and personalization.” Through IoV systems, vehicles can deliver smarter, more personalized, and more convenient services, thereby enhancing the overall driving and riding experience.

3.1. Intelligent cockpit interaction

Intelligent cockpit interaction is crucial for improving user experience. By integrating voice, gesture, and multimodal interaction technologies, it enables natural and convenient human-machine interaction. For instance, the Banma Zhixing system utilizes an NLP engine to enable conversational navigation control, allowing users to issue voice commands to check traffic conditions, adjust the air conditioning, or play music—thus improving convenience and safety during driving.

3.2. Intelligent navigation and real-time traffic information

Intelligent navigation systems collect traffic data through onboard sensors and roadside units, which are transmitted to the cloud via cellular networks (such as C-V2X). Cloud computing platforms process this data to generate real-time traffic information, which is then delivered to users through onboard navigation systems or mobile applications to help drivers avoid congested routes. Furthermore, intelligent navigation systems can dynamically plan optimal driving routes based on real-time traffic conditions and user preferences using machine learning algorithms.

3.3. Personalized services

Personalized service recommendations represent an innovative direction in IoV technology. Based on user profiling and driving behavior analysis, the system can offer customized entertainment content and energy efficiency suggestions. For example, music playlists can be recommended according to user preferences, or energy strategies can be adjusted based on driving habits to extend driving range. Practices from a certain new energy vehicle manufacturer indicate that this feature can increase user retention by 15%.

3.4. Remote control and online services

IoV technology enables users to remotely control their vehicles via smartphones or other mobile devices—for example, starting the engine, turning on the air conditioning, or unlocking the doors—greatly enhancing user convenience and comfort. In addition, users can schedule maintenance and repair services through onboard systems or mobile applications. Service options can be browsed and appointments made directly through these platforms. Service centers, in turn, can provide personalized recommendations based on real-time vehicle data.

3.5. Driver assistance

With advanced sensors and algorithms, IoV technology supports a variety of driver assistance functions that make driving safer, more comfortable, and more efficient. Lane Centering Control (LCC) uses cameras to monitor lane markings and automatically adjusts the steering wheel to keep the vehicle centered in its lane. Navigation On Autopilot (NOA) integrates navigation systems with autonomous driving technologies, enabling automatic lane changes, overtaking, and navigation on highways and urban roads. Automatic Parking Assist (APA) employs ultrasonic sensors and cameras to automatically perform parallel and perpendicular parking maneuvers. These drivers assistance features significantly enhance driving safety and comfort while reducing the operational burden on the driver.

4. Case studies

4.1. Huawei HiCar intelligent connectivity system

Huawei HiCar is a comprehensive Internet of Vehicles (IoV) solution launched by Huawei, aimed at delivering a seamless smart connectivity experience between smartphones and vehicles. Leveraging Huawei's distributed technology, HiCar enables the seamless transfer of smartphone applications and services to the vehicle's display, achieving deep integration between the smartphone and the vehicle to provide users with a more consistent and smooth experience [6]. HiCar also incorporates Huawei's Xiaoyi voice assistant, supporting voice commands for navigation, music, phone calls, and other functions, thereby enhancing convenience and safety during driving. In addition, HiCar supports a wide range of third-party applications and services, such as map navigation, music entertainment, and smart home control, forming a rich IoV ecosystem that expands the functionality of HiCar and offers users more options and convenience.

4.2. Tesla autopilot autonomous driving system

Tesla's Autopilot is one of the most well-known applications of IoV technology currently on the market. This system uses a suite of advanced sensors—including cameras, radar, and ultrasonic sensors—alongside powerful data processing capabilities to enable highly automated driving assistance features [7]. Through sensor fusion technology, the Autopilot system provides comprehensive environmental perception, allowing it to more accurately identify and track surrounding objects and thus enhance driving safety. Real-time data processing is conducted via onboard computers, which employ artificial intelligence algorithms to analyze sensor data and make driving decisions on the fly. Moreover, Tesla continuously updates the Autopilot system via Over-The-Air (OTA) technology, delivering the latest features and improvements to ensure users benefit from the most up-to-date capabilities.

5. Challenges

5.1. Technical challenges

On the technical front, IoV systems face multiple challenges. First, they must handle vast amounts of real-time data, demanding extremely high data processing speed and computational power. Second, the precision of sensors directly affects system performance, particularly under adverse weather conditions and in complex environments. Furthermore, IoV systems rely on low-latency communication networks, especially for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) interactions. Cybersecurity concerns are also increasingly prominent, as hacking attacks could pose serious safety threats. Additionally, issues related to compatibility and integration between different manufacturers and technologies complicate the collaborative operation of the entire system.

5.2. Regulatory challenges

From a regulatory perspective, IoV systems raise several key issues. First, as they involve extensive personal data, protecting user privacy becomes a major concern. Second, different countries and regions have varying regulations on data flows, creating barriers to global deployment of IoV systems. When autonomous vehicles are involved in accidents, questions of liability become complex, necessitating clear standards for responsibility attribution. Moreover, existing legal frameworks may lag behind the rapid development of IoV technologies, resulting in regulatory gaps [8].

5.3. Social acceptance

In terms of social acceptance, IoV systems face several critical hurdles. First, users often have low trust in new technologies, especially regarding the safety and reliability of autonomous driving. Second, widespread adoption of IoV technology requires time and financial investment, particularly in retrofitting and upgrading older vehicles. In addition, users need relevant education and training to properly use and understand IoV systems. Finally, there is a general lack of public awareness regarding the potential value and benefits of IoV technologies.

5.4. Sustainability

Regarding sustainability, IoV systems face a variety of challenges. First, the long-term operation and maintenance of these systems entail high costs and require sustained financial support. Second, the large-scale application of IoV technology may introduce new environmental issues, such as electronic waste and energy consumption. Rapid technological iteration can also render existing systems obsolete, increasing the cost of upgrades and replacements. Moreover, the construction and maintenance of IoV infrastructure demand significant resource investment, making the rational allocation of resources another critical concern.

6. Future trends and developments

6.1. Technological advancements

With ongoing developments in the Internet of Things (IoT), artificial intelligence, big data, and 5G/6G communications, the Internet of Vehicles (IoV) is poised for a series of breakthroughs and new development opportunities [9]. Autonomous driving technology is gradually maturing, and advancements in sensor technologies, computational capabilities, and AI algorithms are driving the commercialization of Level 4 (high automation) and Level 5 (full automation) autonomous driving. Multimodal sensor fusion technologies—integrating data from cameras, radar, LiDAR, and more—will enable more comprehensive environmental perception, significantly enhancing system reliability, particularly in adverse weather and complex environments. Adaptive learning technologies will allow systems to tailor functions to user habits and preferences, offering more personalized and user-centric experiences.

6.2. Market trends

As IoV technology continues to evolve, market trends are also shifting, with new business models and application scenarios constantly emerging. The demand for new energy vehicles, especially electric vehicles, will continue to grow. IoV technology plays a crucial role in these vehicles by enabling smarter charging and energy management services, thereby improving user convenience and reducing vehicle ownership costs. The shared mobility model will continue to develop, with IoV technology providing more efficient vehicle scheduling and management for mobility platforms, enhancing operational efficiency and user experience [10]. Commercial fleets and logistics operations are also increasingly adopting IoV solutions to achieve real-time vehicle monitoring, route optimization, and enhanced safety management.

6.3. Social impact

As IoV technology becomes more widespread, communication and coordination between vehicles will become more seamless, helping to reduce traffic accidents and improve road safety. The integration of IoV with intelligent traffic management systems will enable real-time monitoring of traffic flows and optimized dispatching, thereby alleviating congestion, improving emergency response efficiency, accelerating rescue efforts, and reducing casualties. At the same time, IoV will contribute to more efficient vehicle energy management, reducing energy consumption and carbon emissions, and promoting environmental sustainability.

7. Conclusion

IoV technology has already achieved significant progress, not only enhancing vehicle safety but also greatly improving the driving experience. Through case studies, we have observed the successful technological innovation and market performance of Tesla, Huawei, and Li Auto. Nevertheless, IoV still faces challenges in areas such as technology, regulation, social acceptance, and sustainability. By adopting targeted solutions such as edge computing, high-precision sensors, multilayered security protection, international cooperation, transparent communication, and innovative business models, these challenges can be effectively addressed. Looking ahead, IoV technology is expected to make even greater strides in autonomous driving, 5G/6G communication, and artificial intelligence, offering society a safer, more efficient, and more environmentally friendly travel experience.

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