International Journal of Science and Engineering Applications
Volume 13-Issue 10, 30 – 33, 2024, ISSN:- 2319 - 7560
DOI: 10.7753/IJSEA1310.1007

Research on Key Technologies of "Human-Vehicle-Road" Collaborative Perception for Intelligent Connected Vehicles

Long Ya
Zhejiang Institute of Communications
Hangzhou, 311112, Zhejiang, China

Abstract:The rapid advancement of new energy vehicle technology, coupled with the integration of artificial intelligence (AI), has significantly contributed to the development of intelligent connected vehicles (ICVs). These vehicles, equipped with the Internet of Things (IoT) and advanced end devices, can sense their surroundings, engage in adaptive learning, and perform autonomous driving tasks. Central to the future of ICVs is the human-vehicle-road collaborative perception system, which enables dynamic, multi-dimensional interaction between drivers, vehicles, and road infrastructure. This paper explores the key technologies that underpin this collaboration, focusing on the integration of perception systems, communication technologies, and AI-driven big data analytics. It also addresses the challenges associated with data privacy, real-time traffic management, and the technical bottlenecks in current intelligent transportation systems. The research highlights the importance of sensor fusion, V2X communication, and AI-based decision making in achieving fully autonomous driving and intelligent traffic management. The study provides a detailed examination of the technological ecosystem required for the effective operation of ICVs, emphasizing the role of local processing systems and the development of infrastructure such as 5G networks, smart traffic signals, and energy-efficient solutions.

Keywords: Key technologies, human-vehicle-road, collaborative perception, intelligent connected vehicles

1. INTRODUCTION

Against the backdrop of the rapid development of new energy vehicle technology, the application of artificial intelligence has further promoted the innovation and transformation of the intelligent networked new energy vehicles. Through the Internet of Things technology and advanced intelligent terminal devices, intelligent networked vehicles can not only perceive the external environment, but also perform adaptive learning, thereby achieving more intelligent driving and vehicle management. For example, based on sensors and big data analysis, vehicles can perform real-time path planning and autonomous driving decisions under different road conditions to ensure driving safety and comfort. In addition, the vehicle's autonomous driving system can also interconnect with other vehicles and traffic infrastructure to further optimize traffic flow, reduce congestion, and improve overall traffic efficiency. In terms of energy management, the addition of artificial intelligence makes the energy distribution of new energy vehicles more intelligent and efficient. Through the complex computing models, vehicles can dynamically adjust battery usage and energy recovery strategies according to driving environment, road conditions and energy consumption, thereby extending battery life and improving energy utilization. For pure electric vehicles, artificial intelligence can also minimize charging time and grid pressure through intelligent scheduling of charging modes and times, thereby improving users' car experience.

At the same time, artificial intelligence technology has also played an important role in the training of automotive professionals. The intelligent tutoring system based on artificial intelligence can provide students with customized teaching plans. These systems use domain models, tutor models, and learning models to build a computer learning platform that enables students to simulate real car operation scenarios in a virtual environment. For example, in the engine repair and maintenance course, the system can dynamically adjust the teaching content according to the students' learning progress and understanding, and provide the personalized feedback and suggestions. This interactive and intelligent teaching mode not only greatly improves the students' learning efficiency, but also enhances their practical operation ability, laying a solid foundation for future career development. In addition, traditional automotive teaching materials have also been innovated with the introduction of intelligent tutoring systems. By adopting the hierarchical structures and semantic networks, the system presents complex technical knowledge to students in a more logical and interactive way, replacing the static display of traditional paper teaching materials. This not only improves students' learning interest, but also enhances their mastery of the knowledge. The system can also evaluate each student's learning performance, automatically generate personalized learning reports, and provide further learning suggestions, making training more efficient and accurate. In the Figure 1, the sample of the Intelligent Connected Vehicles is illustrated.

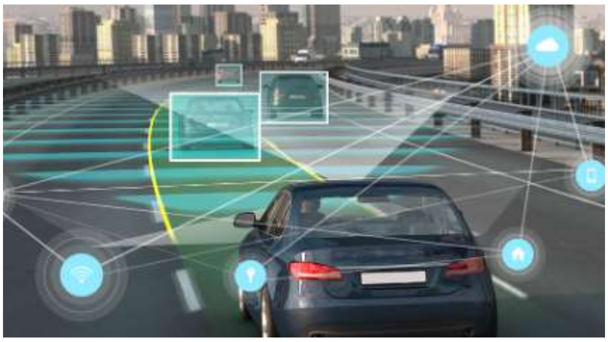

Figure. 1 The Sample of Intelligent Connected Vehicles (Image from Google)

As the core direction of the future automobile industry, intelligent connected vehicles have become an important force in promoting transportation reform. However, to truly achieve this goal, technological breakthroughs and system improvements are still needed at multiple levels. First of all, the intelligent transportation system is the foundation for the development of intelligent connected vehicles, and its core lies in the coordinated operation of vehicles, roads, traffic signals and other aspects. Therefore, a perfect intelligent transportation system should not only cover technological innovations in the field of automobile production and manufacturing, but also make significant progress in urban infrastructure construction, new energy applications, information and communications and other fields. Only through the comprehensive advancement of these fields can the efficiency and reliability of intelligent connected vehicles in actual use be ensured.

Further, the widespread application of intelligent connected vehicles will drive the comprehensive upgrade of the transportation system. For example, in the intelligent traffic management system, the communication between vehicles and road infrastructure can effectively reduce traffic congestion and reduce the rate of traffic accidents. At the same time, based on big data analysis and artificial intelligence technology, the system can adjust traffic lights and optimize traffic flow in real time, which not only improves social benefits, but also brings significant economic benefits. It can be foreseen that the popularization of intelligent connected vehicles will promote the urban transportation to develop in a more intelligent and efficient direction. At the same time, the development of intelligent connected vehicles also requires a highly integrated vehicle control system. This system is usually composed of a locomotive main control subsystem and a cockpit domain control subsystem. During the driving process of the car, the vehicle will generate a large amount of real-time data, which includes not only the vehicle's speed, location, fuel or battery usage, but also the driver's behavior, road conditions and other external environmental data. Due to the huge volume of data, uploading all data to the cloud for processing is not only unrealistic, but also causes excessive network load. Therefore, the vehicle control system must have strong local processing capabilities.

Intelligent connected vehicles analyze and process data in real time through local control systems, achieving rapid response and precise control of vehicles. For example, in emergency braking or obstacle avoidance scenarios, the vehicle's control system can make decisions quickly based on real-time data collected by sensors to reduce the occurrence of accidents. For those data that do not need to be processed immediately, the system can selectively save them locally or upload them to the cloud for further analysis at the right time. This not only improves the system's response speed, but also effectively saves network bandwidth.

In addition, the improvement of infrastructure is also a necessary condition for the smooth operation of intelligent connected vehicles. The development of intelligent connected vehicles depends on the construction of stable 5G communication networks, intelligent traffic signal systems, and related facilities such as charging stations. These facilities can ensure low-latency communication between vehicles and the cloud, allowing intelligent connected vehicles to seamlessly connect with other vehicles and road facilities during driving. In addition, the promotion and application of new generation new energy technologies also provide more environmentally friendly and efficient energy solutions for intelligent connected vehicles. In the future, as related technologies gradually mature, intelligent connected vehicles will play a greater role in reducing carbon emissions and optimizing energy use.

2. THE PROPOSED METHODOLOGY

2.1 The Key Ideas of Human-Vehicle-Road

The optimization and scheduling of smart highway traffic flow depends on the effective integration of the human-vehicle-road collaborative system, but there are many problems that need to be solved in this process. First, the sources of traffic data are extremely scattered, covering multiple channels such as traffic management departments, vehicle-mounted equipment, roadside equipment, and mobile applications. Due to the lack of unified standards for different data sources, the data formats vary greatly, and even some data sharing interfaces are closed, which brings huge challenges to data collection and integration. In reality, traffic management departments and related agencies often act independently, independently collecting and retaining the traffic data they need, forming the so-called "data islands". This phenomenon has exacerbated information asymmetry and seriously hindered cross-departmental and cross-system data sharing and collaborative work. In addition to the problems of standards and interfaces, data privacy protection and information security are also one of the main challenges facing human-vehicle-road collaboration. Traffic data contains a large amount of information involving personal privacy, such as vehicle trajectories, travel habits, etc. If handled improperly, it may cause privacy leakage and security risks. Therefore, in the process of data sharing, it is necessary not only to consider how to ensure the integrity and availability of data, but also to ensure that operations are within the framework of privacy protection. Relevant laws and regulations also put forward strict requirements for data acquisition and sharing, which makes data opening and sharing more complicated. For example, some countries and regions have implemented strict privacy protection policies, such as the General Data Protection Regulation (GDPR), which stipulates that the collection, use and sharing of personal information must meet specific legal standards, which undoubtedly increases the complexity of smart traffic data sharing.

In addition, existing traffic data processing technologies and analysis tools also face technical bottlenecks. Due to the strong real-time nature of traffic flow data and the huge amount of data, especially in the smart highway environment, the traffic is dense and changes rapidly, and the traditional data processing model is difficult to meet the needs of real-time monitoring and response. At the same time, the coordination problems between different data sources and the algorithm efficiency problems of large-scale data processing have affected the accuracy and timeliness of the traffic dispatch system. In the future, how to improve the efficiency of data processing and how to better realize the integration and unification of heterogeneous data are urgent research directions.

The "people-vehicle-road" collaborative perception of the intelligent connected vehicles is one of the key technologies to promote the intelligence of future transportation systems. By closely connecting people, vehicles and road infrastructure to achieve multi-dimensional information sharing and interaction, this collaborative perception system not only improves traffic safety and efficiency, but also provides technical support for the full implementation of autonomous driving and intelligent transportation. When discussing its core technologies, it is necessary to explore from three aspects: perception technology, communication technology, and big data analysis and artificial intelligence.

First, perception technology is the basis of "people-vehicle-road" collaboration. On-board sensors such as radar, lidar, camera, ultrasonic sensor, etc. can obtain dynamic information about the vehicle's surrounding environment in real time, such as pedestrians, vehicles, obstacles and road signs. In addition, the sensor network in the road infrastructure can also capture road condition information, traffic signals and other related data. The accuracy and sensitivity of these perception systems directly determine the quality of collaborative perception. In the future, sensor fusion technology will further enhance the fusion capability of multi-source information, ensure the accuracy and comprehensiveness of data, and thus enhance the stability and reliability of collaborative perception.

Secondly, communication technology is a bridge to achieve "people-vehicle-road" collaboration. Vehicle-to-Everything (V2X) technology enables real-time information sharing through communication between vehicles and other vehicles (V2V), road infrastructure (V2I), pedestrians (V2P) and the cloud (V2C). The low latency and high bandwidth characteristics of 5G communication networks provide strong support for these communication interactions, making the transmission of information more efficient and timely. However, the challenge of communication technology is how to ensure the security and stability of data transmission, especially in high-density traffic flow, where network congestion and delays may lead to a decline in system performance. Therefore, the future development direction is not only to increase communication speed, but also to integrate more sound data encryption and privacy protection mechanisms into the vehicle networking system.

Finally, big data analysis and artificial intelligence are the intelligent core of "human-vehicle-road" collaborative perception. Through real-time analysis and processing of massive traffic data, intelligent algorithms can predict traffic flow, analyze driving behavior, detect road conditions, etc., and provide decision support. Especially in autonomous driving scenarios, artificial intelligence can make driving decisions in real time based on vehicle sensors and road information. Combining deep learning and reinforcement learning, vehicles can learn from historical data, continuously optimize driving strategies, and improve driving safety and efficiency. At the same time, the cloud-based big data platform provides powerful computing power support for the intelligence of the entire system, ensuring that the "human-vehicle-road" collaborative perception system can handle and respond to complex and changing traffic environments. In the Figure 2, the key ideas are illustrated.

Figure. 2 The Key Ideas of Human-Vehicle-Road (Image source: https://www.mdpi.com/1424-8220/22/12/4614)

2.2 Analysis of the Technological Development of Intelligent Connected Vehicles

The development of intelligent networked vehicles will not only draw on the evolutionary model of mobile computer systems, but will also be closely integrated with urban three-dimensional transportation and energy supply systems to form a comprehensive technology ecosystem. In response to this trend, we can explore the development path of future technologies for intelligent networked vehicles from multiple perspectives.

First, the future development of in-vehicle software will be similar to mobile phone software, gradually evolving into a new software platform. Just as the operating system of a smartphone provides support for various applications, in-vehicle software will also shift from traditional functions to a more open platform. The host operating system is still the core of in-vehicle software, covering core functions such as the vehicle's control system, storage system, input and output system, communication system, and battery management system. These software are not only used to realize the basic driving functions of the car, but will also promote the intelligent process of the vehicle, such as automatic driving, smart cruise and other functions. At the same time, with the continuous upgrading of vehicle networking technology, App applications similar to smartphones will gradually become popular in vehicles, providing entertainment, navigation, remote monitoring and other functions, achieving higher personalization and convenience. For example, in the future, car owners can adjust vehicle settings, remotely start or monitor vehicle status at any time through in-vehicle applications.

Secondly, the development of intelligent networked vehicles will be based on the overall technical architecture of "car-road-cloud". Cars are no longer just a means of transportation, but a mobile smart terminal; roads will become nodes for edge computing, combined with cloud systems to jointly process massive amounts of data. The core of this system is that through V2X (Vehicle to Everything) technology, smart connected cars can communicate seamlessly with road infrastructure, other vehicles, pedestrians and cloud systems to achieve perception capabilities across line of sight. For example, when a car is driving, roadside sensors can obtain real-time information about the road ahead in advance, predict traffic conditions and pass data to the vehicle, enabling the driving system to make safer and more accurate decisions. This "car-road-cloud" collaborative work not only improves the intelligence of the vehicle, but also greatly improves driving safety and traffic flow efficiency.

Third, with the development of urban three-dimensional transportation, the application scenarios of smart connected cars will be more extensive. Future urban transportation is not only limited to the ground, but may also involve elevated roads, tunnels and other three-dimensional transportation infrastructure. In order to adapt to this complex and changing traffic environment, smart connected cars need to have stronger environmental perception and adaptability. This includes not only the upgrade of on-board sensor technology, but also the intelligent construction of road infrastructure, such as smart traffic lights, automatic toll collection systems, dynamic traffic signs, etc. In addition, the further development of three-dimensional transportation will also promote the coordinated development of flying cars and ground transportation, while forming a truly multi-dimensional intelligent transportation network.

3. CONCLUSION

This paper presents a comprehensive analysis of the key technologies required for collaborative human-vehicle-road perception in Intelligent Connected Vehicles. The successful deployment of ICVs requires significant advances in perception technology, communication systems, and AI-based data analytics, all of which contribute to safer, more efficient traffic management and autonomous driving. Despite the promise of ICVs, challenges such as data integration, real-time processing, and privacy must be addressed to ensure widespread adoption. Going forward, the development of a robust technology infrastructure, including 5G networks and intelligent road systems, will be critical to realizing the full potential of ICVs. Collaboration among various stakeholders in the automotive, telecommunications, and infrastructure sectors will play a key role in shaping the future of intelligent transportation systems.

4. ACKNOWLEDGEMENT

Fund project: General Research Projects of Zhejiang Provincial Department of Education in 2023：《Research and Application of Key Technologies for "Human-Vehicle-Road" Collaborative Perception in Intelligent Connected Vehicles（Fund number：Y202352134）》

5. REFERENCES

[1] Dibaei, Mahdi, Xi Zheng, Kun Jiang, Robert Abbas, Shigang Liu, Yuexin Zhang, Yang Xiang, and Shui Yu. "Attacks and defences on intelligent connected vehicles: A survey." Digital Communications and Networks 6, no. 4 (2020): 399-421.

[2] Chang, Xin, Haijian Li, Jian Rong, and Xiaohua Zhao. "Analysis on traffic stability and capacity for mixed traffic flow with platoons of intelligent connected vehicles." Physica A: Statistical Mechanics and Its Applications 557 (2020): 124829.

[3] Gao, Kai, Shuo Huang, Jin Xie, Neal N. Xiong, and Ronghua Du. "A review of research on intersection control based on connected vehicles and data-driven intelligent approaches." Electronics 9, no. 6 (2020): 885.

[4] Sun, Chao, Jianghao Leng, and Fengchun Sun. "A fast optimal speed planning system in arterial roads for intelligent and connected vehicles." IEEE Internet of Things Journal 9, no. 20 (2022): 20295-20307.

[5] Mingyang, C. U. I., Heye HUANG, X. U. Qing, W. A. N. G. Jianqiang, Takaaki SEKIGUCHI, G. E. N. G. Lu, and L. I. Keqiang. "Survey of intelligent and connected vehicle technologies: Architectures, functions and applications." Journal of Tsinghua University (Science and Technology) 62, no. 3 (2022): 493-508.

[6] Lian, Yanqi, Guoqing Zhang, Jaeyoung Lee, and Helai Huang. "Review on big data applications in safety research of intelligent transportation systems and connected/automated vehicles." Accident analysis & Prevention 146 (2020): 105711.

[7] Cao, Bin, Xinghan Chen, Zhihan Lv, Ruichang Li, and Shanshan Fan. "Optimization of classified municipal waste collection based on the internet of connected vehicles." IEEE Transactions on Intelligent Transportation Systems 22, no. 8 (2020): 5364-5373.

[8] Petrillo, Alberto, Antonio Pescape, and Stefania Santini. "A secure adaptive control for cooperative driving of autonomous connected vehicles in the presence of heterogeneous communication delays and cyberattacks." IEEE transactions on cybernetics 51, no. 3 (2020): 1134-1149.

[9] Chen, Bokui, Duo Sun, Jun Zhou, Wengfai Wong, and Zhongjun Ding. "A future intelligent traffic system with mixed autonomous vehicles and human-driven vehicles." Information Sciences 529 (2020): 59-72.

[10] Li, Yongfu, Zhenyu Zhong, Yu Song, Qi Sun, Hao Sun, Simon Hu, and Yibing Wang. "Longitudinal platoon control of connected vehicles: Analysis and verification." IEEE Transactions on Intelligent Transportation Systems 23, no. 5 (2020): 4225-4235.

[11] Liu, Jingxin, Xiaofeng Liao, Jin-song Dong, and Amin Mansoori. "A neurodynamic approach for nonsmooth optimal power consumption of intelligent and connected vehicles." Neural Networks 161 (2023): 693-707.

[12] Lv, Zhihan, Liang Qiao, and Ilsun You. "6G-enabled network in box for internet of connected vehicles." IEEE transactions on intelligent transportation systems 22, no. 8 (2020): 5275-5282.

[13] Viktorović, Miloš, Dujuan Yang, and Bauke de Vries. "Connected Traffic Data Ontology (CTDO) for intelligent urban traffic systems focused on connected (Semi) autonomous vehicles." Sensors 20, no. 10 (2020): 2961.

[14] Rehman Javed, Abdul, Zunera Jalil, Syed Atif Moqurrab, Sidra Abbas, and Xuan Liu. "Ensemble adaboost classifier for accurate and fast detection of botnet attacks in connected vehicles." Transactions on Emerging Telecommunications Technologies 33, no. 10 (2022): e4088.

[15] Ge, Xiaohua, Qing-Long Han, Qing Wu, and Xian-Ming Zhang. "Resilient and safe platooning control of connected automated vehicles against intermittent denial-of-service attacks." IEEE/CAA Journal of Automatica Sinica 10, no. 5 (2022): 1234-1251.

[16] Mohammadnazar, Amin, Ramin Arvin, and Asad J. Khattak. "Classifying travelers' driving style using basic safety messages generated by connected vehicles: Application of unsupervised machine learning." Transportation research part C: emerging technologies 122 (2021): 102917.

[17] Dong, Peng, Junwei Zhao, Xuewu Liu, Jian Wu, Xiangyang Xu, Yanfang Liu, Shuhan Wang, and Wei Guo. "Practical application of energy management strategy for hybrid electric vehicles based on intelligent and connected technologies: Development stages, challenges, and future trends." Renewable and Sustainable Energy Reviews 170 (2022): 112947.