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Research on the Application of Vehicle-Road Cooperative Autonomous Driving

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Abstract

In order to solve the safety problem of bicycle intelligence under extreme conditions, a vehicle-road cooperative autonomous driving solution is proposed. The solution completes the real-time data interaction between intelligent networked vehicles and C-V2X (Cellular Vehicle-to-Everything) cloud platform through cellular network communication technology, GPS high-precision positioning technology, edge cloud collaboration and edge computing technologies, realizes "vehicle-road-cloud" digital information sharing, and improves vehicle driving safety and road traffic efficiency.

Keywords

Vehicle-road Collaboration; Autonomous Driving; Bicycle Intelligence; Edge Computing.

1. The Overall Scheme of Vehicle-road Coordination

The intelligent autonomous driving of a single vehicle often requires a large number of high-precision sensors on the vehicle and is equipped with powerful computing chips, which increases a certain cost, and at the same time, when the weather environment and the on-board camera sensor are blocked, the driving safety is also in jeopardy.

With the development of various digital technologies such as artificial intelligence and cloud computing, vehicle-road collaboration as a new solution for autonomous driving has gradually dominated the future research direction in the field of Internet of Vehicles [1-3]. Here, a vehicle-road collaborative autonomous driving solution is proposed, which mainly includes three parts: vehicle-road collaborative smart road, smart vehicle, and smart cloud. Through MEC (Mobile Edge Computing) and a variety of sensors mounted on traffic rods, the regional environment perception of roads is realized. Through the cellular network, the perception results are reported to the cloud platform and the Road Side Unit (RSU) to realize the real-time status control of the area and complete the corresponding command issuance. At the same time, microwave communication between the RSU and the OBU (On Board Unit) enables vehicles equipped with OBU to perceive the area with high accuracy in all directions. Therefore, compared with single-vehicle intelligence, vehicle-road coordination effectively improves the driving safety of autonomous driving.

2. Vehicle-road Synergy Smart Road

The vehicle-road cooperative smart road is an intelligent and comprehensive road that integrates coordinate system matching, environmental perception, and information communication [4]. It is integrated through the renewal and interaction of various roadside facilities. Figure 1 shows the overall architecture of the roadside equipment.

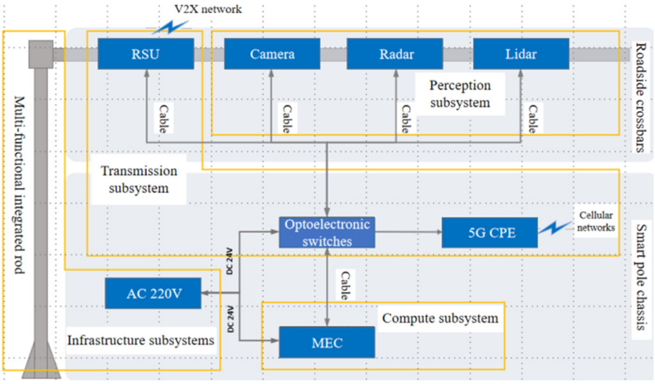

Fig 1. Roadside device architecture

2.1. Coordinate Matching Function

When each sensor works, it carries out perception detection in its own coordinate system, and the use of a single sensor cannot meet the perception requirements required for vehicle-road coordination. Therefore, in order to achieve high-precision cognition of the surrounding environment, it is necessary to fuse the detection results of multiple sensors.

The most important step before the fusion of detection results is to uniformly match the coordinate systems involved in the fusion. The proposed scheme is as follows: firstly, 10-20 fixed reference points are selected, and their position values under the coordinate system of network camera, lidar and millimeter-wave radar are recorded sequentially; Then, the RTK (Real-Time Kinematic) signal receiver was used to collect the position values of the above-mentioned fixed points in the World Geodetic System WGS84 (World Geodetic System 1984). Finally, the rotation and translation relationships from the coordinate systems of different sensors to the WGS84 coordinate system are obtained through the sequential mapping of point pairs, so that the different coordinate systems can be converted to the WGS84 or Universal Transverse MercatorGrid System (UTM) coordinate system.The conversion of the target in the sensor from the coordinates O_C to the WGS84 coordinates O_W can be regarded as obtained by translation and rotation, so the coordinate conversion formula is as in:

$$\begin{bmatrix} X_C \\ Y_C \\ 1 \end{bmatrix} = \begin{bmatrix} Cos\theta & -Sin\theta & X_W \\ Sin\theta & Cos\theta & Y_W \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} X_P \\ Y_P \\ 1 \end{bmatrix} \quad (1)$$

In the above equation, θ is the rotation angle between the coordinate systems, X_P and Y_P are the translation distance between the coordinate systems, X_C Y_C and X_W Y_W are the coordinate values of the target in the sensor coordinate system and the world coordinate system.

2.2. Area-Aware Capabilities

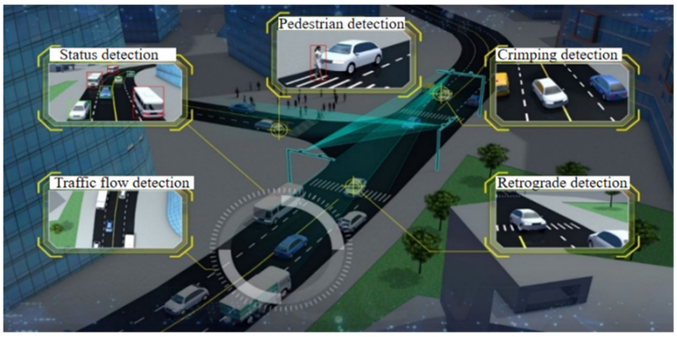

Fig 2. Concept diagram of area-aware features

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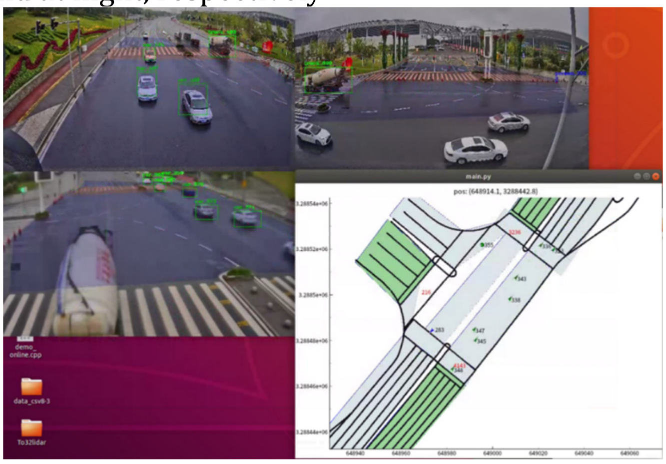
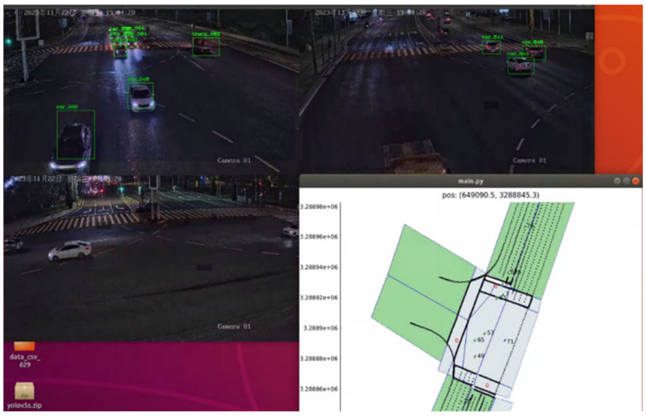
As the eyes of intelligent vehicles, environmental perception plays a pivotal role in subsequent decision-making and planning, as shown in Figure 2. Among them, the perception information includes the situation information of traffic participants and traffic incident information [5].

In the actual intersection application, lidar, millimeter-wave radar and webcam collect the intersection information flow in real time, and transmit the information to the edge computing unit MEC in the LAN through the industrial switch, and then use the fusion perception algorithm deployed on the MEC to realize the real-time detection and tracking of traffic participants.

At the same time, after matching the different sensor coordinate systems with the UTM coordinate system in Section 1.1, the actual geodetic coordinates of the detected and tracked participants can be obtained. Figure 3 shows the actual intersection detection effect image and the corresponding geodetic map display effect, which includes the actual intersection detection effect during the day and at night, respectively.



(a) Practical effect of daytime intersections



(b) Practical effect at night intersections

Fig 3. Actual renderings of vehicle-road coordination intersections

In Figure 3 above, the fusion perception algorithm can detect and track all traffic participants (including pedestrians, cars, trucks, and buses) at the exit of the intersection in real time, and display them in the form of video streams (in the video picture, the blue part represents the motor vehicle detection area of the camera, the red part represents the pedestrian detection area of the camera, and the area that is not covered by the red and blue parts is the area that is not detected). At the same time, the geodetic position and ID tags of traffic participants can also be displayed in real time in the UTM coordinate system.

2.3. Information and Communication Functions

After the area perception information is obtained through different sensors in multiple directions, it only exists in the edge computing unit, and the intelligent vehicle terminal cannot obtain real-time perception information. Therefore, information and communication functions play a very important role in the smart road of vehicle-road cooperation [6,7].

The roadside unit RSU is an important core component of vehicle-road coordination, and it is also the hub responsible for information exchange between systems. It is mainly used to receive traffic and road condition information sent by the MEC side, and transmits the information to the cloud control platform and the on-board unit OBU through cellular network transmission for follow-up processing, and at the same time gives corresponding feedback according to the request of the OBU. In addition, the RSU can also obtain the traffic light second reading information and light color information in real time through the switch and learning machine, and use this information for the interaction with the platform and the OBU, which greatly improves and improves the richness and rationality of vehicle-road cooperation road-end data.

The V2X communication network protocol between the MEC end and the RSU end lays the foundation for the interconnection between the Internet of Vehicles, sensor networks and various wireless networks, and ensures the stability and security of effective information transmission. Figure 4 shows the schematic diagram of road-end information interaction.

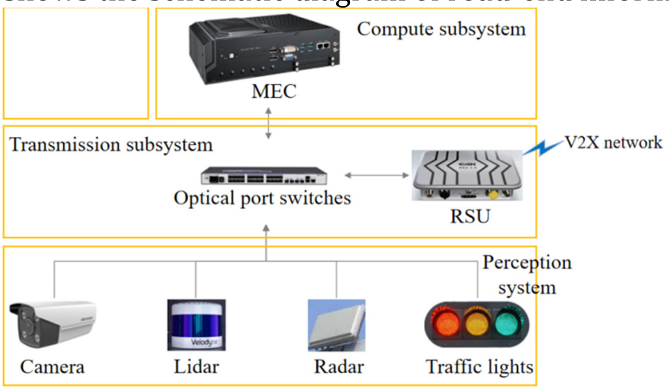
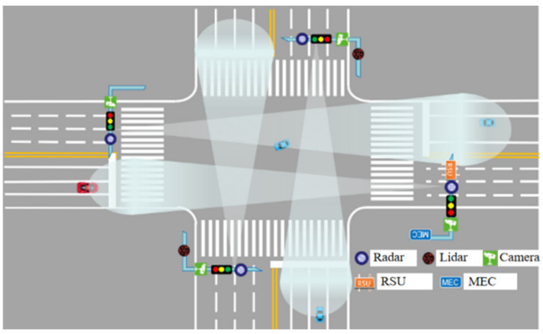


Fig 4. Schematic diagram of road-end information interaction

2.4. Typical Intersection Solutions

From Figure 1, the overall architecture of the vehicle-road cooperative road-end equipment can be obtained. However, for intersections with different road conditions, different solutions need to be designed to complete the global perception function of multiple sensors [8]. Here, a road-end equipment solution for typical intersections such as intersections, roundabouts, and T-junctions is designed, as shown in Figure 5.



(a) Large intersections

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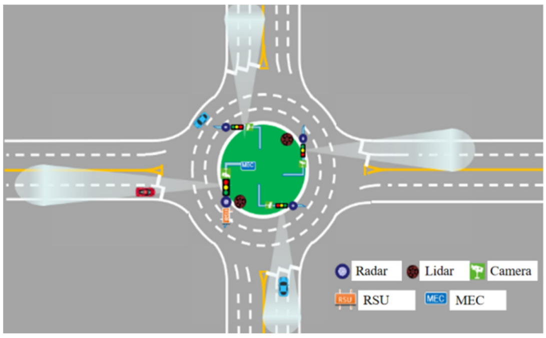
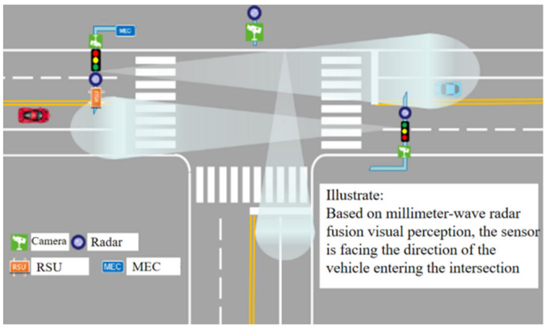


(b) Roundabouts



(c) T-junction

Fig 5. Typical intersection solutions

3. Vehicle-road Collaborative Smart Vehicles

Different from single-vehicle intelligence, intelligent vehicles in vehicle-road coordination only need an intelligent in-vehicle unit OBU to achieve high-efficiency autonomous driving functions. It is mainly due to the fact that the OBU can provide high-precision positioning of the vehicle itself and receive rich real-time road information at the same time [9], including BSM (Basic Safety Msg), RSM (Roadside Safety Msg), MAP (Map Msg), SPAT (Signal Phase and Timing), and RSI (Roadside Information) messages. Figure 6 shows the configuration of the message layer.

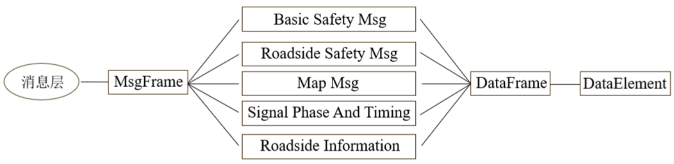


Fig 6. Composition of the data at the message layer of the vehicle

In the figure, the vehicle-side message layer dataset is mainly composed of one message frame format, five most basic message bodies, and their corresponding data frames and data elements.

3.1. BSM Message

BSM messages are the most basic security messages on the vehicle side, and they are also the most widely used application-layer messages. Through the broadcast of the message, the vehicle can inform the rest of the vehicles within the range of near-field communication in real time of its position, heading angle, speed, acceleration status, etc., so as to support a series of cooperative safety and other applications.

At the same time, special vehicle types (ambulances, fire trucks, police cars, etc.), the status of the vehicle's double flashing indicators, and the overtaking status of the vehicle (overtaking on the left, overtaking on the right) can also be broadcast in the vehicle's near-field communication through BSM, which greatly improves the ability of cooperation between vehicles.

3.2. Map Message

Map message is an application-layer message that provides map information for vehicles in real time. It is continuously updated and broadcast to the vehicle-side OBU through the roadside RSU, which can inform the map information of the local area where the vehicle is located, including the intersection information, road section node information, lane information and road connection information in the area.

A single local map message can contain multiple intersection information, and the subsequent lane matching algorithm can calculate the real-time dynamics of the vehicle on the map according to the OBU's self-positioning, the connection relationship between multiple intersection nodes, and the lane positioning information of their respective intersections, so as to plan the best route for the vehicle to reach the destination.

3.3. RSI Message

RSI messages are traffic incidents and traffic sign information sent by the roadside RSU to the on-board OBU. Among them, the traffic incident message contains the queue length, traffic flow statistics, dangerous lane changes, etc., while the traffic sign contains all the traffic signs placed on the roadside. This message frame can package one or more traffic events and traffic sign information at the same time, and when sent to the OBU, the message content also contains the roadside RSU number and its absolute coordinate location of the message.

The on-board OBU will determine the effective area of the traffic sign or event based on its own positioning and running direction, as well as the timestamp information attached to the message body, and the range/associated area of the road segment. When the decision takes effect, the vehicle will inform the driver of the relevant information in advance through voice broadcast. It avoids the misjudgment of traffic information caused by drivers being distracted by driving, or traffic signs being blocked by other vehicles and tree branches.

3.4. RSM Message

RSM messages are roadside safety messages. Through the detection method of multi-sensor fusion used by the edge computing unit, the RSU obtains the real-time dynamic information of the surrounding traffic participants (here the traffic participants are the RSU itself's number, non-motor vehicles, surrounding vehicles, pedestrians, etc.), and organizes these information into corresponding formats and transmits them to the surrounding vehicles to support the subsequent perception of related applications of the vehicle.

The existence of RSM messages makes the detection of the surrounding environment not only rely on the near-field communication between vehicles, but also those vehicles that are not equipped with OBUs can also be accurately detected, which perfectly solves the problem that OBUs cannot be popularized at this stage.

3.5. SPAT Message

When driving to an intersection with complex traffic conditions, a smart vehicle needs to have the ability to perceive, locate, and load real-time maps, as well as the ability to recognize the traffic light status corresponding to the lane in which it is located. The SPAT message makes up for the lack of information in this aspect for the intelligent vehicle, which can send the traffic light information of the current intersection where the vehicle is located to the OBU in real time through the RSU, combined with the MAP message received by the OBU in section 2.2, to ensure that the intelligent vehicle in the vehicle-road coordination can drive in an orderly manner when passing through the intersection of complex traffic, which further improves the reliability and safety of driving.

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4. Vehicle-road Collaboration V2X Smart Platform

The V2X intelligent platform integrates a variety of functional systems to realize the openness and sharing of data at all levels in vehicle-road collaboration, ensuring and improving the security and reliability of the overall system of vehicle-road collaboration. Among them, the application management system is the base of the V2X cloud platform, which realizes the access and aggregation of all data and provides basic data support for the upper-layer application, while the Internet of Vehicles information service system is the cloud exit, providing external services and data sharing.

4.1. Government Information Sharing and Exchange System

The system is deployed on the Internet and the government extranet, and the government extranet part is only used to connect with the government information sharing and exchange system to obtain traffic patrol police, urban management bureau and other departments and vehicle, road-related data, such as road parking data, roadside environment data, traffic situation data, etc., and provide data sharing services to various government agencies.

The Internet area and the government extranet area are synchronized through cross-network security access devices, cloud security is guaranteed by renting cloud security services, and the vehicle and road ends are guaranteed by V2X security certificate services and operator mobile Internet. The architecture of the system is shown in Figure 7.

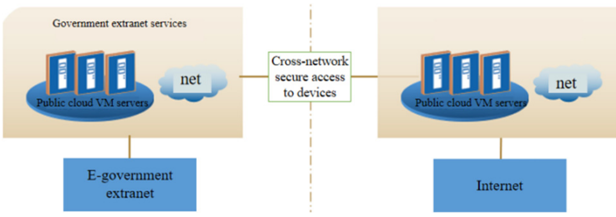

Fig 7. Government information sharing and exchange system architecture

4.2. O&M Management System

It is mainly responsible for real-time intelligent monitoring of the operation status of roadside MEC, RSU, signal and other equipment, to ensure that the equipment can be found in time when the equipment is abnormally disconnected due to unexpected conditions, and to provide the function of automatic remote restart of the equipment. At the same time, it is responsible for serving as the data docking interface of the above-mentioned hardware devices, encapsulating and storing the received data. Achieve unified management of all roadside equipment and provide safe and reliable information.

4.3. Cloud-Based Collaborative Control System

The real-time environment perception data and traffic signal data sent by the vehicle-end OBU, road-end RSU, and signal machine are fused and processed, and the processed V2X shared data is sent to the user's OBU, so as to realize the high-precision perception of the environment in which the user vehicle is located, and make overall decision-making and planning for the vehicle's subsequent journey and purpose, so as to improve the driving safety and reliability of the vehicle when its own field of vision is limited, as shown in Figure 8.

4.4. Vehicle Monitoring and Dispatching System

Through information exchange with the on-board OBU, the overall control and management of the networked vehicle can be realized. The system provides OBU platform users with functions such as information query, vehicle scheduling, monitoring management and vehicle

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management, and users can query all aspects of the connected vehicle according to the displayed menu items.

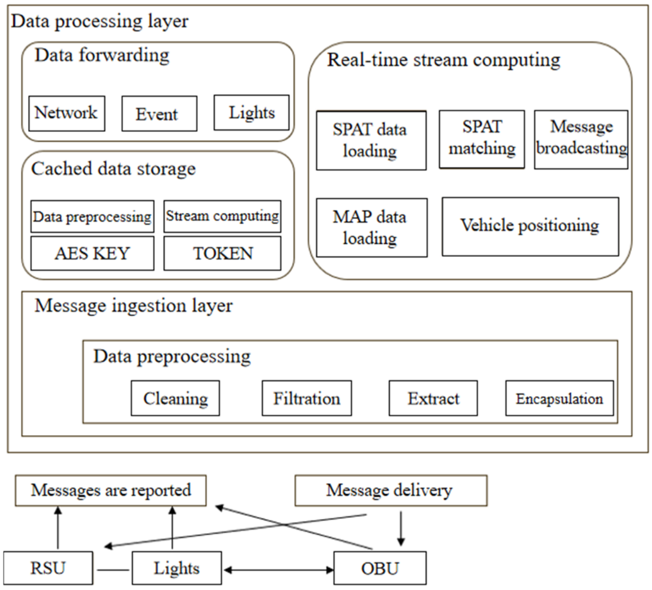

Fig 8. Cloud-based collaborative control system architecture

4.5. Intelligent Traffic Management System

Combined with the platform's own perception data and computing capabilities and the business requirements of the local traffic management department, through the integration and processing of massive mobile Internet information and traffic data information, the diagnosis and evaluation of the historical and real-time state of urban traffic are completed, the problems existing in the transportation system are found and solved, and the prediction of the future traffic state is output based on this.

5. Epilogue

With the help of cellular network communication technology, vehicle-road cooperative autonomous driving has completed the efficient information exchange between the "vehicle-road-cloud", which effectively solves the problems of high investment in existing bicycle intelligence and poor safety in extreme environments, promotes the innovation of autonomous driving technology and the creation of intelligent transportation, and improves the efficiency and safety rate of traffic travel. In the future, the vehicle-road collaboration pilot area will promote the integrated development of intelligent driving, smart transportation and smart city, and continuously fill the technical gap in the development of smart vehicles, which is of far-reaching significance to China's construction of a manufacturing power, a transportation power and a network power.

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