The Combination and Application of Vehicle-Connected Vehicle Intelligence and Digital Twin Technology

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Abstract. LTE-V2X car networking technology has garnered significant attention from research institutions worldwide. This technology has undergone two active phases of technological evolution, with onboard operating systems gradually enhancing functionality to support intelligent control service platforms and integrated businesses, while automotive electronic systems facilitate advancements in autonomous driving, and 5G technology sees increasing application. Key technologies revolve around the integration of intelligence and networking in smart cities. Vehicle networking technology fosters collaboration and interaction between vehicles, roads, and individuals. As information related to people, vehicles, and roads grows increasingly vast, and the surrounding environment becomes more complex, timely, effective, and accurate processing of this data is essential to ensure traffic safety, enhance traffic flow, and improve the driving experience and comfort for both drivers and passengers. Therefore, this paper proposes the application of V2X vehicle networking technology and digital twin technology to enhance vehicle intelligence, creating a corresponding digital space where various scenarios are simulated and analyzed, and accurate results are reflected in the real world. This approach aims to enhance the maturity and reliability of vehicle intelligence and autonomous driving functions.

Keywords: LTE-V2X vehicle-connected vehicle intelligent digital twin, digital space.

1. Introduction

The development of today's network is a rapid and constantly evolving process. In recent years, the scale of China's Internet users and the Internet penetration rate have been on the rise [1], profoundly changing our way of life and work. For example, the development of vehicle networking supporting intelligent transportation in the Internet of Things and V2X communication technology has brought a lot of convenience to our lives. Vehicle networking is an important part of intelligent transportation in the future and is also a hot topic at home and abroad [2]. Vehicle networking is an information communication network that exchanges data and information between vehicles and people, vehicles and vehicles, vehicles and roads, and vehicles and clouds. Vehicle networking is an integrated network that can realize intelligent traffic management, intelligent dynamic information service, and intelligent vehicle control [3]. LTE-V2X vehicle networking technology is effective in solving safety problems such as over-the-horizon traffic event detection and condition detection in extreme weather [4]. In future autonomous driving applications, V2X communication technology is one of the important technologies to realize environment perception. It complements the advantages of traditional vehicle-mounted Lidar, millimeter-wave radar, camera, ultrasonic, and other vehicle-mounted sensing equipment, providing autonomous vehicles with over-the-horizon and complex environment sensing capabilities that radar cannot achieve [5]. The current V2X technology is divided into DSRC (dedicated short-range communication) and C-V2X, with C-V2X being the main focus of research in China today [6]. C-V2X is an emerging technology that leverages and enhances the features and network elements of existing Long-Term Evolution technologies [7].

Digital twin aims to create a virtual model of a physical entity digitally, simulate its behavior in the real environment using data, and enhance its capabilities through virtual and real interactive feedback, data fusion analysis, decision iterative optimization, and other methods [8]. The emergence of digital twins is not just a concept hype but an inevitable outcome of the advancement of information technology to a certain extent, becoming a new tool for humans to structure, describe, and understand the physical world. Digital twin represents a comprehensive technology system for digital

transformation, continuously evolving and deepening in application, and its adoption and promotion constitute a dynamic and long-term process. Currently, it is imperative to adhere to demand-driven and value-oriented principles, focusing on application scenarios with urgent demands, high value, and great potential to achieve breakthroughs in key areas and establish exemplary models. For the second consecutive year, digital twin technology has been recognized as one of the top 10 strategic technology trends by IT research and consulting firm Gartner [9]. Today, digital twin technology has vast development opportunities across various fields worldwide, spanning space exploration, military, medical, transportation, and small household appliances. It not only reduces research costs but also accelerates design and development processes [10]. Integrating digital twin technology with vehicle networking technology involves embedding the digital platform created by digital twin technology into the vehicle networking system, reducing error rates and misjudgment rates in vehicle intelligence's automatic driving function, and enhancing the maturity and reliability of the automatic driving system [11].

The emergence of highly intelligent vehicles represents the current development trend. This paper introduces and designs an automatic driving simulation system based on digital twins, organized into three layers. The first layer, the data platform, also known as the data guarantee layer, serves as the system's foundation, acquiring fundamental data through user feedback, data collection, and continuous simulation and evolution of the digital space. The second layer, the modeling and calculation layer, establishes models of the acquired data on the platform. The third layer, the evaluation and calculation layer, assesses cluster task capability, conducts 3D virtual-real mapping, ensures system cluster maintenance, aids in system design decision-making, and monitors the entire process. Ultimately, the models are applied to individuals and networks.

With the maturity of the digital twin autonomous driving risk avoidance system, research costs will significantly decrease. The cost of uninterrupted high-speed simulation in the digital space is far lower than the expense of real-world simulation collection. This system can provide more real-time, efficient, and intelligent services, enabling accurate and optimal decisions in dangerous and emergency situations. Consequently, it alleviates pressure on drivers, enhances passenger comfort and safety, accelerates traffic flow rates, reduces accident rates, and boosts people's happiness index.

2. IoV System and Digital Twin

Car networking, a specific application of the Internet of Things in urban transportation networks, dynamically collects, distributes, and processes data through vehicle networks, as illustrated below (Figure 1).

Utilizing wireless communication, it facilitates information sharing, enabling interaction between vehicles, buildings, and other infrastructure, effectively integrating cars into urban networks. Moreover, it fosters communication between vehicles and pedestrians, as well as with non-motorized vehicles, promoting enhanced safety and cooperation on the roads. At the heart of car networking are vehicles, which are equipped with sophisticated networking and intelligent systems. Human participants and users of the Internet of Vehicles constitute another crucial aspect, while roads represent the external environment essential for Internet of Vehicles operations, including the design of traffic-related equipment. By enabling drivers to access traffic information, receive real-time navigation guidance, and avail themselves of vehicle fault diagnosis and safety-driving services through wireless signals, car networking enhances vehicle safety and convenience significantly.

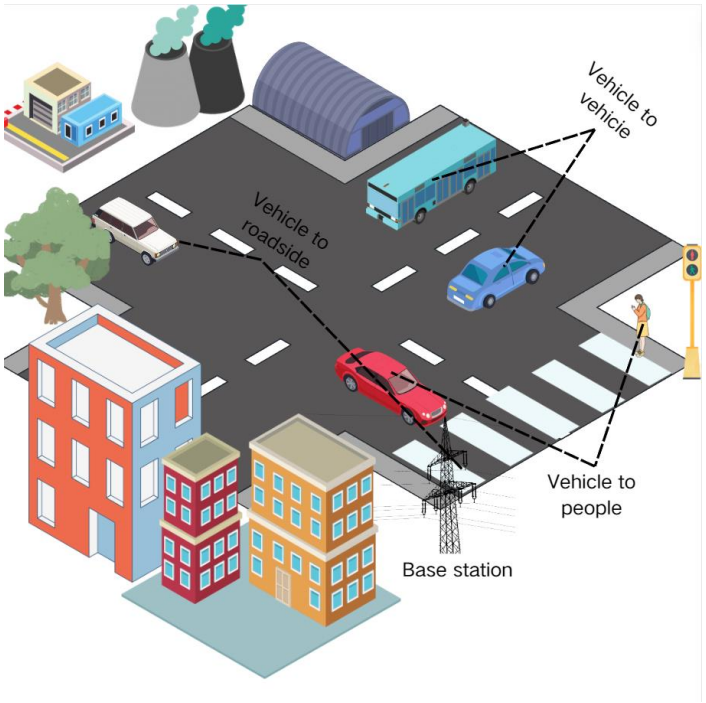


Fig. 1 Information interaction of the IoV System

Digital twin technology encompasses a comprehensive array of information technologies including perception, computing, and modeling. By employing software definition, physical space description, diagnosis, prediction, and decision-making, it facilitates interactive mapping between physical and cyber spaces. When coupled with connected vehicles, digital twins enable various levels of driving automation, ranging from driver assistance to full autonomy. Despite advancements in traffic infrastructure, accidents remain all too common, causing untold suffering for families. This technology not only simplifies and streamlines vehicle operation but also enhances traffic efficiency, reduces accident rates, and ultimately serves to benefit society at large. Thus, the synergistic integration of vehicle networking communication technology and digital twin technology, along with the creation of a vehicle networking automatic driving risk avoidance system as presented in this paper, is indispensable. Such integration promises to advance the field of intelligent automated driving further, contributing to safer and more efficient transportation systems.

The integration of digital twin technology with the Internet of Vehicles (IOV) holds vast potential for enhancing the automotive industry. By harnessing the capabilities of digital twins, IOV can revolutionize vehicle operations and management. Digital twins enable real-time monitoring, predictive maintenance, and performance optimization of vehicles, ensuring safer and more efficient transportation systems. Moreover, the interactive mapping between physical vehicles and their digital counterparts facilitates advanced driver assistance systems (ADAS), partial and conditional autonomous driving, and ultimately, full autonomy. This convergence of digital twin and IOV technologies not only enhances vehicle connectivity and intelligence but also paves the way for innovative services such as personalized driving experiences and fleet management solutions. As the automotive landscape continues to evolve, the application of digital twin technology in IOV promises to drive unprecedented advancements in vehicle safety, efficiency, and overall driving experience.

3. DT-based automatic driving risk avoidance system

The Internet of Vehicles relies on key technologies distributed across three levels: the 'end,' 'tube,' and 'cloud.' At the 'end' level, the acceleration of intelligent and networked processes in vehicles and roadside equipment is paramount. Key technologies encompass automotive electronics, vehicle operating system technology, and more. Meanwhile, at the 'tube' level, crucial technologies include 4G/5G vehicle-mounted cellular communication, LTE-V2X, and 802.11p direct wireless

communication. Finally, at the 'cloud' level, functionalities such as connection management, capability opening, data management, and multi-industry business support are realized through vehicle networking platform technology, serving as the core.

As depicted in the figure 2 below, the establishment of the digital twin autonomous driving risk avoidance system consists of two main parts. The digital realm collects, analyzes, models, and computes data, culminating in feedback reflected in the real world and interactions with users.

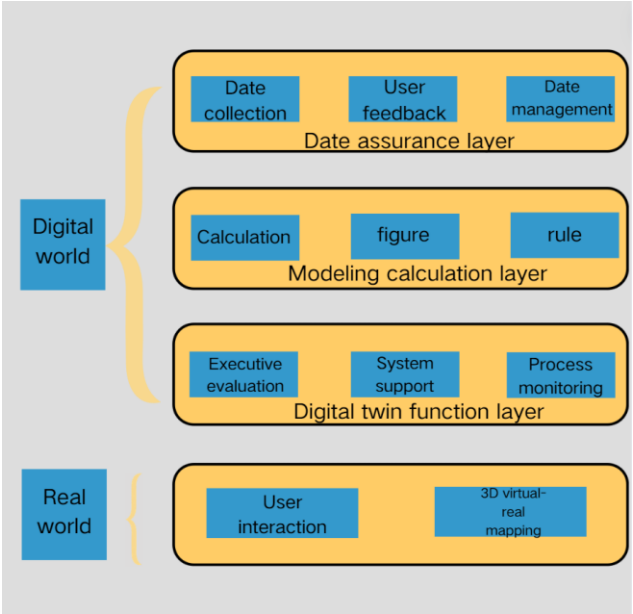


Fig. 2 Establishment of automatic driving risk avoidance system

3.1. Modeling

3.1.1 Modeling virtual-real mapping configuration

From geometric, physical, behavioral, rule-based, and constraint-based perspectives, digital twin virtual modeling is conducted for diverse entities within physical space. This process involves the modeling, combination, and integration of various entities to create an information space model characterized by interconnected elements and high fidelity, facilitating simulation. Formally, various digital twin virtual entities within space are modeled as follows:

$$P'_i, SE'_j :: = gMSet \infty pMSet \infty \quad (1)$$

$$BMSet \infty rMSet \infty cMSet \quad (2)$$

Where SP 'i and SE 'j respectively represent the digital twin virtual body model. The elements in the model set represent its geometric model set (gMSet), physical model set (pMSet), behavioral model set (bMSet), rule model set (rMSet), and constraint model set (cMSet), respectively. These elements are interconnected through natural connectors, forming a multi-disciplinary, multi-modal, and multi-scale "geometric-physics-behavior-rule-constraint" modeling and simulation of all elements in physical space.

3.1.2 Virtual and real mapping association modeling

Building upon digital twin virtual modeling, the intelligent manufacturing information space can be formally depicted as follows: CSF represents the collaborative manufacturing information space for personalized products, where SP' denotes the digital twin virtual body set corresponding to SP, SE, and SG within the information space. These include the digital twin virtual body sets of manufacturing equipment and intelligent gateways. Furthermore, mechanisms for virtual-real mapping, association, and fusion between physical and information spaces are established to address synchronization issues, consistency discrepancies, and low intelligence between the physical and information layers of the manufacturing workshop. Leveraging the inherent capabilities of digital

twin technology, we can discern the potential for significant advancements in intelligent manufacturing processes by:

$$CSF^{1:1}\leftrightarrow PSF\ ,\ SP'^{1:1}\leftrightarrow SP\ ,SE'^{1:1}\leftrightarrow SE,\ SG'^{1:1}\leftrightarrow SG \tag{3}$$

In the formula, the one-to-one mapping relationship between the physical space PSF and the information space CSF is represented, as well as between the intelligent work-in-process entity SP and its virtual counterpart SP', and between the intelligent manufacturing equipment entity SE and its virtual representation SE'.

3.2. Intelligent Computation

3.2.1 Real-time traffic big data module design

(1) Low fog computation layer: This segment constitutes the foundational layer of the fog computing architecture, encompassing a wide array of electronic devices and machinery, ranging from vehicles and personal devices to intelligent transportation systems. Within this layer, these diverse devices play a pivotal role in generating, collecting, and processing various types of data relevant to smart transportation. Additionally, connected vehicle devices embedded within this layer contribute to data processing tasks, enhancing the efficiency of information exchange and decision-making processes.

(2) Intermediate fog computation layer: Positioned as an intermediary between the low fog computation layer and the high fog computation layer, this segment serves as a crucial node for expanding the fog computing network in smart transportation systems. It acts as a hub for receiving and processing data collected from the lower layer, thereby extending the reach and capabilities of the fog computing infrastructure. Comprising wireless access points, base stations, routers, and similar infrastructure components, this layer enables the processing and analysis of a broader spectrum of smart transportation big data. By leveraging the proximity to the fixed network, it facilitates seamless communication and data exchange between various devices and systems.

(3) High fog computation layer: At the apex of the fog computing architecture, the high fog computation layer boasts abundant resources and advanced processing capabilities. This layer excels in executing intricate data processing tasks that require sophisticated algorithms and computational power. Despite potential delays due to data size and communication latency, it remains proficient in accelerating stream-based data processing, conducting data analysis, and implementing intelligent computing techniques. This may involve employing a variety of data analysis calculation methods to derive valuable insights and optimize decision-making processes in smart transportation systems.

(4) Cloud computing layer: Serving as the ultimate destination for data processing and analysis, the cloud computing layer acts as a centralized hub for large-scale big data processing and analytics. Leveraging cloud-based infrastructure and resources, this layer enables comprehensive analysis and computation on a massive scale. It provides a robust platform for storing, managing, and analyzing vast amounts of data generated by smart transportation systems. Through cloud-based services and solutions, stakeholders can access valuable insights and make informed decisions to enhance the efficiency and effectiveness of transportation operations.

3.2.2 System Optimization

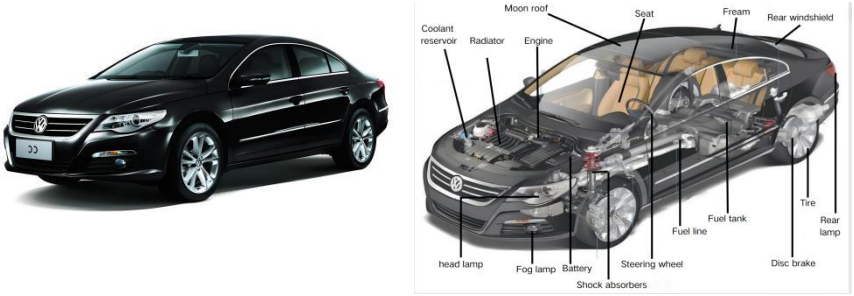


Fig. 3 Vehicle internal structure analysis

Figure 3 depicts the internal and external structure analysis of the vehicle, revealing the intricate nature of this sophisticated tool. The composition of a vehicle is remarkably complex, requiring the installation of sensors around the vehicle to sense the surrounding environment. Additionally, components such as the engine, steering system, signal light control, and computer connection are essential for achieving the automatic driving function. These components provide feedback to the vehicle's intelligent system, enabling feedback and vehicle control. Moreover, adapting the vehicle for different models necessitates corresponding structural and functional changes, all while ensuring no negative impact on factors such as body weight, performance, quality, appearance, and wind resistance.

4. Case Show

In the initial stage, pure software simulation is employed, which typically utilizes a blend of traffic simulators and network emulators. Major network emulators include NS2, NS3, JiST/SWANS, OMNeT++, QualNet, OPNET, and GTNetS, while prominent traffic simulators comprise SUMO, VISSIM, PRESCAN, TransModeler, TRANSIM, and CARSIM. These tools collectively create an environment that replicates the communication among connected vehicle devices. Leveraging the precise vehicle movement provided by the traffic simulator, diverse driver behaviors and traffic scenarios can be accurately simulated. Through this framework, various traffic conditions are simulated, allowing for the evaluation of parameters such as communication channel load under different traffic scenarios (Figure 4).

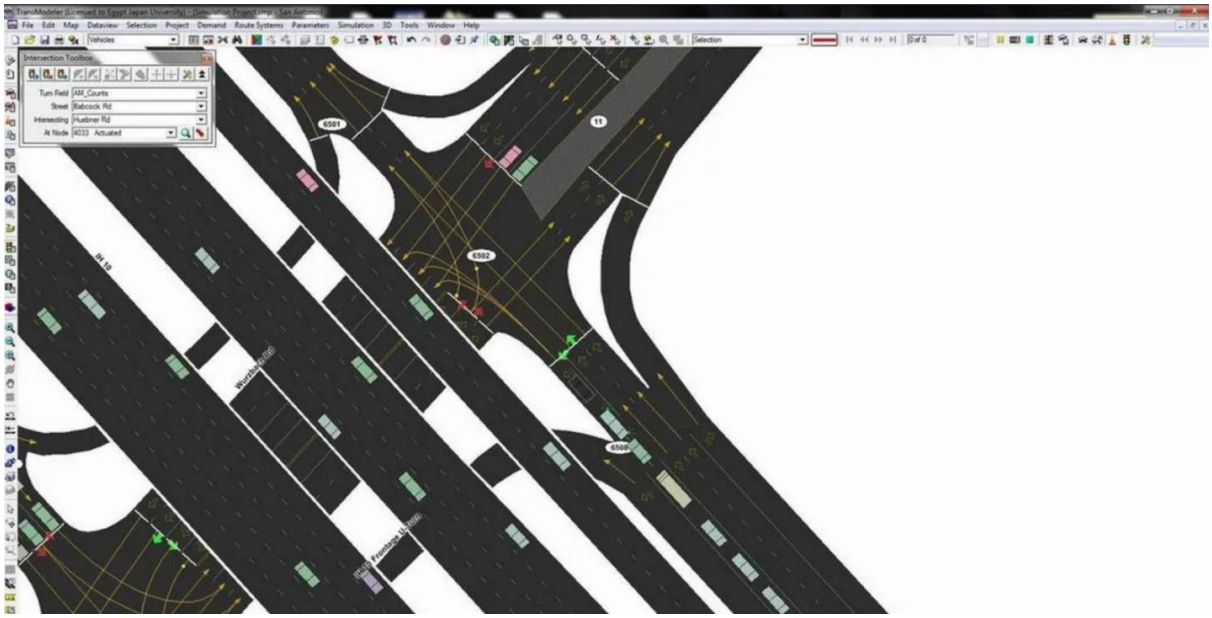


Fig. 4 Tip view of simulation experiment route

The second stage involves hardware simulation, with Hardware-in-the-Loop (HIL) testing commonly utilized in the automotive manufacturing process to provide an effective test environment for the Design Under Test (DUT), or device under test. Similarly, car networking hardware devices also require such an environment. HIL testing offers a cost-effective and reproducible alternative to actual field testing.

In the third stage, real vehicle testing is conducted. An open-loop test method, such as road closure testing, can be employed to establish different traffic scenarios by remotely controlling driverless test vehicles. Additionally, this method enables the tracking and testing of the driving performance of the test vehicle, while collecting real-time data for analysis and evaluation. Compared to real vehicle testing, this method offers higher safety and repeatability. While hardware-in-the-loop simulation reproduces real scenes more accurately, it may fall short in testing various complex scenarios (Figure 5).



Fig. 5 Simulate live and route conditions.

5. Conclusions and Future Work

In conclusion, this paper highlights the prevailing trend of vehicle intelligence development in today's social environment. People increasingly desire easier and more convenient travel, alongside guaranteed personal safety. Despite the emergence of autonomous vehicles, significant safety risks and high manufacturing costs persist. It is evident that vehicle intelligence still has a long path ahead. However, the digital twin of the car network automatic driving risk avoidance system proposed herein offers a promising solution to mitigate these challenges substantially. Moving forward, continued in-depth research is crucial to realize its potential application in the future.

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