Design Of Driving Warning System Based on V2X And Digital Twin

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Abstract. Nowadays, the issue of traffic congestion has garnered increased attention. With the recent advancements in science and technology, cars have brought growing convenience to people in travel. With the growth of the economy, an increasing number of people have purchased cars to meet their travel needs. Unfortunately, the excessive number of vehicles on the road has led to problems such as traffic congestion and gridlock, making an increase in the incidence of traffic accidents inevitable. With the emergence of intelligent transportation, V2X technology has matured significantly, being integrated with other technologies and applied in commercial, industrial, and transportation fields. In this paper, a system providing an early warning for frequent traffic accidents in modern times has been designed. The system construction is completed through V2X and digital twin technology, facilitating information exchange between vehicles and preemptively alerting the driver before disasters occur.

Keywords: Digital twin, Internet of Vehicles, Emergency warning, Blind spot warning, Emergency collision avoidance.

1. Introduction

Traffic congestion has profound economic, social, and environmental consequences. It can be perceived as a resource issue, where vehicles with conflicting intentions require coordination for effective road utilization [1]. Therefore, there is increased attention to vehicle-to-everything communication, which has the potential to reduce traffic-related fatalities or introduce new business models [2]. This paper focuses on the traffic domain, where accidents occur due to various factors such as driver distraction and blind spots caused by surrounding vehicles. The objective of this paper is to leverage current communication technology for information exchange between different vehicles. For instance, by collecting the field of view from other vehicles, merging the complete field of view images around the vehicle, and displaying it on the dashboard, this information can be shared with the public. Drivers can use it as a reference to avoid traffic accidents resulting from blind spots in their field of vision.

To achieve this goal, the Internet of Vehicles is a necessary technology, and it can be referred to as V2X. V2X facilitates information exchange between vehicles and other elements in the transportation network, including basic facilities or individuals on the roadside. By anticipating the possibility of a traffic accident [3], it can sense potential dangers that may exist in the short time and space horizon in the future [4]. Additionally, V2X technology can enhance road safety through vehicle-to-everything (V2X) communication, encompassing vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) communications, thereby improving traffic efficiency [4].



Fig. 1 A typical V2X scenario

To achieve information interaction between different individuals, vehicles, and objects, the main technology employed is DSRC, a short-distance communication technology used to establish fundamental communication between vehicles. Additionally, cellular networks are utilized to facilitate communication between vehicles and everything, known as C-V2X, which is also the primary communication technology of the Internet of Vehicles. However, sensing technology for ranging, global satellite navigation systems for positioning, real-time data processing, and analysis technology for updating real-time traffic information, and intelligent decision-making are all crucial components of the Internet of Vehicles.

The Internet of Vehicles is currently primarily utilized in the automotive industry and transportation systems, yielding remarkable results. It is evident that the number of intelligent vehicles on the road is increasing, encompassing assisted driving systems, intelligent in-vehicle entertainment systems, and autonomous vehicles. To actualize the application of smart cars, digital twin technology is deemed necessary. This technology can enhance the efficiency, safety, and maintenance management level of vehicles and transportation systems.

In this paper, the primary function of the digital twin is to model the road, share data collected by various vehicles and equipment, and then construct a road in a virtual space. This process eliminates business blind spots, facilitates the sharing of vehicle conditions, and enables emergency operations and safety tips. Due to its ability to reflect the vehicle's status in real time, allow simulation testing, and provide behavioral decisions for the vehicle, digital twin technology plays a crucial role. The paper also proposes the application of a driving warning system based on digital twins, utilizing digital twins and V2X technology to address unexpected situations on the road (Figure 1).

2. Background about IoV and Digital Twin

The V2X (Vehicle-to-Everything) technology plays a pivotal role in the realm of vehicle safety, encompassing communication between vehicles and other vehicles, infrastructure, pedestrians, and networks. Currently, the Internet of Vehicles is predominantly employed in the automotive industry and transportation systems, yielding noteworthy results. The increasing prevalence of intelligent vehicles on the roads, including assisted driving systems, intelligent in-vehicle entertainment systems, and autonomous vehicles, is evident. This paper primarily utilizes Internet of Vehicles technology to ensure the safe operation of vehicles in various aspects, such as vehicle coordination, real-time warnings, emergency vehicle alerts, etc.

Specifically, vehicle collaboration involves using V2X technology to share information, including location, speed, and direction, between vehicles. This facilitates vehicles perceiving each other's presence, thereby avoiding collisions. Real-time warnings utilize V2X technology to provide alerts to drivers about traffic conditions, pedestrians crossing the road, and other relevant information, enhancing drivers' awareness of their surroundings. Emergency vehicle alerts employ V2X to issue

warnings to surrounding vehicles when an emergency vehicle approaches, prompting drivers to take emergency avoidance actions.

However, to execute these actions, another crucial technology is required, namely digital twins. Digital twins find important applications in vehicle networks, with various definitions. NASA initially defined digital twin as a scale, physical, unified, stochastic simulation employing the best available models and updated information to emulate the life cycle of its physical twin (flying device) [5]. Digital twins can be categorized into Plain Gadget Models, Embedded DTs (EDT), and Networked Twins. Plain Gadget Models consist of two main groups of data: (a) the current value group, which includes data obtained by the object's sensors, updating DT features; and (b) a set of expected values that the gadget aims to achieve [6].

Embedded DTs (EDT) involve a two-way connection between the real and virtual worlds, where data obtained through sensors is used to make decisions or provide data analysis. Networked Twins enable integrated EDTs to connect with different EDTs in the environment, facilitating communication among them, particularly useful in smart manufacturing environments [7]. In essence, digital twins collect data from real objects through cameras, sensors, etc., and replicate them in a virtual space. In this virtual space, based on the attributes of the physical entity, the digital twin model can be expressed in four dimensions: geometry, physics, behavior, and rule [8]. This virtual object mirrors the properties of the real object, with the real object's state being reproduced in real-time, including its form, actions, and operational status.

Currently, digital twin models can be classified into several sub-applications, including industrial robots, mobile robots, line-following robots, and robot arms [9]. The early warning system proposed in this paper utilizes information from the digital twin's physical world to replicate the digital oviparous body, map it in the virtual space, and construct an early warning system model to facilitate early warning operations. The modeling method employed is an agent-based model, assigning various characteristics to each vehicle to respond to diverse emergency situations. However, this approach does not account for pedestrians [10]. Therefore, this paper also incorporates the modeling method of Intelligent Transportation Systems, integrates V2X technology to address complex vehicle environments [11], and employs gray theory to quantify road safety levels [12].

3. The proposed driving warning system

This paper primarily investigates the driving warning system based on digital twins. The digital twin architecture comprises four main layers: the physical layer, data sensing layer, network transmission layer, and application layer. The physical layer of the digital twin in this study incorporates car cameras, radars, ultrasonic sensors, etc., primarily utilized to perceive the vehicle's surroundings, measure the distance and speed of nearby objects, and identify obstacles around the vehicle. At the data sensing layer, information regarding the vehicle and road traffic is collected and transformed into a digital format for storage. Data collection is primarily conducted through various cameras and sensors in the physical layer. The network transmission layer facilitates data sharing, enabling interaction between cars and individuals, cars and other cars, cars and roads, and cars and the cloud. Ultimately, at the application layer, the collected data and computation analysis results are transmitted to the vehicle and driver to aid in driving. This assistance includes providing an understanding of the traffic environment around the vehicle, enabling the driver to make informed driving decisions (Figure 2).

The Internet of Vehicles system reference model primarily consists of three layers: the data sensing layer, network transmission layer, and application layer.

1. Data Sensing Layer: Vehicles are equipped with various sensors, including radar, lidar, cameras, ultrasonic sensors, etc. These sensors can perceive the surrounding environment, detect other vehicles, pedestrians, obstacles, etc., and provide real-time data on the situation around the vehicle.

2. Network Transmission Layer: This layer facilitates data sharing between vehicles and individuals, vehicles and other vehicles, vehicles and roads, and vehicles and the cloud.

3. Application Layer: Utilizing the collected data, calculations are performed, and information is transmitted to both the vehicle and the driver.

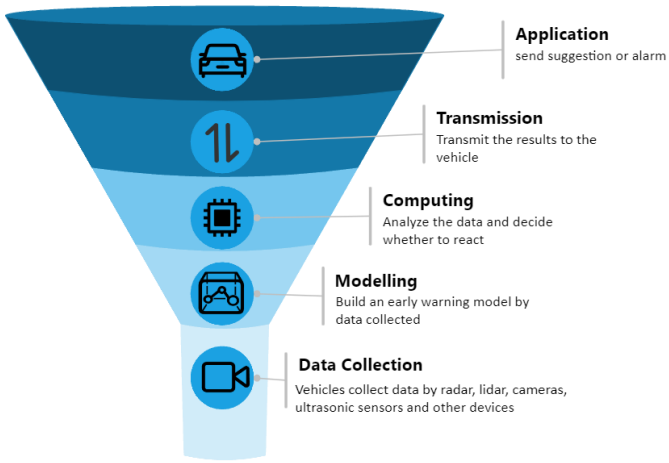


Fig. 2 The framework of the proposed driving warning system

3.1. Modeling

This paper utilizes the Agent-based model as one of the modeling methods. The fundamental idea is to depict the system as a collection of independent individuals (agents). Each individual has its own status, behavior, and interactions with other individuals. ABM is suitable for describing nonlinear dynamics and interactions between individuals in complex systems, making it widely applicable in various fields, including social sciences, ecology, economics, and transportation planning. It typically incorporates a degree of randomness to simulate the uncertainty and variability found in the real world, introducing more realistic behavior into the model.

The agent-based model allows for the existence of multi-agents, consisting of vehicles and road infrastructure. Through information interaction between vehicles and road facilities, it can determine the current road congestion and the dynamics of each vehicle on the road. Building upon this foundation, the paper introduces V2V communication technology and the potential for traffic accidents [2] to facilitate information sharing between vehicles. This is utilized to avoid the possibility of collisions and other traffic accidents. Specifically, each agent (vehicle) is assigned maximum speed, maximum acceleration, and braking characteristics with the aim of reaching the destination as quickly as possible. However, in real road conditions, emergencies such as a small distance between vehicles or a driver temporarily changing lanes require each vehicle to choose the most appropriate road [8]. To construct a predictive model, this paper employs probability allocation to establish a realistic traffic model, simulating interactions between vehicles and road infrastructure.

Agent-based models are primarily employed to address the driving behavior of vehicles. However, the traffic system extends beyond just driving vehicles, as pedestrians are also users of smart roads [7]. Therefore, this paper incorporates another modeling method, Intelligent Transportation Systems (ITS), taking into account both pedestrian safety and the potential negative impact of pedestrians on traffic efficiency. ITS is a comprehensive system that utilizes information technology, communication technology, and control technology to enhance the efficiency, safety, reliability, and sustainability of the transportation system. It establishes a network connecting vehicles, pedestrians, and infrastructure to facilitate information sharing. For the implementation of ITS, the adoption of V2X technology is necessary to address the highly dynamic vehicle environment [8].

3.2. Intelligent Computation

This paper employs various intelligent computing methods for data analysis to ensure the availability and rationality of the system. The primary focus is on the detection and tracking of target vehicles and pedestrians, ensuring that the system can provide real-time feedback based on the current

status of vehicles. Importantly, to ensure the practical application of the system in real-world environments, a data analysis method is required that can handle the diverse changes occurring in the real world. This method should have the capability to predict events that may occur in the near future.

This paper primarily utilizes machine learning methods for intelligent computing and data analysis to accomplish tasks such as blind spot detection and collision prediction. Firstly, for blind spot detection, a vehicle safety system employs the Convolutional Neural Network (CNN) in the deep learning model to achieve target detection of vehicles and pedestrians in the surrounding environment, including blind spots. The target tracking algorithm and Kalman filter are utilized to track targets, ensuring a real-time response to dynamic vehicles and pedestrians. Deep learning models can learn from images in blind spots, enhancing object recognition, and are trained with labeled datasets to improve data accuracy. The output of the trained deep learning model is the identification and tracking of targets in the blind spot. The system issues early warnings, such as sound or vibration prompts, to reduce the likelihood of traffic accidents in the blind spot area.

Furthermore, machine learning methods are also employed for the data analysis of safety systems, specifically for collision prediction and avoidance. To establish data quality and diversity models, machine learning methods are utilized to train vehicles and environmental information collected by vehicle sensors, cameras, radars, etc. The supervised learning method is applied to train the collision prediction model. The machine learning training model can be categorized into two modes: "collision" or "no collision." It incorporates two methods, namely Recurrent Neural Network (RNN) and Long Short-Term Memory Network (LSTM), to analyze the movement trends of vehicles and obstacles in the future. The data collected is then fed into a machine learning model for training to predict the risk of a collision and the actions that may need to be taken to avoid a collision. Machine learning is chosen for its adaptability and ability to update based on real-time data, reducing the possibility of misjudgment in response to changes in the real traffic environment.

3.3. System Optimization

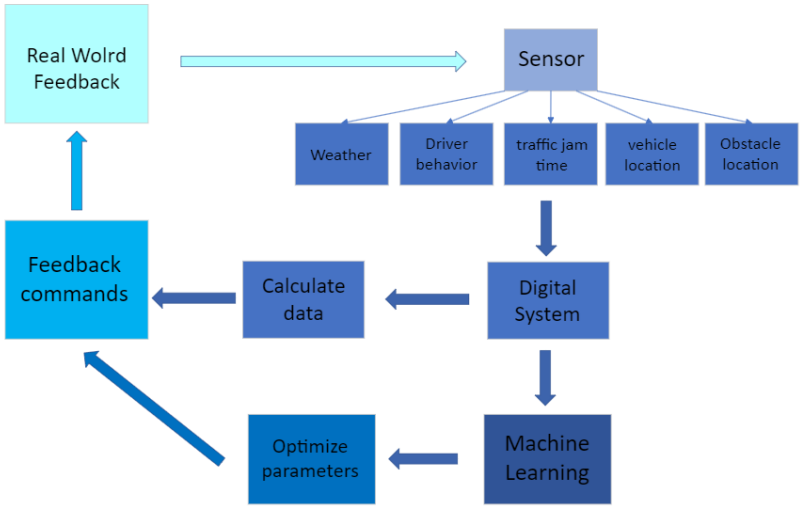


Fig. 3 Optimizing process of the proposed system

The data analysis method of machine learning has certain shortcomings and challenges because the machine learning model is highly sensitive to the collected data. If the data is not universal, its applicability in real traffic scenarios will be significantly reduced. Moreover, the real traffic environment is very complex and can change with the driver's varying driving actions or the sudden intrusion of pedestrians. This complexity poses great challenges to data analysis. To mitigate the probability of providing incorrect decisions, the input data set must be of high quality and diversity, encompassing different weather conditions, various driving behaviors, and extended data collection

times. Additionally, the raw data collected involves the vehicle's speed, acceleration, and the location of the vehicle and surrounding obstacles. When transmitting these data to the training model, they need to be converted into features that the machine learning model can comprehend. Improving the accuracy of features can enhance the precision of system data analysis. Integrated learning models can be employed to adapt to different problems and data scenarios (Figure 3).

4. Emergency warning at the intersection

When drivers approach an intersection, they may encounter unforeseen situations, such as pedestrians disregarding traffic rules and crossing the road despite traffic lights. Due to potential obstructions in the driver's field of vision, such as other vehicles, buildings, or trees, it becomes challenging to anticipate the presence of pedestrians in advance, making timely deceleration and avoidance actions difficult.

Through the implementation of V2X (vehicle-to-everything communication) and digital twin technology, sensors, cameras, and other equipment can be deployed at intersections to collect real-time data, including traffic light status and vehicle locations. This data is transmitted to the cloud, where a virtual environment corresponding to the actual road conditions is constructed. In this digital twin environment, cloud computing enables the provision of immediate and comprehensive situational awareness to drivers.

In the event of a traffic light detecting a pedestrian violating the crossing rules or other emergency situations, the digital twin system can rapidly identify and simulate the scenario. Utilizing these simulation data, the system offers the driver optimal solutions, such as recommending emergency braking or suggesting avoidance maneuvers. If the driver is unable to react within a limited timeframe, the digital twin system possesses the capability to automatically avert dangers, ensuring that the vehicle takes appropriate measures to prioritize safety in hazardous situations (Figure 4).

By seamlessly integrating V2X and digital twin technologies, we can furnish drivers with real-time, comprehensive information in intricate traffic scenarios, empowering them to respond effectively to emergencies and enhance driving safety. This intelligent system is poised to play a pivotal role in future intelligent transportation systems. Specifically, it leverages V2X information technology, using communication data as sensory input for collision detection. Subsequently, employing two calculation methods, Time to Collision (TTC) or Distance to Collision (DTC), and comparing the calculated results allows the determination of time and distance differences for the vehicle to reach the intersection. The gray theory assessment method is then employed to quantify the safety level of intersections [9].

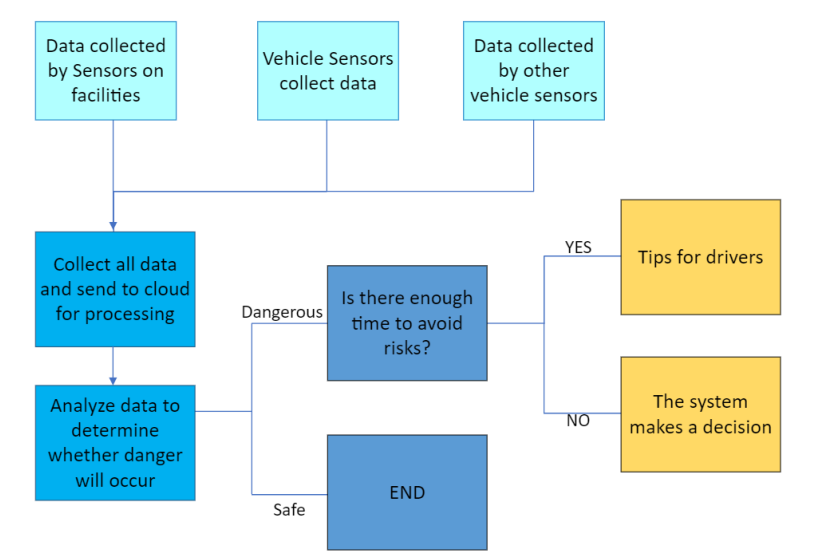


Fig. 4 The flowchart of the Emergency warning scheme at the intersection

5. Conclusions and Future Work

Digital twins and V2X technologies play a pivotal role in intelligent transportation systems, opening up new possibilities for connectivity between vehicles and road infrastructure. Digital twin is a virtual simulation technology that creates a real-time virtual replica of the actual system by simulating the physical characteristics and behavior of physical objects. The early warning system presented in this paper aims to diminish the likelihood of accidents and enhance driving safety by facilitating information exchange among vehicles, as well as between vehicles and public facilities. It can mitigate accidents stemming from blind spots and address traffic incidents occurring in complex road sections, such as intersections.

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