



Application of Video Artificial Intelligence in Smart Expressway Scenarios

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Abstract. Using video artificial intelligence analysis and IoT technology, it is possible to digitize the information perceived from individuals, vehicles, roads, and the environment on expressways. This data can then be integrated with big data technology to create a digital intelligent expressway transportation system. With artificial intelligence perception, it becomes possible to accurately monitor road conditions at a lane level around the clock, enhancing the refined operation of expressway transportation. This significantly improves access efficiency, ensures driving safety, shortens accident rescue times, and enhances driving information guidance as well as other expressway travel protection and services.

Keywords: Intelligent Expressway; Road Network Road Conditions; Real-Time Event Discovery; Video Relay; Visual Paths; Video Artificial Intelligence Analysis

1 INTRODUCTION

In recent years, video artificial intelligence technology has increasingly penetrated the domain of intelligent expressway transportation systems. This integration has facilitated a transformation in expressway transportation management, advancing from rudimentary protections afforded by traditional electromechanical and communication systems to the expedited transit enabled by Electronic Toll Collection (ETC) non-stop charging, culminating in the ongoing evolution towards free-flow, all-weather travel [1]. Conventional expressway operations relied predominantly on manual interventions, with roadway conditions being monitored through labor-intensive dynamic inspection videos and reactive rescue measures [2]. The incorporation of artificial intelligence, however, has enabled round-the-clock real-time sensing of road conditions, substantially enhancing management and service capabilities. Moreover, leveraging accumulated data, simulation, and predictive models have been developed, thereby extending the capacity for prognostications and strategic planning [3].

2 RESEARCH ON VIDEO ARTIFICIAL INTELLIGENCE

2.1 Artificial Intelligence Perception

In the realm of traditional computer data processing, the ability to calculate activity and target object information within the context of road space was limited. However, with the advent of vision artificial intelligence, utilizing video captured by roadside cameras, computers can now structure the target bodies present in the video along with the trajectory information of their movements. This results in the creation of structured information that is more amenable to computer processing [4].

Within the domain of transportation research, the information that needs to be sensed in road space is categorized into four distinct classes: people, vehicles, roads, and the environment. 1) People: This involves sensing the overall target and tracking the movement of individuals, as well as identifying their attributes, such as whether they are traffic police officers or construction workers. 2) Vehicles: This includes sensing the overall target and tracking the movement of vehicles, determining whether they are stationary or traveling at high speeds, and identifying vehicle attributes, such as whether they are family cars, engineering construction vehicles, or hazardous chemical vehicles. 3) Roads: This entails perceiving road conditions, such as congestion, as well as interpreting road signs and other relevant information. 4) Environment: This involves perceiving environmental conditions, such as foggy or snowy weather.

In the field of basic perception technology, numerous scenarios necessitate the linkage of multiple cameras and the perception of spatial distance and depth information [5]. For instance, in tunnels, to establish intuitive vehicle trajectory information, video relay is essential. This requires video calibration and cross-camera target alignment, ensuring data consistency for vehicles and other target objects based on video splicing. To accommodate varying camera angles, pseudo-3D perception of vehicle information is performed, where ordinary monocular cameras construct 3D vehicle target information. Furthermore, to balance normalized monitoring with targeted detail amplification during events, a combination of box cameras and dome cameras is employed. artificial intelligence detects events and subsequently controls the dome camera to rotate and focus, maximizing the detail effect.

2.2 Engineering Challenges

In the real-world scenario, video analysis faces numerous challenges due to various factors. These common challenges include: 1)Lighting Conditions: The brightness difference between early morning and late evening, as well as direct sunlight at certain times, affects video quality. To enhance adaptability, the model should be optimized and integrated with radar data. 2)Angle of View: Unfavorable angles caused by construction or road curvature can distort the video. This can be mitigated using pseudo-3D techniques and data augmentation. 3)Occlusion: Large vehicles obscuring smaller ones, or nearby objects like tree branches, can lead to incomplete or missing vehicle data. 4)Adverse Weather: Severe fog, heavy rain, or snow can impact visual clarity. 5)Distance: As video represents continuous spatial information, distant targets may

have insufficient pixel information, affecting artificial intelligence analysis effectiveness. 6)Video Jitter: High-speed vehicles on poor roadbeds or bridges can cause vibrations, leading to jitter in video images. This requires jitter elimination during the initial stage of video analysis and processing. 7)Multi-Camera Analysis: Information from multiple cameras needs to be correlated, necessitating cross-lens analysis, such as for long-distance traffic jams. 8)Transmission Quality: In real-world network environments, video transmission has higher bandwidth and robustness requirements. Poor transmission quality can result in screen splashes and frame drops, requiring pre-processing and fault-tolerant analysis. 9)Precision-Recall Trade-offs: Precision and Recall are conflicting parameters. When applying these, it's essential to balance and make trade-offs based on business scenarios and objectives to find the optimal point.

3 APPLICATION SCENARIOS OF INTELLIGENT EXPRESSWAY

Video artificial intelligence is employed across a diverse array of applications within expressway management and operations. These applications include, but are not limited to: lane-level network condition monitoring, real-time event detection and emergency response coordination, visual-based toll transaction verification, tunnel safety oversight, specialized vehicle monitoring, traffic flow modeling and simulation, intelligent road hazard identification, and construction zone safety regulation.

3.1 Lane-level road network conditions

A lane-level road network provides detailed information about road conditions, including vehicle recognition on the lane, real-time perception of traffic flow, model categories, vehicle-vehicle interval time, and estimated speed. This allows for the creation of precise spatial and temporal data regarding vehicles, enabling the integration of road network information with corresponding measures in practical applications. Typically, individual users utilize road information from sources such as Baidu Maps or Google Maps, which provide relative calculations of traffic congestion. However, accurate lane-level information can be highly beneficial during operations. Consequently, based on the traffic status of each segment of the road network and its structure, event information is automatically generated and released to the intelligence board through preset model calculations and analyses, as demonstrated in Figure 1.



Fig. 1. Expressway incident information intelligence board

3.2 Real-time incident discovery and emergency command

Upon perceiving and analyzing the behavior of vehicles within the lanes, various events can be discerned, such as abnormal parking, traffic accidents, solid line lane changes, traffic congestion, occupation of emergency lanes, reverse movement against traffic, object ejection, pedestrian intrusion, road construction, foggy weather, and other occurrences, as depicted in Figure 2. For incidents impacting traffic safety, the system facilitates real-time automatic identification, promptly alerting the command center mere seconds after event detection. This enables immediate dispatch of rescue operations and remote command, a stark contrast to conventional alarm mechanisms, thus significantly curtailing response times and reducing the likelihood of secondary accidents [6].

The crux of traffic event sensing lies in harnessing surveillance resources to meticulously profile abnormalities based on image processing, deep learning, and other specialized algorithms.



Fig. 2. Event analysis of vehicles in expressway lanes

3.3 Toll auditing based on visual path

Following the implementation of the national ETC network, most expressways allow for non-stop travel across provinces. However, this system has introduced operational challenges, particularly in the form of loopholes that enable illegal toll evasion. The ETC card can be separated from the vehicle, and the ETC system relies on gantries' signal perception to determine the path taken by the card. Human intervention can exploit this mechanism, facilitating illegal toll evasion. Observations from practice have revealed over twenty unique toll evasion scenarios. By installing cameras on gantries and employing camera-based splicing algorithms, it becomes possible to accurately identify vehicle license plate and axle information. This integration enables the inter-connection and analysis of gantry information, resulting in the formation of a visual path for each vehicle. As a result, card and vehicle body data remain consistent, preventing discrepancies due to human intervention. With the aid of visual path information, a comprehensive record can be constructed, allowing for the prevention and tracking of toll evasion incidents.

3.4 Tunnel safety management

A tunnel presents a high-risk environment. Vehicles entering the tunnel aim to achieve a swift and safe passage, yet in the event of an accident, precise localization is crucial [7]. Cameras within the tunnel can accurately monitor the status of vehicles, and through video stitching and vehicle position information integration, as illustrated in Fig. 3, the system can construct a comprehensive digital twin of the tunnel, providing operators with an intuitive display of the vehicle situation.

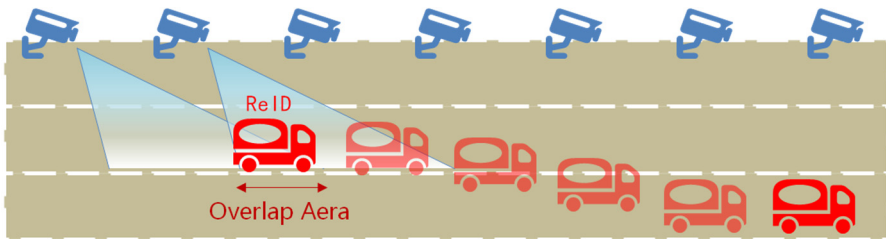


Fig. 3. Schematic diagram of the tunnel camera layout and video stitching

The artificial intelligence algorithm utilizes various vehicle data such as front and rear-end features, color, model, and license plate information. It employs a feature-matching cross-domain tracking process, as depicted in Figure 4, to facilitate multi-target cross-camera relay tracking. The system boasts a tracking matching rate exceeding 95% and an accuracy rate surpassing 90%.

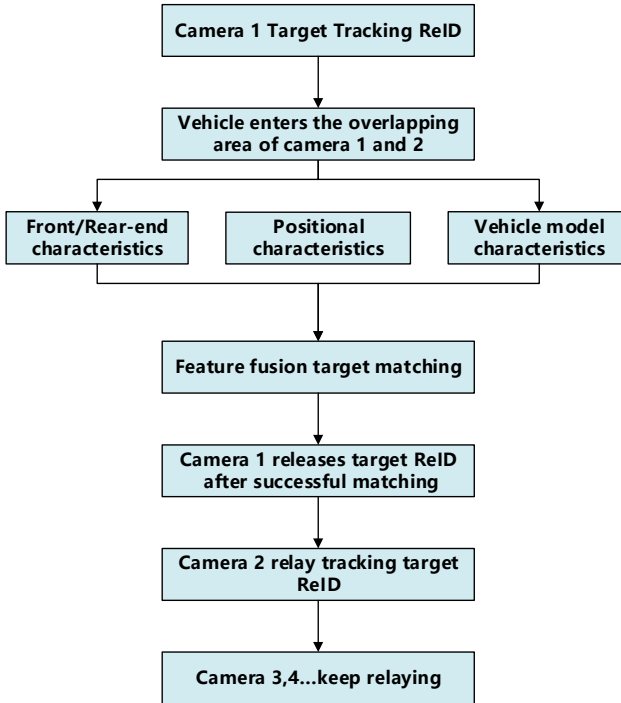


Fig. 4. Flowchart of feature-matching cross-domain tracking

3.5 Specialized vehicle management

For hazardous vehicles, such as those transporting hazardous chemicals on expressways, it is imperative for expressway managers to constantly be aware of their location. This is due to the potential for accidents involving these vehicles to result in large-scale disasters, posing significant dangers. Additionally, the safety of large buses, which involves group safety, is also a critical concern. The management of vehicles with similar characteristics can be effectively achieved through the use of visual artificial intelligence technology. The availability of visual information on vehicles facilitates the successful construction of their trajectory information.

3.6 Traffic flow modeling and simulation

Utilizing precise data on road traffic and events, it is possible to develop data models that capture the influence of traffic incidents, weather conditions, time, and other relevant informational dimensions on traffic flow. Such models are instrumental in making predictions and conducting simulations [8]. For instance, in scenarios where roadwork or traffic police intervention is planned for a specific day, simulating these events in advance can help identify periods with minimal traffic impact, thereby mitigating widespread congestion.

3.7 Road construction safety control

Recognition of the road environment enables the detection of ongoing construction, occupation status, and fluctuations in traffic flow. This information serves dual purposes: it provides construction crews with advanced vehicle risk warnings and informs the road management center. Consequently, during periods of high traffic volume, vehicles can be directed to alternate routes at other major interchanges [9]. Such measures not only ensure smoother travel but also enhance the safety of the construction personnel.

3.8 Intelligent detection of road hazards

For the detection of expressway pavement cracks, gaps, potholes, and other road hazards, the conventional method involves dispatching personnel to visually observe the road from a moving vehicle. To ensure accurate observation, the vehicle's speed often cannot be excessively high. Driving at low speeds on expressways, however, is considered a high-risk activity, which not only impedes the efficiency of traffic flow but also poses a potential risk for accidents [10]. Additionally, the effectiveness of manual observation is subject to human factors such as the observer's level of fatigue and attention to detail, which can lead to suboptimal results. An alternative approach that circumvents these issues is the use of vehicle-mounted cameras to analyze various types of road disasters.

4 THE OUTLOOK OF LARGE LANGUAGE MODEL

The visual model is capable of detecting and tracking the target object, as well as determining its position. However, it lacks access to common knowledge about the object's attributes and the relationship between objects. In contrast, a large language model demonstrates significant advantages in this regard [11]. The large language model serves as a repository of knowledge. Once an object is identified, the model can utilize its understanding of the object's correlation with other entities within the screen or the background scene to facilitate further reasoning. Nonetheless, the current large language model still encounters certain challenges. By integrating industry knowledge constraints with the large model, the generalization capability for various application scenarios can be substantially enhanced [12].

Experiments using ChatGPT4, as depicted in Figure 5 and Figure 6, indicate that the large language model already possesses a considerable ability to recognize scene information [13].



You
What happened in this picture?

ChatGPT
This image shows a yellow taxi and a white sedan traveling on a city road. Analysis of the image suggests that the two vehicles may be changing lanes, or the taxi may be attempting to overtake. Due to the relatively close proximity between the two vehicles, this situation may raise safety concerns. Road markings indicate a right turn lane ahead, and the taxi is in the process of changing lanes from the straight lane to the turn lane. This driving behavior could result in a traffic violation, especially if the taxi fails to properly use its turn signal before changing lanes. The photo may have been taken from a vehicle traveling behind, thus capturing this possible traffic violation. Some trees and buildings can be seen in the background, indicating that this is in an urban environment.

Fig. 5. ChatGPT4's interpretation of lane change images for traveling vehicles



You
What happened in this picture?

ChatGPT
This image shows a section of expressway undergoing road construction. On the left side of the image, a row of traffic cones mark the construction area, restricting the lanes of vehicular traffic. There are several visible construction vehicles and crews in the construction zone that appear to be working on road repairs or inspections. Traffic is relatively unobstructed in the right lane, allowing vehicles to move normally. In the background of the image, we can see city buildings, indicating that this expressway may be located on the outskirts of the city. There are also visible warning signs alerting drivers to the construction ahead and to slow down. Overall, the image captures one of the common scenarios of urban infrastructure maintenance.

Fig. 6. ChatGPT4's interpretation of road construction images

5 CONCLUSION

The fusion of artificial intelligence technology with the progressive deepening of the industry has played a pivotal role in the management and operation of expressway

transportation. From the perspective of expressway transportation managers, this integration enhances management efficiency, reduces administrative costs, and minimizes safety intervention expenses. For expressway drivers and passengers, it elevates the level of service and fosters trust in safe driving practices [14]. At the national management level, it augments overall transportation efficiency and bolsters safety capacity [15]. With the advancement of large language models, we anticipate the exploration of more scenarios and the realization of superior outcomes and benefits.

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