Article

Not peer-reviewed version

Application of Computer Vision Technology in Intelligent Transportation Systems

Qin Yang *

Posted Date: 23 December 2024

doi: 10.20944/preprints202412.1850.v1

Keywords: Intelligent Transportation Systems; Computer Vision; Traffic Monitoring; Autonomous Driving; Vehicle Recognition

Article

Application of Computer Vision Technology in Intelligent Transportation Systems

Qin Yang

Georgia Institute of Technology, USA; yqin0709@gmail.com

Abstract: With the acceleration of urbanization, Intelligent Transportation Systems (ITS) have become vital for addressing urban traffic congestion, enhancing road safety, and optimizing traffic management. As an advanced image processing and analysis technology, computer vision has been widely applied in various aspects of ITS, including traffic monitoring, autonomous driving, violation detection, and intelligent parking management. This paper explores the fundamental principles and technologies of computer vision, analyzes its typical application scenarios in ITS, and, through practical cases, demonstrates the advantages and challenges of this technology in improving traffic flow, enhancing road safety, and automating traffic management. Finally, this paper forecasts the future development of computer vision in ITS and highlights the technical bottlenecks and data privacy issues it faces.

Keywords: intelligent transportation systems; computer vision; traffic monitoring; autonomous driving; vehicle recognition

1. Introduction

As urbanization accelerates and populations grow, traffic congestion, accidents, and inefficient management are increasing challenges. To address these, Intelligent Transportation Systems (ITS) have become essential for managing traffic efficiently. ITS integrates advanced technologies like IoT, artificial intelligence, and big data analytics to improve traffic flow, reduce accidents, and optimize resource allocation. A key technology in ITS is computer vision, which processes and analyzes images and videos to extract information and make automated decisions. It enables real-time traffic monitoring, autonomous driving assistance, and vehicle recognition. Recent advancements in deep learning and neural networks have enhanced the accuracy and efficiency of computer vision, expanding its role in ITS. This paper explores the core principles and technologies of computer vision and analyzes its applications in ITS. It also examines how computer vision improves traffic management and discusses the challenges and future directions of this technology.

2. Fundamentals and Principles of Computer Vision Technology

Computer vision aims to give machines the ability to simulate human vision by analyzing and processing visual data from images or videos to extract meaningful information[1]. It relies on image processing and pattern recognition, using complex algorithms to transform raw visual data captured by cameras or sensors into structured information[2]. As a key branch of artificial intelligence, computer vision combines principles from computer science, mathematics, and statistics, covering subfields like object detection, image segmentation, and object tracking. These technologies are essential in many industries, including Intelligent Transportation Systems (ITS), where they have driven automation and advancements.The core tasks of computer vision are divided into three stages: image acquisition, processing, and information extraction. In the acquisition stage, sensors or cameras capture real-world scenes and convert them into digital data. The processing stage enhances the raw images through noise removal, edge detection, and feature extraction, helping the system interpret the image. Information extraction involves algorithms recognizing objects, shapes, and movements,

 doi:10.20944/preprints202412.1850.v1

providing deeper scene analysis. Recent advancements in deep learning, particularly convolutional neural networks (CNNs), have significantly improved computer vision's performance in tasks like object recognition, image classification, and semantic segmentation, making it widely applicable in traffic monitoring and autonomous driving. In ITS, computer vision is used for object detection, image segmentation, and object tracking[3]. Object detection identifies specific objects, such as vehicles, pedestrians, and traffic signs, using deep learning models like YOLO (You Only Look Once) or Faster R-CNN[4]. These models provide real-time data for traffic management and driving decisions. Image segmentation divides images into different regions, allowing the system to differentiate between roads, obstacles, and pedestrians, which is crucial in autonomous driving[5]. Object tracking monitors vehicle and pedestrian movements, enhancing dynamic traffic flow management. These combined technologies significantly improve traffic system intelligence. However, challenges exist, including environmental factors like weather, lighting, and traffic density, which can reduce image quality and system accuracy. ITS requires real-time performance, especially in autonomous driving and emergency situations, where decisions must be made in milliseconds. To address these issues, researchers are optimizing algorithms and integrating multi-sensor fusion, combining LiDAR, infrared imaging, and computer vision to increase system robustness. Additionally, distributed and edge computing are improving real-time responsiveness[6]. In conclusion, computer vision, supported by deep learning, is driving rapid ITS development. However, improving adaptability and processing efficiency in complex traffic scenarios remains a challenge for its broader application[7].

3. The Structure and Functions of Intelligent Transportation Systems

3.1. Structure of Intelligent Transportation Systems

The structure of an intelligent transportation system typically consists of four main components: the data acquisition layer, communication transmission layer, data processing layer, and application service layer. These four layers work together to ensure efficient and real-time system operations. The data acquisition layer serves as the foundation of the system, responsible for gathering real-time traffic data through various sensing devices. Cameras, radars, laser sensors, RFID, and ground-based intelligent sensors are widely used for monitoring traffic, measuring traffic volume, vehicle identification, and pedestrian movement detection. The data gathered from these sensors is transmitted to the communication transmission layer for further processing[8]. This transmission layer acts as the bridge between data acquisition and data processing, ensuring fast and reliable transfer of traffic data. ITS requires high-speed, low-latency communication networks to meet real-time demands, especially for traffic management and autonomous driving applications. Wireless technologies (like 5G), fiber optics, and satellite communications are employed to ensure stable data transmission. The communication transmission layer is essential in vehicle-to-infrastructure and vehicle-to-vehicle (V2X) communication[9]. The data processing layer, considered the "brain" of the system, handles the storage, analysis, and processing of large volumes of traffic data using big data, cloud computing, and artificial intelligence. It enables real-time analysis and prediction, supporting system decision-making processes. For example, traffic flow forecasting models can identify potential congestion points and generate real-time traffic diversion strategies[10]. Additionally, this layer supports historical data mining and analysis, aiding long-term traffic planning and optimization. The application service layer, which interfaces with users and managers, offers various transportation services and management functions. For ordinary users, the application service layer provides real-time traffic information, route navigation, and intelligent parking services. For traffic managers, it offers functions like violation detection, emergency response, signal control, and autonomous driving assistance. Through intelligent management and services, the application service layer enhances the overall efficiency of the transportation system and improves user experience.Overall, the structure of ITS is complex and multi-layered, with each component working efficiently together to meet modern traffic management needs. It also lays a technological foundation for future smart city development[11].

 doi:10.20944/preprints202412.1850.v1

3.2. Key Functional Modules

The primary functional modules of ITS are essential for achieving intelligent traffic management and optimization. These modules cover key areas such as traffic monitoring, autonomous driving assistance, traffic information services, and traffic signal control, all designed to improve traffic flow, reduce accidents, and enhance the overall travel experience.This is one of the core modules of ITS. It utilizes computer vision, IoT sensors, and big data analytics to monitor road traffic conditions in real-time, including traffic volume, vehicle speed, and road congestion. The monitoring system captures and analyzes real-time traffic data using cameras, radars, and sensors installed along the roadways[12]. From this data, the system generates dynamic traffic flow information. The system can automatically detect traffic accidents, illegal parking, and traffic violations, enabling authorities to respond promptly. The management module can also implement dynamic traffic signal control based on real-time traffic conditions, improving intersection efficiency and reducing congestion during peak hours.This module is closely tied to autonomous driving technology. It uses computer vision, LiDAR, and sensor fusion technologies to enable vehicles to perceive and make decisions autonomously. Specifically, the module helps vehicles recognize road markings, traffic signs, pedestrians, and other vehicles and perform automated driving tasks according to traffic rules. Additionally, it facilitates real-time communication between vehicles and infrastructure, such as traffic signals and other vehicles, to enhance safety and driving efficiency[13]. As autonomous driving technology continues to develop, this module's capabilities are being continuously improved, especially in complex urban environments.This module serves the public and traffic participants by providing real-time traffic information, route planning, and parking guidance. Through mobile applications, navigation devices, and road information displays, the module communicates current road conditions, congestion updates, and accident reports to drivers and pedestrians, helping them make better travel decisions. For example, the navigation service provides optimal route suggestions based on real-time conditions, helping drivers avoid traffic jams and keeping route information updated. Intelligent parking management is another crucial function of this module, where cameras and sensors detect available parking spots and guide drivers to them, reducing parking time. The traffic signal control module dynamically adjusts traffic light timings and switching frequencies based on real-time traffic data to optimize traffic flow[14]. Using computer vision and sensing technologies, this module monitors vehicle queues and traffic volume at each intersection and employs intelligent algorithms to calculate the most efficient signal timing. For example, at heavily congested intersections, the system can extend green light durations in certain directions to reduce vehicle wait times[15]. In case of emergencies, the signal control module also has the capability to prioritize emergency vehicles like ambulances and fire trucks by creating "green corridors."This module is designed to handle traffic accidents, natural disasters, or other emergencies. Using monitoring equipment, the system captures real-time images and data from the incident location, enabling rapid identification of the type and severity of the accident. Traffic managers are then notified to initiate emergency responses. The module can also automatically generate rerouting plans through the automated dispatch system, redirecting traffic away from the accident site to prevent further congestion. During extreme weather conditions, such as heavy rain or snowstorms, the system can issue early warnings to help traffic participants avoid hazardous areas.By working together, these functional modules enable ITS to manage and control traffic flow comprehensively and intelligently. This enhances the operational efficiency of urban traffic, reduces accidents, and improves the travel experience. As technology continues to advance, these modules will continue to expand their capabilities, laying a solid foundation for future smart city transportation systems[16].

3.3. Key Technology Integration in the System

The efficient operation of ITS relies on the integration and collaboration of multiple advanced technologies. These key technologies, when combined, not only enhance system functionality but also improve overall efficiency and stability. In ITS, information and communication technology, IoT, artificial intelligence, cloud computing, and big data analytics form the core support, and their seamless integration ensures that the system operates effectively in complex traffic environments.IoT

 doi:10.20944/preprints202412.1850.v1

plays a crucial role in data collection and device interconnectivity within ITS. Sensors, cameras, and RFID devices deployed on roads, vehicles, and infrastructure enable the interconnection of physical devices within the transportation system and the internet. The data collected from traffic volume, vehicle speed, road conditions, and air quality is transmitted to backend systems via IoT for processing and analysis[17]. This data provides real-time decision support for traffic management and key inputs for autonomous driving assistance, signal control, and accident handling. For example, V2X communication allows vehicles to interact with road infrastructure, enhancing the real-time perception and response capabilities of autonomous vehicles. AI, particularly deep learning, is widely used in ITS for data processing and decision-making support. Tasks such as vehicle recognition, pedestrian detection, and traffic flow prediction rely on deep learning algorithms within computer vision technology. CNN models trained on large datasets can accurately identify and classify various traffic targets, such as vehicle types, license plates, and pedestrian movements[18]. AI is also applied in traffic flow forecasting and optimization. By analyzing historical data and recognizing patterns, the system can predict congestion and implement appropriate signal control or route planning to improve overall efficiency.Big data and cloud computing support the massive data processing and storage needs of ITS. The system generates large amounts of data daily, covering vehicle trajectories, traffic flow, accident information, and environmental data from sensors[19]. Efficient storage and processing capabilities are required for this data to be quickly handled and used in decision-making. Cloud platforms provide elastic computing resources and distributed storage capabilities, ensuring real-time data processing and responsiveness. Additionally, big data analytics is applied to traffic pattern analysis and forecasting. For instance, by analyzing historical traffic data, long-term bottlenecks can be identified, and optimization strategies can be developed.In highly real-time traffic scenarios, edge computing complements cloud computing by enabling data processing at local devices. By shifting part of the computing tasks from the cloud to network edge devices, the system can quickly process data without relying on central servers[20]. Typical applications include traffic signal control and local perception and decision-making for autonomous vehicles. In these scenarios, the low-latency processing offered by edge computing is more advantageous than cloud computing. Edge computing ensures faster responses and higher reliability for ITS, particularly in emergency handling and autonomous driving. The high bandwidth and low latency of 5G communication technology provide strong support for real-time data transmission in ITS, especially in autonomous driving and V2X applications. The introduction of 5G significantly improves communication efficiency between vehicles and infrastructure, as well as between vehicles themselves. V2X technology enables vehicles to exchange real-time information with other vehicles, roadside infrastructure, and traffic management systems. For example, when a vehicle approaches a traffic signal, it can receive information about the signal status via V2X, allowing the driver or vehicle to adjust speed and reduce unnecessary stops. The combination of 5G and V2X enhances the real-time and stable nature of ITS and lays a foundation for the widespread application of autonomous driving technology[21]. As the volume of ITS data grows, data security and privacy protection have become critical concerns. Blockchain technology, as a decentralized ledger, ensures data immutability and transparency. In ITS, blockchain can be used for vehicle identity verification, traffic data sharing, and payment systems. Smart contracts enable automatic execution of pre-defined traffic rules or payment procedures, reducing human intervention. Furthermore, blockchain ensures data privacy in V2X communications, preventing unauthorized access or data breaches[22]. Through the deep integration of these key technologies, ITS can achieve real-time, accurate traffic management, while supporting functions like autonomous driving, intelligent dispatch, and emergency response[23]. As technology continues to evolve, ITS will become increasingly intelligent and automated, providing strong support for the sustainable development of urban transportation systems[24].

4. Conclusion

The application of computer vision technology in intelligent transportation systems has significantly enhanced the automation and efficiency of traffic management. Through real-time monitoring and handling of traffic flow, violations, and emergency events, computer vision

 doi:10.20944/preprints202412.1850.v1

technology has effectively alleviated congestion, reduced traffic accidents, and improved travel experiences. Although challenges such as adapting to complex environments and ensuring data privacy remain, the continuous advancement of technologies like deep learning, 5G, and IoT offers broad prospects for the future application of computer vision in intelligent transportation. It will provide more innovative solutions for the traffic management of smart cities.

References

1. Gao D, Shenoy R, Yi S, et al. Synaptic resistor circuits based on Al oxide and Ti silicide for concurrent learning and signal processing in artificial intelligence systems[J]. Advanced Materials, 2023, 35(15): 2210484.
2. Wu, X., Sun, Y., & Liu, X. (2024). Multi-Class Classification of Breast Cancer Gene Expression Using PCA and XGBoost. Preprints. https://doi.org/10.20944/preprints202410.1775.v1
3. Xu, Q., Wang, T., & Cai, X. (2024). Energy Market Price Forecasting and Financial Technology Risk Management Based on Generative AI. Preprints. https://doi.org/10.20944/preprints202410.2161.v1
4. Diao S, Wei C, Wang J, et al. Ventilator pressure prediction using recurrent neural network[J]. arXiv preprint arXiv:2410.06552, 2024.
5. Zhao Q, Hao Y, Li X. Stock price prediction based on hybrid CNN-LSTM model[J]. Applied and Computational Engineering, 2024, 104: 110-115.
6. Zhao Y, Hu B, Wang S. Prediction of brent crude oil price based on lstm model under the background of low-carbon transition[J]. arXiv preprint arXiv:2409.12376, 2024.
7. Zhang W, Huang J, Wang R, et al. Integration of Mamba and Transformer--MAT for Long-Short Range Time Series Forecasting with Application to Weather Dynamics[J]. arXiv preprint arXiv:2409.08530, 2024.
8. Mo K, Chu L, Zhang X, et al. DRAL: Deep reinforcement adaptive learning for multi-UAVs navigation in unknown indoor environment[J]. arXiv preprint arXiv:2409.03930, 2024.
9. Tang X, Wang Z, Cai X, et al. Research on heterogeneous computation resource allocation based on data-driven method[C]//2024 6th International Conference on Data-driven Optimization of Complex Systems (DOCS). IEEE, 2024: 916-919.
10. Min, Liu, et al. "Financial Prediction Using DeepFM: Loan Repayment with Attention and Hybrid Loss." 2024 5th International Conference on Machine Learning and Computer Application (ICMLCA). IEEE, 2024.
11. Yang H, Cheng Z, Zhang Z, et al. Analysis of Financial Risk Behavior Prediction Using Deep Learning and Big Data Algorithms[J]. arXiv preprint arXiv:2410.19394, 2024.
12. Ma D, Yang Y, Tian Q, et al. Comparative analysis of x-ray image classification of pneumonia based on deep learning algorithm[J]. Theoretical and Natural Science, 2024, 56: 52-59.
13. Cheng Y, Yang Q, Wang L, et al. Research on Credit Risk Early Warning Model of Commercial Banks Based on Neural Network Algorithm[J]. arXiv preprint arXiv:2405.10762, 2024.
14. Xiang A, Zhang J, Yang Q, et al. Research on splicing image detection algorithms based on natural image statistical characteristics[J]. arXiv preprint arXiv:2404.16296, 2024.
15. Huang B, Lu Q, Huang S, et al. Multi-modal clothing recommendation model based on large model and VAE enhancement[J]. arXiv preprint arXiv:2410.02219, 2024.
16. Zhang J, Zhang W, Tan C, et al. YOLO-PPA based efficient traffic sign detection for cruise control in autonomous driving[J]. arXiv preprint arXiv:2409.03320, 2024.
17. Li X, Cao H, Zhang Z, et al. Artistic Neural Style Transfer Algorithms with Activation Smoothing[J]. arXiv preprint arXiv:2411.08014, 2024.
18. Huang S, Yang H, Yao Y, et al. Deep adaptive interest network: personalized recommendation with context-aware learning[J]. arXiv preprint arXiv:2409.02425, 2024.
19. Li X, Wang X, Qi Z, et al. DTSGAN: Learning Dynamic Textures via Spatiotemporal Generative Adversarial Network[J]. Academic Journal of Computing & Information Science, 7(10): 31-40.
20. Yang H, Sui M, Liu S, et al. Research on Key Technologies for Cross-Cloud Federated Training of Large Language Models[J]. arXiv preprint arXiv:2410.19130, 2024.

doi:10.20944/preprints202412.1850.v1

21. Wang Z, Chen Y, Wang F, et al. Improved Unet model for brain tumor image segmentation based on ASPP-coordinate attention mechanism[J]. arXiv preprint arXiv:2409.08588, 2024.
22. Liu H, Shen Y, Zhou C, et al. TD3 Based Collision Free Motion Planning for Robot Navigation[J]. arXiv preprint arXiv:2405.15460, 2024.
23. Shen Y, Liu H, Zhou C, et al. Deep Learning Powered Estimate of The Extrinsic Parameters on Unmanned Surface Vehicles[J]. arXiv preprint arXiv:2406.04821, 2024.
24. Yan H, Wang Z, Bo S, et al. Research on image generation optimization based deep learning[C]//Proceedings of the International Conference on Machine Learning, Pattern Recognition and Automation Engineering. 2024: 194-198.