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Research on Road Traffic Sign Detection and Recognition Technology

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Abstract: With the development of intelligent transportation systems (ITS) and autonomous driving technologies, road traffic sign detection and recognition have become increasingly important in the fields of traffic safety, road management, and vehicle automation. Road traffic signs not only provide crucial information for drivers but also offer essential perception data for autonomous vehicles within intelligent transportation systems. This paper systematically reviews the current research progress in road traffic sign detection and recognition technology, analyzing the classification, visual features of signs, and the challenges faced in complex traffic environments. By comparing traditional image processing methods with advanced deep learning-based technologies, this paper discusses the advantages and disadvantages of sign detection and recognition in different application scenarios, and explores future technological development trends. Finally, the paper provides an outlook on the research directions in this field, aiming to provide theoretical support for future technological improvements and application promotion.

Keywords: road traffic signs; detection and recognition; deep learning; image processing; intelligent transportation systems; autonomous driving; technological challenges

1. Introduction

With the rapid development of intelligent transportation systems (ITS) and autonomous driving technologies, road traffic signs, as an essential part of traffic safety and road management, have become increasingly critical in modern transportation environments. Traffic signs not only provide necessary guidance for drivers but also deliver important environmental perception information for autonomous driving systems. By accurately recognizing and interpreting traffic signs, autonomous vehicles can make real-time decisions, enhancing road safety and traffic efficiency. As urban roads become more complex and traffic signs diversify, traditional sign recognition methods are increasingly unable to meet practical application needs. Therefore, accurately and real-time detecting and recognizing road traffic signs in complex and dynamic environments has become a key research direction in intelligent transportation and autonomous driving.

Currently, traditional sign detection methods based on image processing and feature extraction have gradually been replaced by deep learning technologies. Deep learning, particularly the application of convolutional neural networks (CNNs), has significantly advanced road sign detection and recognition in terms of accuracy, robustness, and real-time performance. However, practical applications still face challenges such as occlusion,

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degradation, and lighting variations, which remain bottlenecks in technological development. As a result, researchers continue to explore new algorithms and technologies aimed at improving sign recognition accuracy and system adaptability.

This paper will systematically review the current state of research on road traffic sign detection and recognition technologies, discussing both traditional methods and advanced deep learning-based techniques in various application scenarios. It will also address the challenges faced in this field and propose potential future development trends and solutions, providing theoretical support and practical guidance for subsequent research [1].

2. Classification and Characteristics of Road Traffic Signs

2.1. Classification of Signs

The classification of road traffic signs is primarily based on their function, shape, color, and symbols, and they are typically divided into three main categories: warning signs, prohibition signs, and instruction signs. Warning signs are designed to alert drivers to potential hazards or special conditions ahead on the road, prompting appropriate precautions. Common examples include "Sharp Turn," "Construction Ahead," and "Slippery Road." These signs are typically triangular in shape with a yellow or red background to enhance their warning effect. Prohibition signs, on the other hand, are used to restrict or prohibit certain actions to ensure the safety and smooth flow of traffic. Examples include "No Parking," "Speed Limit," and "No Entry," which are usually round in shape with red or blue backgrounds, clearly indicating prohibited or restricted behaviors. Instruction signs provide drivers with information about the direction of travel, lane usage, and other instructions to help guide them correctly on the road. Common instruction signs include "Straight Ahead," "Left Turn," and "Detour." These are typically rectangular or square, with green or blue backgrounds, clearly showing the driving requirements. Additionally, there are some special-purpose signs, such as auxiliary and service signs, which provide extra guidance or service information to drivers. The design of traffic signs not only needs to meet functional requirements but also ensure high recognizability under various environmental conditions, providing the foundation for the development of traffic sign detection and recognition technologies [2].

2.2. Visual Features of Signs

The visual features of road traffic signs are key factors that affect their effective recognition and understanding. The shape, color, symbols, and other visual elements of signs directly influence their recognizability and determine whether drivers can interpret the information quickly and accurately. First, the shape of the sign plays a crucial role in recognition. Different types of signs typically have fixed shapes. For example, warning signs are usually triangular, prohibition signs are round, and instruction signs are typically rectangular or square. The standardization of these shapes allows drivers to quickly distinguish between different types of signs and respond accordingly. Secondly, color is another important visual feature of traffic signs. Color not only helps to emphasize the warning effect but also aids drivers in rapidly identifying the nature of the sign. For instance, red is commonly used to indicate prohibition or warning, yellow and orange are used for warning signs, while green and blue are used for instruction signs [3]. By contrasting colors, drivers can quickly assess the meaning of a sign. In addition, symbols or text on the sign also play a vital role. The design of traffic sign symbols is usually simple and clear, making them easy to recognize. The symbols are often designed according to international standards to ensure consistent recognition worldwide. For example, the numeric symbol on a speed limit sign or the graphic symbol for "No Parking" allows drivers to quickly understand the sign's message, regardless of the language environment. Finally, the size and placement of the sign also influence its visual effectiveness and recognition. The size of the sign should be designed according to the type of road, vehicle speed, and

traffic density to ensure visibility at different distances. Proper installation height and positioning are also crucial for the sign's visibility, preventing issues caused by angle limitations or obstructions. In conclusion, the visual features of road traffic signs, through the coordination of factors such as shape, color, and symbols, ensure their efficient recognition in complex road environments. These visual features not only provide effective means of information transmission for traffic management but also offer important design guidelines for automatic sign detection and recognition technologies [4].

3. Road Traffic Sign Detection Technology

3.1. Traditional Methods

In the early stages of road traffic sign detection, traditional methods mainly relied on image processing technologies for detection and recognition. These methods typically involved analyzing image features such as color, shape, edge characteristics, and texture information. While some success was achieved in simpler environments, these methods often faced limitations in more complex scenarios. Color features are one commonly used technique in traditional detection methods. By analyzing the distribution of different colors in an image, it is possible to identify potential areas that may contain traffic signs. For example, common sign colors such as red, yellow, and green can serve as effective filtering conditions. By converting color spaces (e.g., from RGB to HSV), pixel values within specific color ranges can be extracted to locate traffic signs. However, the limitation of color-based methods lies in their sensitivity to lighting changes. For instance, under varying weather conditions or times of day, color information can change significantly, leading to reduced detection accuracy. Shape features are another key factor in traditional methods [5]. By detecting the contours in an image and extracting regions with specific geometric shapes—such as triangles, circles, and rectangles—the potential areas containing traffic signs can be narrowed down. Common shape detection techniques include Hough Transform and edge detection algorithms (such as Canny edge detection). These methods can identify major edges and contours in an image, thus determining the location and shape of traffic signs. However, these methods often require extensive preprocessing and feature extraction, and their accuracy can be affected in complex scenarios, such as when signs are partially obscured or when a complicated background exists. Furthermore, texture analysis methods have also been applied to traffic sign detection. Texture analysis typically involves extracting texture features (e.g., gray-level co-occurrence matrix) from different regions in the image to distinguish signs from the background. However, this method has high computational complexity and is sensitive to texture variations under different environmental conditions, making it challenging in practical applications. In general, while traditional sign detection methods can be effective under certain conditions, they are often limited in complex and dynamic traffic environments. In scenarios involving lighting changes, weather interference, damaged or obstructed signs, their performance is usually constrained. As a result, deep learning-based detection methods have gradually become mainstream in recent years, offering higher accuracy and robustness in more complex scenarios [6].

3.2. Deep Learning Methods

With the development of computer vision technology, deep learning methods have gradually become the mainstream approach in road traffic sign detection. In particular, the successful application of Convolutional Neural Networks (CNNs) in image recognition has led to significant advancements in detection accuracy, robustness, and real-time performance for deep learning-based sign detection methods. Compared to traditional methods, deep learning techniques can automatically learn high-level features from images, avoiding the complexity and limitations of manually designed features. This makes them especially suitable for scenarios where environmental factors such as complex backgrounds, lighting variations, and sign occlusion pose challenges for traditional methods.

The core advantage of deep learning methods lies in their powerful feature extraction capabilities. CNN-based sign detection models can extract multiple levels of features from raw images through successive convolution and pooling operations, including edges, textures, shapes, and complex semantic information. This enables deep learning models to automatically recognize and locate traffic signs in different complex scenarios [7], bypassing the challenges of manual feature design and parameter tuning encountered in traditional methods. In sign detection tasks, Region Proposal Networks (RPN) and candidate box generation techniques are often combined with CNNs to locate image regions that may contain signs. For example, Faster R-CNN and YOLO (You Only Look Once) are typical applications based on CNNs. Faster R-CNN combines RPN networks to generate candidate regions, improving both the speed and accuracy of object detection. YOLO, on the other hand, uses end-to-end training and a single convolutional network to perform the entire process from image input to output of sign locations and categories, offering high real-time performance. YOLO's advantage lies in its fast detection capability, making it highly suitable for real-time traffic monitoring and autonomous driving applications [8].

4. Road Traffic Sign Recognition Technology

4.1. Character Recognition Methods

One of the core tasks of road traffic sign recognition technology is to accurately identify the text information on the signs to convey traffic instructions or warnings. In traditional sign recognition methods, character recognition is usually treated as an independent step, mainly relying on image processing techniques and pattern recognition algorithms. However, with the rapid development of deep learning, character recognition technology has gradually transitioned from traditional methods to deep learning-based approaches. In traditional character recognition methods, the most commonly used techniques include template matching, region growing, and projection methods. Template matching involves comparing the character to be recognized with pre-stored character templates to find the closest match. This method is simple and intuitive, but it is sensitive to character rotation, distortion, and occlusion, and requires a large template library to handle characters of different fonts and shapes. Region growing is based on the pixel connectivity of the character regions in the image to extract these areas for recognition. This method effectively handles some noise and background interference, but in complex backgrounds, the segmentation of character regions may not be precise. The projection method analyzes the vertical or horizontal projection of the character image to extract distribution information, and then recognition is performed. While this method is computationally simple, it performs poorly with complex character shapes or overlapping characters. With the development of computer vision and machine learning techniques, deep learning has become the mainstream in character recognition. Particularly, the application of Convolutional Neural Networks (CNN) has transformed character recognition from manual feature extraction to automated feature learning. CNN-based character recognition methods can automatically extract high-level features from images and classify and recognize them through multi-layer network structures. Compared to traditional methods, deep learning effectively handles issues like character deformation, rotation, occlusion, and different fonts, providing stronger robustness and accuracy. In deep learning-based character recognition, both Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) are widely used. CNN extracts spatial features from character images through convolutional and pooling layers, effectively recognizing different forms of characters. For continuous character sequences, RNNs and Long Short-Term Memory networks (LSTM) can better handle the temporal features of characters, which is particularly useful for tasks like speed limit signs that involve multiple characters. By combining the advantages of CNN and RNN, the CNN-RNN model has shown good performance in sign character recognition. This model can not only effectively extract spatial features of characters but also handle the sequential information, adapting to various arrangements

and shape changes of characters in different signs. In practice, the accuracy of character recognition technology is often influenced by several factors, such as character clarity, font diversity, size variation of signs, and spacing between characters. To address these issues, researchers continuously optimize model structures and propose techniques like data augmentation (increasing training data diversity through affine transformations, rotations, noise addition, etc.), multi-scale detection (effectively detecting characters of different sizes), and end-to-end training (performing character localization and recognition within a single model).Overall, the development of character recognition technology, especially with the application of deep learning, has greatly improved the accuracy and robustness of traffic sign recognition. With the ongoing development of autonomous driving technology and intelligent transportation systems, accurate and real-time character recognition technology will become a crucial support for efficient traffic management and improving road safety [9].

4.2. Image Classification and Recognition Methods

Image classification and recognition is one of the core tasks in road traffic sign recognition technology, aimed at processing input images to accurately classify and recognize different types of traffic signs. Traditional image classification methods typically rely on manual feature extraction and classical machine learning algorithms. However, in recent years, deep learning methods, especially the application of Convolutional Neural Networks (CNN), have made significant breakthroughs in image classification and recognition technology, and are widely used in automatic traffic sign detection and recognition tasks. In traditional image classification and recognition methods, feature extraction is a key step. Classical image classification methods generally rely on manually extracted features (such as edges, colors, shapes, etc.) for classification. One commonly used feature extraction method is the Histogram of Oriented Gradients (HOG), which captures the edge information in the image and is significant for traffic sign detection and classification. The HOG feature computes the gradient direction histogram of local image regions, effectively describing the shape contour of objects, and is suitable for static scene sign recognition. However, manual feature methods do not perform well in complex environments, as they are easily affected by background interference, lighting changes, and sign occlusion. With the development of deep learning technology, Convolutional Neural Networks (CNN) have become the mainstream method for image classification and recognition. CNNs automatically learn high-level features from images without the need for manual feature extraction. The basic structure of a CNN includes convolutional layers, pooling layers, and fully connected layers, progressively extracting features from low-level to high-level through a multi-layer network structure, and ultimately performing classification. Compared to traditional methods, CNNs show significant advantages in traffic sign classification and recognition, especially in complex backgrounds, lighting changes, and sign damage, where deep learning models outperform manual feature methods by far. In traffic sign image classification, common deep learning models include LeNet, AlexNet, VGG, ResNet, etc. These models emphasize enhancing feature extraction capabilities in their design. For example, the VGG network improves image feature representation by increasing the depth of convolutional layers, while ResNet introduces residual connections to solve the gradient vanishing and overfitting issues in deep networks. These architectures have achieved significant results on multiple sign recognition datasets. Furthermore, transfer learning has been widely applied in image classification and recognition, especially when sign datasets are relatively small. Transfer learning uses pre-trained models from large datasets (such as ImageNet) to help the model better learn features and improve classification accuracy. By fine-tuning pre-trained models, transfer learning allows effective training with limited labeled data, reducing the need for large-scale labeled datasets. To improve image classification and recognition accuracy, researchers have also

proposed various data augmentation techniques. For example, expanding the training dataset through rotation, translation, scaling, color transformations, etc., helps the model become more robust to different scales, perspectives, and lighting conditions of the signs. Additionally, multi-scale training techniques are widely used by training models with image inputs of different sizes, allowing the model to recognize traffic signs of various sizes. In conclusion, image classification and recognition technology is a crucial part of road traffic sign detection and recognition. With the continuous development of deep learning technology, CNN-based image classification methods have become the mainstream in the sign recognition field, greatly improving recognition accuracy and efficiency. In the future, as datasets grow and technology continues to optimize, image classification and recognition technology will play an increasingly important role in autonomous driving, intelligent traffic management, and other fields [10].

5. Application of Road Traffic Sign Detection and Recognition Systems

The application of road traffic sign detection and recognition technology is of great importance in modern traffic management and intelligent driving. With the continuous development of autonomous driving technology and the promotion of intelligent transportation systems, the ability to efficiently and accurately detect and recognize road traffic signs has become one of the key technologies for ensuring road safety and improving traffic efficiency. In particular, in autonomous driving systems, the recognition and interpretation of traffic signs are prerequisites for safe driving and compliance with traffic regulations. Autonomous vehicles rely on various sensors and algorithms to perceive their surroundings, with traffic sign recognition being an indispensable part. Using cameras and other sensors, the autonomous driving system can detect various road traffic signs in real-time and make decisions such as adjusting speed, changing the driving route, or stopping. For example, when the system detects a speed limit sign, it will automatically control the vehicle's speed; when it detects a stop or yield sign, the vehicle will slow down and determine whether it is safe to proceed. This capability is crucial for enhancing the safety of autonomous driving systems. Autonomous driving not only relies on cameras for sign recognition but can also integrate with V2X (Vehicle-to-Everything) technology, enabling intelligent interaction with traffic infrastructure to further optimize traffic flow and improve traffic management efficiency. Intelligent Transportation Systems (ITS), as an important part of modern urban traffic management, use information technology for real-time monitoring and regulation of traffic conditions, which effectively improves traffic efficiency and safety. In ITS, traffic sign detection and recognition technology plays a crucial role. By installing smart cameras or sensors, the ITS can monitor the status of traffic signs in real time and promptly detect issues such as damaged, blurred, or obstructed signs, preventing traffic accidents caused by unclear signs. Additionally, traffic sign recognition technology can work with traffic flow monitoring systems to automatically adjust traffic lights and signs, increasing road capacity, reducing congestion, and enhancing the intelligence of traffic management. In road monitoring and law enforcement, traffic sign detection and recognition technology is also widely used. Traffic enforcement usually relies on manual patrols or traffic surveillance cameras to capture images for identifying violations. However, by leveraging image recognition and deep learning technologies, automatic traffic sign recognition can significantly improve the efficiency of traffic law enforcement. Monitoring systems can not only detect traffic signs on the road in real time but also identify whether vehicles are violating speed limits, restricted areas, or parking regulations. This information is instantly transmitted to traffic management departments, generating automated violation records and penalty notifications, helping to reduce human error in enforcement and improve the efficiency of handling traffic violations. Moreover, in-vehicle navigation and driver assistance systems fully utilize traffic sign recognition technology to provide real-time traffic information to drivers. In in-vehicle navigation systems, recognized traffic sign information can be immediately relayed to the

driver, guiding route planning and speed control. For example, when the navigation system detects a speed limit sign, it will remind the driver of the speed limit via voice prompts or the display screen, helping the driver comply with traffic regulations and ensure safe driving. For advanced driver assistance systems (ADAS), traffic sign recognition helps the vehicle make decisions in complex traffic environments, such as automatically stopping at a stop sign or adjusting speed when approaching a sharp turn, improving both safety and comfort. With the increasing number of road traffic signs and their aging, issues such as sign damage, fading, or obstruction are becoming more serious. Traditional manual inspection methods can no longer efficiently and comprehensively address these challenges. Through intelligent sign detection and recognition technology, traffic management departments can achieve round-the-clock monitoring of road sign status, quickly detect and report damage, obstruction, or malfunction of signs. The system can automatically identify signs with broken parts or reduced reflectivity and send alerts to maintenance personnel in real time for repair or replacement. This not only reduces the burden of manual inspections but also improves sign management efficiency, ensuring road safety. The rise of drone inspection technology has also provided a new solution for road traffic sign monitoring and maintenance. Drones equipped with high-definition cameras and traffic sign recognition systems can quickly survey large areas of road from the air, detecting any anomalies in traffic signs. Especially in areas with complex traffic or hard-to-reach locations, drone inspections can play an important role by providing real-time status data and images, offering data support to traffic management departments, and facilitating traffic accident handling and road maintenance. In conclusion, traffic sign detection and recognition technology is widely applied in multiple fields, including autonomous driving, intelligent transportation systems, road law enforcement, and in-vehicle navigation. With the continuous advancement of technology, especially the development of deep learning and artificial intelligence, traffic sign detection and recognition systems will become more accurate and intelligent, playing an increasingly important role in improving road safety, optimizing traffic management, and enhancing transportation efficiency.

6. Conclusion

Road traffic sign detection and recognition technology plays an increasingly important role in intelligent transportation, autonomous driving, road enforcement, and other fields. With the continuous progress of deep learning and image processing technologies, traditional sign detection methods have gradually been replaced by more efficient and intelligent deep learning algorithms. By combining computer vision, convolutional neural networks, and other technologies, the system can achieve high-precision sign recognition in complex environments, providing strong support for traffic management. In the future, with the continuous innovation of data collection methods and the deepening application of technology, road traffic sign detection and recognition will further improve traffic safety and management efficiency, laying the foundation for the development of intelligent transportation systems.

References

1. A. Alam and Z. A. Jaffery, "Indian traffic sign detection and recognition," *Int. J. Intell. Transp. Syst. Res.*, vol. 18, no. 1, pp. 98–112, 2020, doi: 10.1016/j.ijtst.2022.06.002.
2. R. K. Megalingam, et al., "Indian traffic sign detection and recognition using deep learning," *Int. J. Transp. Sci. Technol.*, vol. 12, no. 3, pp. 683–699, 2023, doi: 10.1016/j.ijtst.2022.06.002.
3. R. Lahmyed, M. El Ansari, and Z. Kerkaou, "Automatic road sign detection and recognition based on neural network," *Soft Comput.*, vol. 26, no. 4, pp. 1743–1764, 2022, doi: 10.1007/s00500-021-06726-w.
4. Y. Zhu and W. Q. Yan, "Traffic sign recognition based on deep learning," *Multimed. Tools Appl.*, vol. 81, no. 13, pp. 17779–17791, 2022, doi: 10.1007/s11042-022-12163-0.
5. A. Hechri and A. Mtibaa, "Two-stage traffic sign detection and recognition based on SVM and convolutional neural networks," *IET Image Process.*, vol. 14, no. 5, pp. 939–946, 2020, doi: 10.1049/iet-ipr.2019.0634.

6. I. S. B. Md Isa, J. Y. Choy, and N. L. A. B. M. Shaari, "Real-time traffic sign detection and recognition using Raspberry Pi," *Int. J. Electr. Comput. Eng.*, vol. 12, no. 1, p. 331, 2022, doi: 10.11591/ijece.v12i1.pp331-338.
7. M. Sudha and Dr. V. P. G. Pushparathi, "Traffic sign detection and recognition using RGSM and a novel feature extraction method," *Peer-to-Peer Netw. Appl.*, vol. 14, no. 4, pp. 2026–2037, 2021, doi: 10.1007/s12083-021-01138-x.
8. R. Zhang, et al., "Traffic sign detection based on the improved YOLOv5," *Appl. Sci.*, vol. 13, no. 17, p. 9748, 2023, doi: 10.3390/app13179748.
9. N. Ahmed, et al., "Traffic sign detection and recognition model using support vector machine and histogram of oriented gradient," *Int. J. Inf. Technol. Comput. Sci.*, vol. 13, no. 3, pp. 61–73, 2021, doi: 10.5815/ijitcs.2021.03.05.
10. H. Wan, et al., "A novel neural network model for traffic sign detection and recognition under extreme conditions," *J. Sens.*, vol. 2021, no. 1, Article ID 9984787, 2021, doi: 10.1155/2021/9984787.