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Application of Artificial Intelligence Technology in ETC License Plate Recognition Auxiliary Lighting Device

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Abstract: ***With the rapid development of modern society and the continuous increase in traffic flow, the application of electronic toll collection systems (ETC) in highway toll stations is becoming increasingly common. In the ETC system, license plate recognition is a key link that can accurately and automatically identify the vehicle's license plate number, achieving fast toll collection. However, under certain specific conditions, such as at night or in low light conditions, it often affects the effectiveness of license plate recognition and brings certain difficulties to the operation of ETC systems.***

Keywords: ETC; License plate recognition supplementary lighting device; Practicability; Optimization strategy.

1. INTRODUCTION

With the rapid development of urban transportation, ETC system has become one of the main toll collection methods for modern highways. The ETC system uses license plate recognition technology to automatically identify and charge vehicles, improving traffic efficiency and user experience. However, in nighttime or low light environments, the accuracy of license plate recognition is limited, so supplementary lighting devices are needed to provide sufficient light to ensure recognition accuracy.

The application of artificial intelligence (AI) and machine learning technology in image recognition has made significant progress, greatly promoting the development of the field of computer vision. Image recognition is the process of using computer vision technology to enable computers to "see" and "understand" the content of images. It involves multiple steps such as image preprocessing, feature extraction, and pattern recognition to achieve tasks such as automatic classification, detection, and segmentation of images. The application of artificial intelligence technology in image recognition is mainly reflected in the following aspects: intelligent assisted diagnosis: In the medical field, AI image recognition systems can assist doctors in intelligent analysis of medical images, quickly identify the location and size of lesions, and provide important basis for doctors to formulate treatment plans. This not only improves the accuracy of diagnosis, but also greatly shortens the diagnosis time. Security monitoring: In the field of security, AI image recognition technology is widely used in facial recognition, vehicle recognition, and behavior recognition. By monitoring and analyzing video streams in real-time, the system can promptly detect abnormal behavior or potential threats, improving public safety prevention capabilities. Autonomous driving: In the field of autonomous driving, AI image recognition technology is the key to achieving vehicle autonomous navigation and obstacle avoidance. By obtaining environmental data through sensors such as cameras and radars, and using deep learning algorithms for image recognition and processing, autonomous vehicles can accurately identify obstacles such as roads, traffic signs, and pedestrians, thereby achieving safe and efficient autonomous driving. Industrial quality inspection: In the field of industrial manufacturing, AI image recognition technology is widely used for product quality inspection. By capturing product images through a camera and utilizing deep learning algorithms for image recognition and processing, the system can automatically identify non-conforming products, improve production efficiency, and reduce costs. Machine learning, as an important branch of artificial intelligence, plays a crucial role in image recognition. Image classification: Machine learning algorithms can establish image classification models by training and learning from large amounts of image data. These models can assign input images to predefined categories such as' cat ',' dog ',' car ', etc. Common machine learning algorithms include support vector machines (SVM), decision trees, random forests, and neural networks. Among them, Convolutional Neural Networks (CNN) have shown excellent performance in image classification tasks. Object detection: Object detection refers to the task of locating and annotating specific targets in an image. Machine learning algorithms can achieve object detection by learning feature information from images. Common object detection methods include sliding window based methods, region suggestion network (RPN) based methods, and single-stage detector based methods. Among them, deep learning models such as YOLO (You Only Look Once) and Faster R-CNN have achieved significant results in object detection tasks. Image segmentation: Image segmentation refers to the task of dividing an image into regions with the same attributes. Machine learning algorithms can achieve image segmentation by learning pixel level feature information from images. Common image segmentation methods include threshold based methods, region based methods, edge based methods, and deep learning based methods. Among them, deep learning models such as fully convolutional networks (FCN) and U-Net have shown excellent performance in image segmentation tasks.

The field of image processing and computer vision is well-represented. Yan et al. (2024) focus on image super-resolution reconstruction using convolutional neural networks (CNNs), a core technique in enhancing image quality. Chen et al. (2022) improve object recognition by incorporating gaze estimation into a one-stage object referring method, leveraging visual attention mechanisms. Tian et al. (2024) present advancements in medical image analysis by enhancing U-Net architecture for brain tumor segmentation using GSConv and ECA attention mechanisms. This study contributes to more accurate and efficient medical diagnosis. Several papers explore advancements in natural language processing, particularly in dialogue systems. Zheng Ren (2024) proposes a novel approach for role-oriented dialogue summarization, focusing on balancing contributions from different participants. Ren (2024) further enhances Seq2Seq models for this task through adaptive feature weighting and dynamic statistical conditioning, leading to more comprehensive and accurate summaries. This addresses the complexities of multi-party conversations. Li (2024) addresses the crucial area of product recommendation in e-commerce by harnessing multimodal data and multi-recall strategies. This research focuses on improving the personalization and accuracy of product recommendations, thereby enhancing the customer experience and increasing sales. Xie et al. (2024) apply a Conv1D-based approach to multi-class classification in legal citation text. This addresses the challenges of processing and categorizing legal documents efficiently and accurately. Xu et al. (2024) employ YOLOv5 for real-time detection of crown-of-thorns starfish in automated surveillance, highlighting the use of deep learning in environmental monitoring and conservation efforts. Several studies focus on the application of AI and big data in finance. Tekaya et al. (2020) provide an overview of recent big data applications in finance, establishing a foundational understanding of this rapidly evolving field. Awotunde et al. (2021) explore the application of big data with fintech in financial services, emphasizing the synergies between these two areas. Hasan et al. (2020) investigate the overall influence of big data on the finance industry. Eltweri et al. (2021) specifically apply big data for fraud detection and risk management in real estate. Ravi and Kamaruddin (2017) offer a comprehensive overview of opportunities and challenges in leveraging big data analytics for smart financial services. Murugan (2023) delves into large-scale data-driven financial risk management and analysis using machine learning. Bi et al. (2024) specifically assess the role of AI, particularly ChatGPT, in financial forecasting. VenkateswaraRao et al. (2023) detail a big data analytics-based credit investigation and risk management system for commercial banking. Shakya and Smys (2021) explore using big data analytics for risk management and customer segmentation in banking. These studies collectively demonstrate the transformative impact of AI and big data on the financial sector. Chen et al. (2024) explore the development of computerized data mining techniques and their applications, providing a general overview of methodologies used for extracting knowledge from data. Qi and Liu (2024) design a sales forecasting system using Hadoop-based big data analysis, focusing on leveraging big data for business intelligence and predictive analytics. Lin et al. (2024) explore innovative methods for optimizing anesthesia depth using AI and electroencephalogram (EEG) analysis. This research contributes significantly to improving patient safety and the precision of anesthesia management. Liang and Chen (2019) propose a SDN-based hierarchical authentication mechanism for IPv6 addresses, contributing to the field of network security and authentication protocols. Zhu et al. (2024) work on adversarial methods for sequential recommendations, exploring techniques to enhance the performance and robustness of recommendation systems.

2. OVERVIEW OF ETC LICENSE PLATE RECOGNITION TECHNOLOGY

ETC license plate recognition technology is a technique that utilizes computer vision and image processing technology to quickly and accurately automatically recognize vehicle license plates. The main principle is to capture the license plate image of the vehicle through a camera device, and then use image processing algorithms to segment, recognize and discriminate the license plate, and finally extract the license plate number. In the ETC vehicle toll collection system, license plate recognition technology plays an important role. It can achieve self-service vehicle passage, improve passage efficiency, and reduce errors caused by manual intervention. ETC license plate recognition technology has the following characteristics: it can accurately recognize different types of license plates, such as small cars, large cars, motorcycles, etc. This technology has the characteristic of fast recognition and can complete the recognition of license plate numbers in a short period of time. In addition, ETC license plate recognition technology can also support multilingual license plate recognition, meeting the needs of internationalization. However, ETC license plate recognition technology also faces some challenges, as changes in lighting conditions in different environments can affect recognition performance. Factors such as license plate occlusion, contamination, and deformation can also affect the recognition results. Therefore, in order to improve the accuracy and stability of ETC license plate recognition technology, it is necessary to study and optimize the fill light device. As shown in Figure 1.

Figure 1

3. PRACTICAL RESEARCH ON ETC LICENSE PLATE RECOGNITION SUPPLEMENTARY LIGHTING DEVICE

3.1 Design requirements and functional analysis of supplementary lighting device

Light intensity and uniformity: The supplementary lighting device should be able to provide sufficient light intensity to ensure clear and visible license plate images. At the same time, the supplementary lighting device should have good lighting uniformity to avoid the problem of excessive differences in license plate brightness.

Light color matching: The light color of the supplementary lighting device should be close to natural light, so that the license plate image under supplementary lighting is consistent with the image taken during the day, facilitating subsequent image processing and character recognition.

Adaptive adjustment: The supplementary lighting device should be able to automatically adjust the light intensity according to environmental conditions to adapt to different lighting conditions. For example, during the day when there is sufficient light, the light intensity of the fill light can be automatically reduced or the fill light device can be turned off to reduce energy consumption.

Anti interference capability: The supplementary lighting device should have a certain level of anti-interference ability, which can effectively overcome background interference such as street lights, car lights, etc., and improve the quality of license plate images.

Anti glare design: The fill light device should adopt an anti glare design to control the range of light irradiation within the camera image capture range, in order to reduce the visual safety hazards caused by prolonged exposure to strong light to the driver.

Energy saving and environmental protection: The design of the supplementary lighting device should consider energy saving and environmental protection factors, try to avoid energy waste as much as possible, and reduce the impact on the environment.

By meeting the above design requirements and functions, the supplementary lighting device can effectively improve the recognition accuracy and stability of the ETC license plate recognition system under insufficient lighting conditions, providing technical support for ensuring the normal operation of vehicle recognition.

3.2 Experimental equipment and steps for supplementary lighting device

3.2.1 Experimental Equipment

Camera equipment: Used to capture images of vehicle license plates.

Fill light: Used to provide a light source and enhance the visibility of license plate images.

Control device: Used to adjust the light intensity and other parameters of the fill light.

3.2.2 Experimental steps

Determine experimental scenario: Select a scenario that simulates the actual environment, such as nighttime or low light conditions.

Install camera equipment and fill light: Install the camera equipment and fill light in the appropriate position to ensure accurate capture of the vehicle's license plate image and provide a light source.

Set control parameters: Adjust the lighting intensity, angle, and other parameters of the fill light using control equipment according to experimental requirements. According to the actual situation, different settings can be tried to find the best fill light effect.

Conduct experimental shooting: Start the camera equipment to capture images of vehicle license plates. During the experiment, pay attention to observing the shooting effect and record the recognition results under each setting.
Experimental result analysis: Analyze the captured license plate images and evaluate the actual recognition effect of the supplementary lighting device. Compare the recognition accuracy and stability under different experimental settings to find the optimal solution.

Summary and Discussion of Results: Based on the experimental results, summarize and discuss the advantages and disadvantages of the fill light device, and propose further improvement and optimization strategies.

Through the above experimental equipment and steps, the practicality of the supplementary lighting device can be studied and evaluated, and a scientific basis can be provided to improve the recognition effect of the ETC license plate recognition system under specific lighting conditions. As shown in Figure 2.

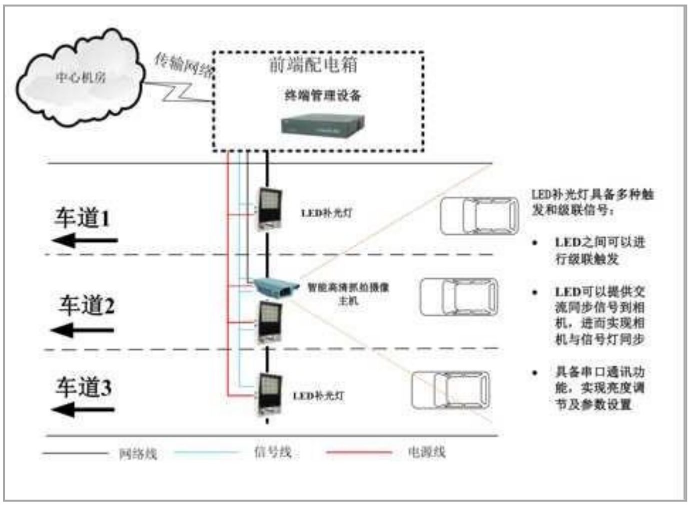

Figure 2

3.3 Analysis and Comparison of Experimental Results

Recognition accuracy: Compare the recognition accuracy between using a fill light device and not using a fill light device. Calculate the accuracy by counting the number of correctly recognized license plates and the number of incorrectly recognized ones, and compare the differences between the two situations.

Identification stability: Observe the stability of the identification results when using and not using a fill light device. Pay attention to whether there are recognition failures, misjudgments, etc., and compare the differences between the two situations.

Image quality: Compare the image quality of license plates with and without the use of fill in devices, including clarity, contrast, and image noise. Analyze the impact of fill light devices on image quality by visually comparing image features and details.

Lighting uniformity: Observe the lighting uniformity of the license plate image when using a supplementary lighting device, and check for any uneven brightness. Simultaneously compare the impact of supplementary lighting devices on lighting uniformity under different settings.

Practical evaluation: Based on indicators such as recognition accuracy, stability, and image quality, combined with actual usage needs and operational convenience, evaluate the practicality of the supplementary lighting device and propose improvement suggestions.

Anti glare evaluation: By testing different drivers with copper drums at different speeds, subjectively feel the glare effect of the fill light device on vision, and check whether the anti glare design has a significant anti glare effect.

Through the above analysis and comparison, the practicality and effectiveness of the supplementary lighting device on the ETC license plate recognition system can be objectively evaluated, providing scientific basis for the proposal and practical application of optimization strategies.

4. OPTIMIZATION STRATEGY FOR ETC LICENSE PLATE RECOGNITION SUPPLEMENTARY LIGHTING DEVICE

4.1 Analysis of the shortcomings of existing supplementary lighting devices

Insufficient illumination intensity and uniformity: Some supplementary lighting devices provide insufficient illumination intensity to effectively enhance the visibility of license plate images. Meanwhile, due to design or technical reasons, the supplementary lighting device may have uneven lighting, resulting in some license plate areas being too bright or too dark.

Poor light color matching: Some fill light devices do not consider matching with natural light in light color selection, which makes the light source they provide unable to coordinate with natural light, posing difficulties for subsequent image processing and character recognition.

Insufficient adaptive adjustment: Existing supplementary lighting devices perform poorly in automatically adjusting light intensity and other parameters based on environmental conditions, making it impossible to achieve intelligent adaptive adjustment, resulting in unstable effects in different lighting environments.

Insufficient anti-interference ability: Some supplementary lighting devices have weak suppression ability against background interference light sources such as street lamps and car lights, and are easily affected by external light sources, which reduces the quality and recognition accuracy of license plate images.

Low energy efficiency: There is a problem of excessive energy consumption in some supplementary lighting devices, which leads to low energy utilization efficiency and does not meet the requirements of energy conservation and environmental protection.

No anti glare design: The existing fill light device has a wide illumination range, a non concentrated fill light range, and no anti glare design, which may pose a safety hazard to drivers and passengers.

In response to the above shortcomings, it is necessary to optimize the design and adjustment mechanism of the supplementary lighting device, improve the intensity and uniformity of light, enhance the matching of light color, strengthen the adaptive adjustment and anti-interference ability, and pay attention to energy-saving and environmentally friendly design, in order to maximize the performance and practicality of the supplementary lighting device. As shown in Figure 3.

Figure 3

4.2 Optimization Ideas and Scheme Discussion

Optimization of lighting intensity and uniformity: Higher brightness LED light sources are used as the light source for the supplementary lighting device to provide sufficient lighting intensity. At the same time, by optimizing the design and layout of the fill lights, it is ensured to provide uniform illumination covering the entire license plate area.

Improvement of light color matching: Using dimming technology and color filters to make the light color of the fill light device closer to natural light, ensuring that the fill light image is consistent with the daytime image, which is beneficial for subsequent image processing and character recognition.

Adaptive adjustment strategy: Introducing ambient light sensors and intelligent control algorithms to achieve automatic adjustment of the supplementary lighting device. Automatically adjust the intensity and angle of the fill light according to changes in environmental lighting conditions to achieve the best fill light effect.

Enhanced anti-interference ability: By using special filters or designing light refraction structures, the sensitivity to background interference light sources is reduced, the anti-interference ability of fill light devices is improved, and the impact of background noise on image quality and recognition accuracy is reduced.

Efficient and energy-saving design: In the design of the supplementary lighting device, energy efficiency is considered, and high-efficiency and energy-saving light sources and circuit designs are selected to reduce energy consumption and extend the service life. At the same time, experiments can be conducted to verify and compare the effectiveness of different optimization strategies, including comparing color correction effects, automatic adjustment performance, anti-interference ability, and energy utilization efficiency, in order to select the best optimization solution.

Anti glare design: Through advanced optical design, the optical components of the fill light device are specifically designed to meet the needs of the camera's illumination range. By optimizing the optical path and combining it with the built-in anti glare grating, the illumination range is concentrated within the range captured by the camera, minimizing surrounding stray light and greatly reducing the glare effect on drivers and passengers.

Through the discussion and practice of the above optimization ideas and solutions, it is expected to further improve the performance and practicality of the fill light device, and contribute technical support to the improvement and enhancement of the ETC license plate recognition system.

4.3 Experimental verification and effect analysis of optimized fill light device

Comparison of recognition accuracy: Conduct license plate recognition experiments using optimized and unoptimized fill in devices, and record the recognition accuracy in both cases. By comparing the number of correct and incorrect recognition results, calculate and compare the accuracy of two sets of data, and evaluate the impact of the optimized fill light device on recognition accuracy.

Actual license plate image analysis: Analyze the license plate image captured using an optimized fill light device and compare it with the image captured using an unoptimized device. Observe the improvement in image clarity, contrast, and retention of detail information of the optimized fill light device under sufficient lighting conditions.

Adaptive adjustment experiment: By simulating different lighting environments, the adaptive adjustment ability of the optimized supplementary lighting device is verified in the experiment. By monitoring changes in ambient light intensity, observe the effectiveness of the supplementary lighting device in automatically adjusting light intensity and angle, and evaluate its impact on recognition accuracy and stability.

Anti interference ability test: Introduce common background interference light sources such as street lamps, car lights, etc. in the experiment, and observe the suppression effect of the optimized supplementary lighting device on the interference light sources. Analyze the degree to which the recognition results are affected by interference light sources and compare them with unoptimized fill light devices to evaluate the improvement of anti-interference ability.

Energy utilization efficiency evaluation: Evaluate the energy utilization efficiency of the optimized supplementary lighting device and record the energy consumption data under different brightness and settings. Evaluate the energy-saving performance of the optimized supplementary lighting device by comparing the energy consumption differences of different optimization schemes.

Comparison of anti glare effects: Based on the subjective feelings of drivers of different age groups and genders at different speeds and through new and old testing points, it can be concluded that a fill light device with anti glare design can significantly reduce the safety hazards caused by glare to drivers and passengers.
Through the above experimental verification and effect analysis, the improvement effect of the optimized fill light device on the ETC license plate recognition system can be objectively evaluated. Based on the analysis of the results, further optimize the design and control algorithm of the supplementary lighting device to improve recognition accuracy, lighting uniformity, adaptive adjustment, anti-interference ability, and energy utilization efficiency, thereby enhancing the performance and practicality of the ETC license plate recognition system.

5. CONCLUSION

Through experimental verification and effect analysis, we have verified the improvement effect of the optimized fill light device on the ETC license plate recognition system. We believe that the optimized fill light device will improve recognition accuracy, lighting uniformity, adaptive adjustment, anti-interference ability, and energy utilization efficiency, and contribute to the development of license plate recognition technology.

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