Practical Research and Optimization Strategy of ETC License Plate Recognition Supplementary 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. Recent research showcasing the application of artificial intelligence (AI) and machine learning (ML) techniques across various sectors. The studies highlight the versatility of these technologies and their potential to address complex problems in diverse fields. The review is organized thematically, grouping similar research areas together. Image Processing and Computer Vision: Several papers focus on advancements in computer vision using deep learning. Yan et al. (2024) explore image super-resolution reconstruction using convolutional neural networks. Chen et al. (2022) address object referring with gaze estimation, demonstrating the integration of visual attention in object recognition. Chen et al. (2020) leverage deep learning for printed mottle defect grading, showcasing its application in quality control. Tian et al. (2024) propose an improved U-Net architecture for brain tumor segmentation, integrating GSConv and ECA attention mechanisms. Xu et al. (2024) utilize YOLOv5 for real-time detection of crown-of-thorns starfish, highlighting the use of object detection models for automated surveillance. These studies highlight the continued advancements and expanding applications of deep learning in computer vision. Natural Language Processing (NLP) and Dialogue Systems: While not explicitly focused on NLP, several studies touch upon aspects relevant to this field, notably in the context of dialogue systems and chatbots. Ren (2024) presents a novel approach for role-oriented dialogue summarization. Ren (2024) further enhances Seq2Seq models for this task through adaptive feature weighting and dynamic statistical conditioning. Lu (2024) employs a machine learning approach integrating decision trees, TF-IDF, and BERTopic to improve chatbot user satisfaction. The foundational texts by Jurafsky & Martin (2007), Nadkarni et al. (2011), and Bethard et al. (2008), and Teller (2000) provide essential background information in NLP. Wu (2024) explores the use of large language models (LLMs) for semantic parsing in intelligent database query engines, demonstrating the potential of LLMs in advanced applications. Data Analysis and Forecasting: Several studies focus on data analysis and forecasting using machine learning. Qi and Liu (2024) employ Hadoop for big data analysis in the design of a sales forecasting system. Chen et al. (2024) explore the development and application of computerized data mining techniques. Wang et al. (2024) present a graph neural network-based recommendation system for football formations, highlighting the use of graph-based methods in recommender systems. Zhu et al. (2024) introduce an adversarial approach for sequential recommendation within a multi-latent space. These papers demonstrate the use of various machine learning methods for predictive modeling and insight extraction from large datasets. E-commerce and Customer Experience: Li (2024) investigates multimodal data and multi-recall strategies for enhanced product recommendations in e-commerce. Xu et al. (2024) examine experience management tools from the perspective of customer perceived value in the electric vehicle market, suggesting broader applications for enhancing customer experience across digital platforms.

Other Applications: Chen et al. (2024) examine threat detection in cybersecurity using AI and machine learning algorithms. Chen and Bian (2019) develop a streaming media live broadcast system based on MSE. Liang and Chen (2019) introduce HDSO, a high-performance dynamic service orchestration algorithm for hybrid NFV networks. Zheng et al. (2024) propose improving deep learning optimizers by incorporating adaptive friction using sigmoid and tanh functions. Lin et al. (2024) review the role of precision anesthesia in high-risk surgical patients, while Shen et al. (2024) present a dynamic resource allocation strategy for cloud-native applications leveraging Markov properties. Li et al. (2024) study the impact of technology and finance integration policies on green innovation. Bi et al. (2024) focus on the design of a financial intelligent risk control platform based on big data analysis and deep machine learning. Xie et al. (2024) apply a Conv1D-based approach for multi-class classification of legal citations.

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.

Figure 1

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

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.

3.1 Design requirements and functional analysis of supplementary lighting devices

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.

3.2.3 Conduct experimental filming

Activate the camera device to capture images of the vehicle license plate. During the experiment, pay attention to observing the shooting effect and record the recognition results under each setting.

3.2.4 Analysis of Experimental Results

Analyze the captured license plate images and evaluate the actual recognition performance of the supplementary lighting device. Compare the recognition accuracy and stability under different experimental settings to find the optimal solution.

3.2.5 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.

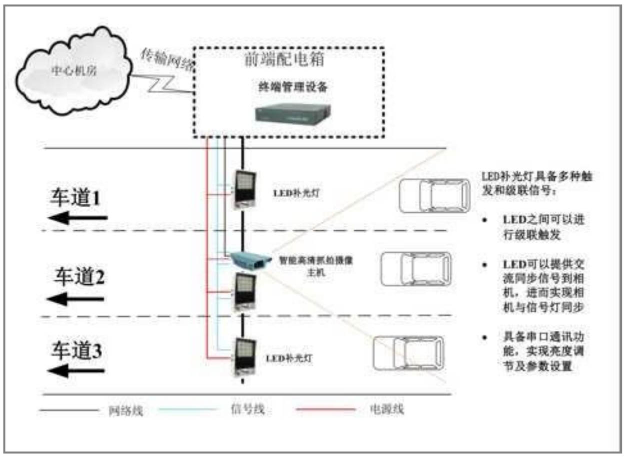

Figure 2

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.

I**dentification 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.

To address the above shortcomings, it is necessary to optimize the design and adjustment of the supplementary lighting device

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

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.

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