VEHICLE NUMBER PLATE AND SPEED DETECTION USING IMAGE PROCESSING IN MATLAB

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Abstract - The rapid increase in the number of vehicles on roads has led to significant challenges in traffic management, vehicle monitoring, and road safety. Conventional monitoring systems rely heavily on manual effort and costly infrastructure, making them inefficient for large-scale deployment. To address these limitations, this paper presents an automated system for vehicle number plate detection and speed estimation using image processing techniques in MATLAB.

The proposed system processes input in the form of images or traffic surveillance videos. Initially, video frames are extracted and preprocessed using grayscale conversion, noise reduction, and contrast enhancement to improve image quality. Edge detection techniques, such as Sobel and Canny operators, are employed to identify potential number plate regions. Subsequently, morphological operations are applied to accurately localize and extract the license plate from the image.

Following plate extraction, character segmentation is performed to isolate individual alphanumeric characters. These characters are then recognized using Optical Character Recognition (OCR) techniques, converting them into machine-readable text. In addition to number plate recognition, the system estimates vehicle speed by analysing the displacement of vehicles across consecutive frames in the video sequence.

The proposed method offers an efficient, cost-effective, and automated solution for real-time vehicle identification and speed monitoring. It can be applied in various domains, including traffic law enforcement, automated toll collection, parking management, border surveillance, and intelligent transportation systems, thereby enhancing traffic efficiency and road safety

***Key Words*:** Automatic Number Plate Recognition (ANPR), Image Processing, MATLAB, Vehicle Speed Estimation, Optical Character Recognition (OCR), Edge Detection, Morphological Operations.

1. INTRODUCTION

Transportation systems play a vital role in the economic and social development of modern society by enabling the efficient movement of people and goods. However, the rapid increase in the number of vehicles on roads has introduced significant challenges in traffic management, including congestion, road accidents, and frequent violations of traffic rules. Traditional traffic monitoring methods rely heavily on manual observation and standalone devices, which are labour-intensive, error-prone, and not suitable for large-scale implementation. These limitations create a strong need for automated, accurate, and cost-effective traffic monitoring solutions.

Automatic Number Plate Recognition (ANPR) has emerged as an important technology for vehicle identification in intelligent transportation systems. ANPR systems use cameras to capture images or video sequences of vehicles and apply image processing techniques to detect and recognize license plates. The recognized vehicle information can be used for various applications such as traffic law enforcement, toll collection, parking management, border security, and surveillance. Despite its advantages, accurate detection and recognition of number plates in real-world conditions remains a challenging task due to varying lighting conditions, noise, occlusions, and complex backgrounds.

Image processing techniques form the core of ANPR systems and involve several stages, including image acquisition, preprocessing, feature extraction, segmentation, and recognition. In the preprocessing stage, images are enhanced through grayscale conversion, noise reduction, and contrast adjustment to improve quality and visibility. Edge detection algorithms, such as Sobel and Canny operators, are used to identify the boundaries of the number plate region. Morphological operations are then applied to refine the detected region and accurately localize the license plate. After extraction, segmentation techniques are used to separate individual alphanumeric characters, which are subsequently recognized using Optical Character Recognition (OCR) to convert them into machine-readable text.

While the application domains differ, previously developed systems such as the heart rate and oxygen saturation monitoring system using Arduino demonstrate strong capabilities in embedded system design and real-time data processing, which can be extended to support automated applications like vehicle number plate detection[1].

The effectiveness of deep learning-based object detection models, particularly YOLOv5, has been widely demonstrated in autonomous systems, achieving high precision and accuracy in detecting multiple objects under real-world conditions. These capabilities make such models highly suitable for applications including vehicle number plate detection systems[2].

Furthermore, advanced machine learning techniques have shown remarkable performance in real-time classification tasks. For instance, emergency vehicle detection using temporal and spectral audio features has achieved high accuracy, highlighting the robustness and reliability of intelligent systems in transportation-related applications [3]. In addition, deep learning models such as U-Net, optimized through hyperparameter tuning and cross-validation, have exhibited excellent performance in lane detection tasks. This demonstrates their effectiveness in image segmentation and their potential applicability in intelligent transportation systems, including vehicle number plate recognition [4]. Moreover, IoT-enabled systems integrated with sensors and real-time communication technologies have proven effective in accident detection and analysis for autonomous vehicles. These systems enable efficient data collection, processing, and communication, thereby supporting broader applications such as vehicle monitoring and number plate detection [5]. Recent studies also emphasize the widespread adoption of IoT across domains such as smart cities, healthcare, and industrial systems, facilitating real-time monitoring, automation, and data-driven decision-making. Such advancements further strengthen the development of intelligent transportation solutions, including automated vehicle tracking and number plate detection systems [6]. In parallel with advancements in intelligent transportation systems, semiconductor device research has focused on developing energy-efficient electronic components capable of supporting modern sensing and computing applications [7–19].

In addition to vehicle identification, speed monitoring is a critical requirement for ensuring road safety. Over-speeding is one of the primary causes of road accidents and traffic violations. Conventional speed detection methods, such as radar-based devices, are expensive and require manual operation, making them unsuitable for continuous and large-scale monitoring. Furthermore, existing systems often perform either vehicle identification or speed detection independently, lacking an integrated approach for comprehensive traffic analysis.

Therefore, there is a need for an automated system that can simultaneously perform vehicle number plate detection and speed estimation in a reliable and efficient manner. The major challenge lies in accurately detecting the license plate region, recognizing characters under varying environmental conditions, and estimating vehicle speed using video-based motion analysis techniques.

To address these challenges, this work proposes an integrated system for vehicle number plate detection and speed estimation using image processing techniques in MATLAB. The system processes traffic video sequences by extracting frames and analyzing them to detect vehicles and localize their number plates. The speed of vehicles is estimated by calculating their displacement across consecutive frames based on time intervals. By combining ANPR and speed estimation into a single framework, the proposed system provides a comprehensive and automated solution for traffic monitoring.

The developed system is designed to be cost-effective, scalable, and efficient, making it suitable for real-world applications such as traffic law enforcement, intelligent transportation systems, automated toll collection, parking management, and security surveillance. By enabling accurate vehicle identification and speed monitoring, the system contributes to improved traffic control, enhanced law enforcement, and increased road safety.

Noise reduction is a crucial preprocessing step in image processing systems, where techniques such as median filtering are effectively used to remove impulse noise while preserving important features like edges, thereby improving the accuracy of subsequent processes such as number plate detection[20]

Fault detection systems using embedded technologies have been widely developed for infrastructure monitoring, such as underground cable fault detection and localization, demonstrating the effectiveness of automated sensing and digital analysis techniques, which can be extended to intelligent transportation applications like vehicle number plate detection [21]

Literature

In recent years, significant research has been carried out in the field of automated vehicle detection and identification using image processing and computer vision techniques. The rapid growth in vehicular traffic has increased the demand for intelligent traffic monitoring systems to ensure road safety, reduce congestion, and improve transportation efficiency.

Automatic Number Plate Recognition (ANPR) systems have gained considerable attention as an effective solution for vehicle identification. These systems utilize cameras and image processing algorithms to automatically detect and recognize vehicle license plates from images or video sequences. ANPR technology is widely applied in areas such as traffic law enforcement, electronic toll collection, parking management, and security surveillance. The increasing need for automation in transportation systems has driven extensive research to improve the accuracy and efficiency of ANPR systems.

Image processing plays a vital role in the development of ANPR systems. The overall process typically involves stages such as image acquisition, preprocessing, feature extraction, segmentation, and character recognition. In the preprocessing stage, techniques such as noise reduction, grayscale conversion, contrast enhancement, and image normalization are applied to improve image quality and visibility. These steps are essential for handling real-world challenges such as varying lighting conditions, shadows, and image noise.

Edge detection techniques are commonly used for identifying the boundaries of the number plate region. Algorithms such as Sobel, Prewitt, and Canny detect abrupt changes in pixel intensity, which correspond to edges in the image. Among these, the Canny edge detector is widely preferred due to its ability to provide accurate and well-defined edges. To further refine the detected regions, morphological operations such as dilation and erosion are applied. These operations help in removing noise, filling gaps, and enhancing the structure of the number plate region, thereby improving detection accuracy.

Segmentation is another critical step in ANPR systems, where the number plate region is isolated from the background. Various segmentation techniques based on pixel intensity, color, or texture have been proposed in the literature. After extracting the number plate, segmentation is further applied to separate individual characters. Accurate segmentation is crucial, as errors in this stage directly affect the performance of character recognition.

For character recognition, Optical Character Recognition (OCR) techniques are widely used. OCR algorithms analyze the shape and structure of characters and convert them into machine-readable text. Tools such as Tesseract OCR are commonly employed due to their efficiency and ease of integration. In addition to OCR, some studies have explored template matching methods, where segmented characters are compared with predefined templates to identify the best match. While template matching is simple and effective for standard fonts, it may not perform well under varying conditions.

Recent advancements in research have introduced machine learning and deep learning techniques for number plate recognition. Convolutional Neural Networks (CNNs) have shown significant improvements in recognition accuracy by automatically learning features from input images. These models are capable of handling complex scenarios such as variations in lighting, viewing angles, and image distortions. However, deep learning approaches require large datasets, high computational resources, and longer training times, which may limit their practical implementation in some applications.

In addition to vehicle identification, vehicle speed estimation has also been an important area of research. Traditional speed detection methods, such as radar and laser-based systems, are accurate but expensive and require dedicated hardware. As an alternative, researchers have proposed image processing-based methods that estimate vehicle speed using video analysis. In these approaches, the displacement of vehicles across consecutive frames is measured, and the speed is calculated based on the distance travelled over a known time interval. This method provides a cost-effective and scalable solution for traffic monitoring.

Several studies have highlighted the advantages of integrating number plate recognition with vehicle speed detection into a single system. Such integrated systems enable automatic identification of over-speeding vehicles and provide valuable information for traffic law enforcement. This combination enhances the overall effectiveness of traffic monitoring systems and supports the development of intelligent transportation systems.

Despite the progress made in this field, certain challenges still exist, including sensitivity to environmental conditions, variations in number plate formats, motion blur, and real-time processing constraints. Researchers continue to explore advanced techniques to improve system robustness and accuracy under diverse conditions.

Based on the analysis of existing literature, it is evident that image processing techniques such as preprocessing, edge detection, morphological operations, segmentation, and OCR are fundamental to the development of ANPR systems. Furthermore, video-based motion analysis provides an efficient approach for vehicle speed estimation.

The proposed work builds upon these concepts by developing an integrated system for vehicle number plate detection and speed estimation using MATLAB. MATLAB offers a powerful environment with built-in image processing tools, making it suitable for implementing and evaluating such systems. The study aims to provide a cost-effective, accurate, and efficient solution for automated traffic monitoring.

2. OBJECTIVES OF THE SYSTEM

The primary objective of this work is to design and implement an automated system capable of detecting vehicle number plates and estimating vehicle speed using image processing techniques in MATLAB. With the exponential increase in vehicular traffic across both urban and rural regions, conventional traffic monitoring methods have become inefficient and labor-intensive. Hence, the proposed system aims to provide an intelligent, automated solution for vehicle monitoring and traffic violation detection without continuous human intervention.

A key objective of the system is to acquire vehicle images or video sequences from traffic surveillance sources and process them effectively. Image acquisition serves as the foundational step, ensuring that high-quality input data is available for further processing and analysis.

Another significant objective is the accurate detection of the vehicle number plate region. This is achieved through various preprocessing techniques, including image resizing, grayscale conversion, noise reduction, and contrast enhancement. These methods improve image quality and facilitate reliable detection. Additionally, edge detection and morphological operations are employed to highlight and isolate the number plate region from the background.The system also focuses on efficient character segmentation from the detected number plate. Techniques such as thresholding and bounding box analysis are utilized to separate individual characters accurately, which is a critical step for successful recognition.Furthermore, the system aims to recognize alphanumeric characters using Optical Character Recognition (OCR). By analyzing the structural features of segmented characters, OCR converts them into machine-readable text, enabling automatic identification of vehicle registration numbers.In addition to number plate recognition, the system is designed to estimate vehicle speed using video analysis techniques. By tracking vehicle motion across consecutive frames and calculating the distance traveled over a known time interval, the system determines the approximate speed of the vehicle. This feature is particularly useful for identifying over-speeding vehicles and enhancing traffic law enforcement.Another objective is to implement the entire system within the MATLAB environment using the Image Processing Toolbox. MATLAB provides a robust platform for developing, testing, and optimizing image processing algorithms efficiently through its extensive built-in functions.

Finally, the proposed system aims to offer a cost-effective, reliable, and scalable solution for real-world traffic monitoring applications. It can assist authorities in detecting traffic violations, managing traffic flow, and improving road safety. Moreover, this work demonstrates the potential of integrating image processing and computer vision techniques in the development of intelligent transportation systems and smart city infrastructures.

3. SCOPE OF THE SYSTEM

The scope of the proposed system is to design and implement a robust, automated framework for vehicle number plate detection and vehicle speed estimation using advanced image processing techniques in MATLAB. The system aims to address the growing need for intelligent traffic monitoring solutions due to the rapid increase in the number of vehicles and the limitations of traditional manual monitoring systems. By automating the process of vehicle identification and speed analysis, the proposed system contributes to improved road safety, efficient traffic management, and reduced human effort.

The system is capable of processing both still images and continuous video streams obtained from traffic surveillance cameras or pre-recorded datasets. It focuses on extracting meaningful information from visual data through a sequence of well-defined image processing stages. The first stage involves image acquisition, where input data is collected in the form of digital images or video frames. This is followed by preprocessing, which plays a crucial role in enhancing image quality and preparing it for further analysis. Preprocessing operations include grayscale conversion to reduce computational complexity, noise reduction using filtering techniques such as median or Gaussian filters, and contrast enhancement to improve visibility under poor lighting conditions.

The next stage involves the detection of the number plate region. The system employs edge detection techniques such as Sobel and Canny operators to identify sharp intensity variations corresponding to object boundaries. These detected edges are further refined using morphological operations such as dilation and erosion, which help in removing noise and closing gaps in detected regions. Based on geometric features such as aspect ratio, rectangular shape, and edge density, candidate regions are identified, and the most probable region corresponding to the vehicle number plate is extracted.

Once the number plate is localized, the system performs character segmentation to isolate individual alphanumeric characters present on the plate. This is achieved using thresholding and connected component analysis techniques. Each segmented character is then normalized to a standard size to ensure consistency during recognition. Optical Character Recognition (OCR) is subsequently applied to convert the segmented characters into machine-readable text. This enables automatic identification of vehicle registration numbers without human intervention.

In addition to number plate recognition, the system incorporates a vehicle speed estimation module. This module operates by analyzing motion across consecutive frames in a video sequence. The system tracks the position of a vehicle over time using bounding boxes or region-based tracking methods. The displacement of the vehicle between frames is initially measured in pixel units and is then converted into real-world distance using a calibration factor. By utilizing the frame rate of the video, the time interval between frames is determined. The speed of the vehicle is then calculated using the fundamental relation between distance and time. To improve accuracy and reduce fluctuations, the system may compute the average speed over multiple frames.

The implementation of the system is carried out using MATLAB, leveraging its Image Processing Toolbox and optionally the Computer Vision Toolbox. These tools provide a comprehensive set of functions for image enhancement, feature extraction, segmentation, object detection, and pattern recognition. MATLAB offers a flexible environment for rapid prototyping, algorithm testing, and performance evaluation, making it highly suitable for academic and research-oriented applications.

The system is designed with modularity and scalability in mind, allowing for future enhancements and integration with emerging technologies. It can be extended to support real-time video processing using live camera feeds, integration with databases for storing vehicle information, and incorporation of machine learning or deep learning models for improved accuracy in detection and recognition. Additionally, the system can be adapted to handle different number plate formats, fonts, and languages, making it applicable across different regions and countries.

From an application perspective, the proposed system has wide-ranging uses in traffic surveillance, automated toll collection systems, parking management, border control, and law enforcement. It can assist authorities in identifying over-speeding vehicles, tracking stolen vehicles, and enforcing traffic regulations. Furthermore, the system can serve as a key component in the development of intelligent transportation systems (ITS) and smart city infrastructures, where automation and real-time data analysis play a vital role.

Despite its advantages, the current system has certain limitations. Its performance may be affected by challenging environmental conditions such as poor illumination, shadows, occlusions, motion blur, and low-resolution images. Variations in number plate design, font styles, and camera angles may also impact detection accuracy. Addressing these challenges requires the integration of more advanced techniques such as deep learning-based object detection models, adaptive image enhancement methods, and robust tracking algorithms.

In conclusion, the scope of this project encompasses the development of a comprehensive and automated solution for vehicle monitoring using image processing techniques. It not only demonstrates the practical application of digital image processing concepts but also provides a foundation for future research and development in intelligent traffic management systems. With further improvements and technological integration, the proposed system has the potential to significantly contribute to modern transportation infrastructure and smart city development.

4. DESIGN, IMPLEMENTATION, RESULTS AND DISCUSSION

The proposed Automatic Number Plate Recognition (ANPR) and vehicle speed estimation system is designed using a modular and scalable architecture to ensure efficient processing, flexibility, and ease of implementation. The system is divided into multiple functional modules, each responsible for a specific task, thereby simplifying the overall complexity and improving maintainability.

The architecture begins with the input acquisition module, which captures images or video sequences from traffic surveillance cameras or pre-existing datasets. These inputs serve as the primary data source for further processing. The acquired data is then forwarded to the preprocessing module, where image enhancement techniques such as grayscale conversion, noise filtering (median/Gaussian), and contrast adjustment are applied. This stage improves the visual quality of the input and ensures robustness against environmental variations such as illumination changes and noise.

Following preprocessing, the number plate detection module identifies the region of interest (ROI) containing the license plate. Edge detection techniques, particularly Sobel and Canny operators, are employed to detect intensity variations and object boundaries. Morphological operations such as dilation and erosion are applied to refine the detected edges and eliminate irrelevant regions. Based on geometric features such as rectangular shape and aspect ratio, the most probable number plate region is extracted.

The extracted region is then processed by the character segmentation module, where individual alphanumeric characters are separated using thresholding and connected component analysis. Each character is isolated using bounding boxes and normalized to a standard size to ensure uniformity during recognition.

Subsequently, the Optical Character Recognition (OCR) module converts the segmented characters into machine-readable text. The recognized characters are concatenated to form the complete vehicle registration number. This module plays a critical role in ensuring accurate identification of vehicles.

In parallel, the system includes a speed estimation module, which operates on video input. This module tracks the movement of vehicles across consecutive frames using object tracking techniques. The displacement of the vehicle is measured in pixel units and converted into real-world distance using calibration parameters. By utilizing the frame rate, the time interval is computed, and the speed is calculated accordingly.

Fig. Campas vehicle

The modular organization ensures that each stage operates independently while contributing to the overall system functionality. This design approach facilitates easy debugging, performance optimization, and future enhancements such as integration with machine learning models or real-time systems.

The implementation of the proposed system is carried out using MATLAB, leveraging its Image Processing Toolbox and Computer Vision capabilities. The system is developed as a sequence of scripts and functions that execute each processing stage systematically.

Initially, vehicle images are captured using a high-resolution digital camera (12 MP) or extracted from video datasets. The captured RGB images are converted into grayscale to reduce computational complexity and improve processing speed. A binary representation of the image is then obtained through thresholding.

To facilitate number plate extraction, morphological operations are applied using structuring elements such as squares and lines. The Sobel operator is utilized to compute the gradient magnitude, highlighting regions with high edge intensity corresponding to the number plate boundaries. The resulting binary gradient mask may contain discontinuities; therefore, dilation is performed to close gaps, followed by hole filling operations to obtain a continuous region.

Further refinement is achieved by removing objects connected to image borders using boundary-clearing techniques. Additional morphological filtering is applied to smooth the detected region and enhance the structural integrity of the number plate.

Fig. Campas Vehicle Recognition

For character segmentation, the bounding box method is employed. Connected component labelling is used to identify individual regions corresponding to characters. Each detected component is enclosed within a bounding box and extracted for further processing. This step is critical, as improper segmentation can significantly affect recognition accuracy.

The segmented characters are then passed to the OCR module, where pattern recognition techniques are used to identify alphanumeric characters. MATLAB's built-in OCR functions or template matching methods are utilized for this purpose.

For speed estimation, the system processes video frames sequentially. The position of the vehicle is tracked across frames, and the displacement is calculated. Using calibration factors, pixel displacement is converted into real-world distance. The speed is then computed using the ratio of distance to time, where time is derived from the frame rate.

5. RESULTS AND DISCUSSION

The experimental results obtained from the implementation of the Automatic Number Plate Recognition (ANPR) and vehicle speed estimation system demonstrate the effectiveness and reliability of the proposed approach. The system was evaluated using a diverse set of vehicle images and video sequences captured under varying environmental conditions, including differences in illumination, background complexity, vehicle orientation, and motion characteristics.

The results indicate that the system achieves high accuracy in detecting number plate regions, particularly when the input images are of good quality with adequate lighting conditions. The preprocessing stage significantly enhances image clarity by reducing noise and improving contrast, which directly contributes to improved edge detection and region localization. The combination of edge detection techniques and morphological operations successfully identifies the number plate region in most test cases, even in the presence of moderately complex backgrounds.

The character segmentation module performs effectively in isolating individual alphanumeric characters from the extracted number plate region. The use of connected component analysis and bounding box techniques ensures proper separation of characters, provided that the plate is not severely distorted or occluded. The Optical Character Recognition (OCR) module demonstrates high recognition accuracy when the segmented characters are clear, properly aligned, and free from excessive noise. The recognized number plates are accurately reconstructed and displayed in textual format, validating the effectiveness of the recognition process.

The speed estimation module provides reasonably accurate results by analysing vehicle motion across consecutive frames. The system calculates displacement in pixel units and converts it into real-world distance using calibration parameters. By incorporating frame rate information, the system computes vehicle speed values that closely approximate actual speeds. The use of multi-frame analysis and averaging techniques helps reduce fluctuations and improves the stability of the estimated speed.

Quantitatively, the system achieves strong performance in terms of detection accuracy, recognition accuracy, and computational efficiency under controlled conditions. The processing time is within acceptable limits, making the system suitable for near real-time applications.

The results clearly demonstrate that the proposed system is capable of performing automated vehicle identification and speed estimation with a high degree of accuracy under favourable conditions. One of the key strengths of the system lies in its modular architecture, which allows each processing stage—preprocessing, detection, segmentation, recognition, and speed estimation—to operate independently while contributing to the overall performance. This modularity enhances system flexibility, maintainability, and scalability.

The preprocessing stage plays a crucial role in determining overall system performance. Effective noise reduction and contrast enhancement significantly improve the reliability of edge detection and segmentation processes. The use of Sobel and Canny edge detection techniques, combined with morphological operations, ensures robust localization of number plate regions in most scenarios.

Another major advantage of the system is its ability to handle both image and video inputs, making it versatile for a wide range of applications such as traffic surveillance, automated toll collection, and law enforcement. The integration of speed estimation with number plate recognition provides a comprehensive solution for traffic monitoring, enabling simultaneous identification and behaviour analysis of vehicles.

However, the system also exhibits certain limitations that must be addressed for real-world deployment. The performance is highly dependent on input quality. Factors such as poor illumination, shadows, reflections, motion blur, and low-resolution images can significantly degrade detection and recognition accuracy. In addition, variations in number plate formats, fonts, sizes, and orientations can affect the performance of the OCR module.

The speed estimation module, while effective, relies on accurate calibration and consistent frame rates. Any deviation in these parameters may lead to errors in speed calculation. Perspective distortion and camera positioning also influence the accuracy of displacement measurement, thereby affecting the final speed estimation.

To overcome these limitations, future enhancements can incorporate advanced techniques such as machine learning and deep learning-based object detection and recognition models. Convolutional Neural Networks (CNNs) and modern object detection frameworks can significantly improve robustness under challenging conditions. Additionally, adaptive image enhancement techniques and improved camera calibration methods can enhance both detection and speed estimation accuracy.

Further improvements may include real-time system deployment using high-resolution cameras, integration with cloud-based databases for vehicle information storage, and support for multiple vehicle tracking in complex traffic scenarios. These enhancements would extend the applicability of the system to large-scale intelligent transportation systems and smart city infrastructures.

6. CONCLUSION AND FUTURE SCOPE

The proposed Automatic Number Plate Recognition (ANPR) and vehicle speed estimation system presents an effective and reliable solution for automated vehicle monitoring using image processing and computer vision techniques. The system integrates multiple processing stages, including image acquisition, preprocessing, number plate detection, character segmentation, Optical Character Recognition (OCR), and speed estimation, into a unified framework. This integration enables the system to perform both vehicle identification and speed analysis efficiently within a single platform.

The implementation using MATLAB provides a flexible and efficient environment for handling both image and video data. The preprocessing stage significantly improves image quality through grayscale conversion, noise reduction, and contrast enhancement, which enhances the accuracy of number plate detection. The use of edge detection and morphological operations allows precise localization of the number plate region, while segmentation and OCR techniques successfully extract and recognize alphanumeric characters under normal operating conditions.

The speed estimation module further enhances the system by analysing vehicle motion across consecutive frames and computing speed based on displacement and time. The results obtained during testing demonstrate that the system achieves satisfactory accuracy in both number plate recognition and speed estimation, particularly when the input data is clear and well-conditioned. The system reduces manual effort, improves operational efficiency, and provides a practical solution for applications such as traffic surveillance, automated toll collection, parking management, and law enforcement.

Despite its effectiveness, the system has certain limitations, especially when operating under challenging conditions such as poor lighting, motion blur, shadows, and low-resolution inputs. Variations in number plate formats, fonts, and orientations may also affect recognition accuracy, while speed estimation depends on proper calibration and consistent frame rates.

To address these limitations, future enhancements can focus on integrating advanced techniques such as machine learning and deep learning algorithms to improve detection and recognition performance. The system can be further developed to support real-time processing using high-speed cameras and optimized algorithms, making it suitable for live traffic monitoring. Integration with database systems can enable automatic storage and retrieval of vehicle information, supporting applications such as automated fine collection, stolen vehicle tracking, and traffic analysis.

Additionally, the incorporation of cloud computing and Internet of Things (IoT) technologies can facilitate remote monitoring and large-scale deployment. The system can also be extended to handle multiple vehicles simultaneously with improved tracking accuracy. Further improvements in camera calibration, image resolution, and hybrid algorithm design can enhance the robustness and scalability of the system.

In conclusion, the proposed system provides a strong foundation for intelligent vehicle monitoring and demonstrates the practical application of image processing techniques in real-world scenarios. With continued advancements and integration of modern technologies, the system can be significantly improved to meet the demands of next-generation intelligent transportation systems and smart city infrastructures.

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