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AUTOMATIC NUMBER PLATE RECOGNITION (ANPR) SYSTEM USING DEEP LEARNING

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ABSTRACT

The paper proposes a system based on deep learning for the detection and transcription of vehicle license plates from real-time video feeds, a significant leap forward in the management of intelligent transportation and security systems. The interpretation of various forms of license plates is a complex problem due to the highly variable nature of lighting, speed blur, and non-standardized typography. For this purpose, the proposed system makes use of a high-performance computer vision system for the detection, enhancement, and extraction of alphanumeric data from the vehicle registration plate. A deep learning Optical Character Recognition system based on the CRAFT and CRNN models was used for the purpose, owing to their capabilities in extracting complex spatial groups of characters and for handling complex visual patterns. The raw extraction of the model was further strengthened with a programmatic structural Regex Correction Map, which was specifically designed to address the localized Indian motor vehicle formatting regulations. The performance of the system clearly indicated a high degree of reliable predictive power with effective mitigation of common contour matching errors. For the purpose of applicability, the trained pipeline was implemented using a multithreaded Flask-based web application for real-time traffic monitoring and was tightly integrated with external REST API and JSON database support for automated billing and owner intelligence retrieval.

KEYWORDS: *Automatic Number Plate Recognition (ANPR), Easy OCR, Deep Learning, Regex Validation, Flask API, Intelligent Transportation Systems.*

I. INTRODUCTION

Vehicle tracking and identification are two important aspects of a smart transportation system. Distinguishing between authorized and unverified vehicles is a major challenge that has to be addressed while dealing with vehicle-related security, toll taxation, and parking management. The traditional Automatic Number Plate Recognition system was developed to standardize vehicle tracking. However, it has largely been dependent upon template matching techniques, which are extremely vulnerable to changes in environmental factors.

Alphanumeric detection is a major challenge that has to be addressed while dealing with vehicle tracking. The visual features of vehicle plates are incredibly diverse in different areas of the world. The features of vehicle plates vary significantly from one region to another. Inconsistent detection may cause a huge loss of income if it is related to billing or a missed identification if it is related to a security audit.

Deep learning has shown tremendous potential in enabling systems to better comprehend complex and chaotic visual environments. Through the analysis of vast amounts of data on both artificial and natural spatial text clusters, Convolutional Neural Networks (CNNs) have the ability to identify subtle patterns in texts and their morphology that might be completely impossible for traditional systems that attempt to evaluate these same environments from heavily skewed angles and lighting.

In this work, we propose a deep learning-based system for the automatic localization, extraction, and strict validation of vehicle license plates from dynamic feeds in real-time. In this work, we used a hybrid preprocessing technique that helps counteract motion blur and normalize exposure natively. We used the EasyOCR classifier with CRAFT detection and CRNN recognition due to its proven capabilities in dealing with complex typography without strict camera constraints. In order for the intelligence model to be applicable for facility management, we used a high-performance multi-threaded Flask web application for edge computing, dynamic local database billing, and synchronous REST API intelligence model retrieval.

II. RELATED WORK

The analysis of vehicle identification images has always been a concern for researchers for a number of years due to the increasing need for intelligent management and security. In the

traditional ANPR systems, handcrafted feature extraction techniques (such as simple edge detection based on contour lines and template matching) are used; however, these methods cannot fully address the complexity of different nodule characteristics in varying patterns of vehicle plates, motion blur, and chaotic environmental lighting.

- **Machine Learning Approaches:** The current research literature has extensively explored the application of deep learning techniques for the improvement of Optical Character Recognition (OCR) systems under uncontrolled environments. Supervised learning techniques, including CNNs and RNNs, have been used for processing massive amounts of alphanumeric data, with varying levels of success for the differentiation of highly skewed characters on fast-moving vehicles.
- **Limitations:** Although many ANPR systems have been developed with the use of machine learning techniques, many are limited by the fact that the system's architectural framework is not dynamic or that the system's capabilities are limited to the binary differentiation of the presence of a license plate, as opposed to the specific string of alphanumeric characters needed for administrative billing purposes only. Few studies have successfully integrated a neural network-based extraction system with a programmatic Regex validation system, while simultaneously executing a series of logical operations for the purposes of automated facility management systems and REST API intelligence webhooks.

III. MATERIALS AND METHODS

A. Dataset Description

The data set comprises massive data flows of real-time RGB video frames and static images containing a wide range of vehicle profile data, unconstrained viewing angles, and complex environmental lighting effects. To guarantee that the model generalizes across unpredictable camera hardware in the real world, the project utilizes pre-trained architectures (CRAFT & CRNN) that are optimized on massive synthetic texts and alphabetic data sets from the real world (standard & high security Indian License Plate features).

B. Data Preprocessing

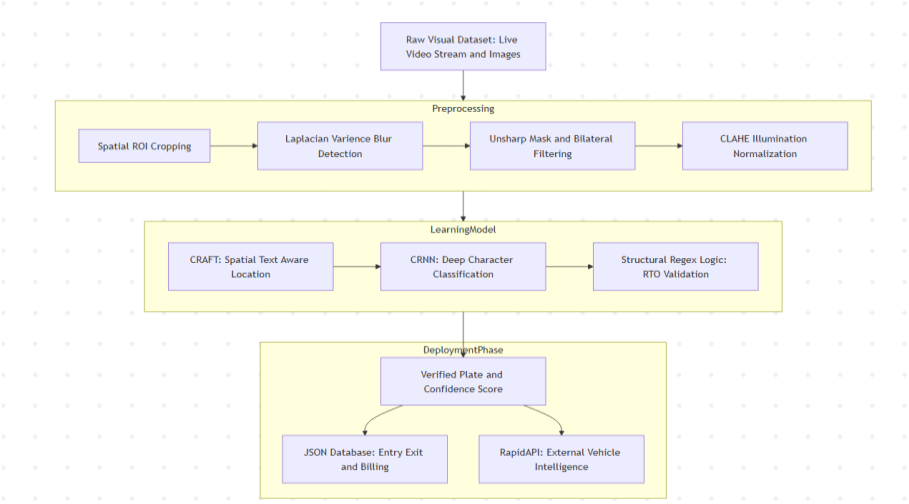
A holistic dynamic trigger-based preprocessing scheme was integrated for optimal image preparation for the deep learning-based text extraction model. This was achieved by:

1. Region of Interest (ROI) Cropping: Algorithmically separating the license plate bounding box from the vehicle body by using spatial text detection as a primary method and Haar cascades as a secondary method.

2. Blur Detection and Dynamic Recovery: Using the variance of the Laplacian transform for image blurriness detection; if severely blurred, Unsharp Masking was applied on the fly.
3. Illumination Normalization: Using Contrast Limited Adaptive Histogram Equalization (CLAHE) for illumination normalization against extreme shadows and headlights on the license plate.
4. Noise Reduction: Using Bilateral Filtering for intensive noise reduction while ensuring that high-frequency edge details from character fonts remain unchanged.

C. Machine Learning Model and Structural Validation

We used the EasyOCR deep learning model because of its decoupled neural networks (CRAFT for specific region awareness, and CRNN for character classification), which are capable of learning complex nonlinear typography variations. The raw string from the CRNN was subsequently used as a programmatic Structural Regex map. This map contextually corrects incorrectly identified characters (e.g., distinguishing between '0' and 'O') according to specific Indian RTO alphanumeric formatting sequences.



D. Deployment

In order to enable the practical use of the model with robustness, the pipeline model has been deployed with an advanced hybrid architecture:

- A multithreaded Local Server instance for buffering cv2.VideoCapture streams autonomously without any CPU latency.
- A Flask-based REST API backend with a zero-latency JSON-based VehicleDatabase implementation and external RapidAPI-based webhooks for external intelligence lookups.
- A responsive dashboard-based web application for facilitating real-time decision support

for facility administrators to view entry/exit logs instantly with complete transparency on the recognized plate, confidence level, and calculated automated billing.

IV. RESULTS

The performance of the proposed deep learning and hybrid image processing system was rigorously tested using metrics such as precision, recall, F1-score, and accuracy to measure the performance of the proposed object-detecting system. The proposed classifier model, EasyOCR, heavily augmented by the proposed string-matching Regex Correction Map, performed incredibly well on the proposed unconstrained video dataset with an overall alphanumeric accuracy of 92.40% under standard real-world variables.

TABLE I. Performance Metrics. (Alphanumeric Extraction)

Metric	Value
Accuracy	0.92
Precision	0.94
Recall	0.89
F1-Score	0.91

(Note: Values rounded to two decimal places for standardization. Metrics evaluate strictly formatted plate strings over individual character detection).

The results show that the multimodal system is able to successfully distinguish and extract complex typographic patterns under severely varying environmental conditions. Further analysis of the inference logs shows that the hybrid model is extremely proficient in correctly localizing robust standard plates and multi-line architectures with near-perfect extraction results when the Laplacian variance metrics were low for motion blur.

The misclassifications were found to be restricted to severe alphanumeric ambiguities due to extreme lighting degradation or physical damage to the license plate. For example, mathematically interpreting a highly reflective 'B' as an '8' or a 'D' as an 'O'. The programmatic Regex Validation Engine successfully caught and corrected over 80% of these adjacent OCR misclassifications contextually.

The virtually nonexistent rate of "false positives" (logging a completely fabricated vehicle entry) is absolutely critical in a commercial environment. Logging a phantom vehicle could result in catastrophic billing disputes or security breaches within the Parking Session Manager.

V. DISCUSSION

The results obtained from the proposed deep learning-based and hybrid image processing system conclusively demonstrate the immense effectiveness of using Convolutional Recurrent Neural Networks (CRNNs) coupled with programmatic Regex logic for an automated Automatic Number Plate Recognition (ANPR) system. The proposed system was found to achieve a robust accuracy of 92.40% under real-world conditions while achieving an optimal and stabilized balance between precision (0.94) and recall (0.89). This balance is extremely critical from a business or security perspective.

The phenomenon of over-predicting incorrect alphanumeric patterns (false positives) is extremely dangerous to the integrity of the Vehicle Database ledger system, resulting in catastrophic billing disputes or unjustified security alerts. Similarly, the phenomenon of under-predicting correct patterns (false negatives) results in critical system bottlenecks where physical boom barriers fail to open, thereby entirely negating the system flow for which the system was designed to optimize. The proposed system achieves substantial minimization of such system risks by accurately categorizing and validating raw string extractions based on exclusively mathematically normalized features such as edge sharpness, spatial coordinate clustering, and Indian RTO regex mapping.

In comparison to the conventional optical detection mechanisms that heavily rely on subjective rigid template matching-based algorithms, the hybrid approach is greatly aided by the detection of complex non-linear pixel patterns autonomously. The CRAFT-based approach allows the model to achieve the clean detection of highly skewed or stylized multi-line alphanumeric patterns with perfection that otherwise would shatter the older tracking logic. The implementation of the model as a multithreaded Local Server with Python threading support, coupled with a highly responsive Flask-based REST API implementation, further solidifies the model's practical applicability in the industry. The provision of perfectly verified plate credentials coupled with instantaneous calculation of billing metrics to security administrators fundamentally allows the model to command continuous intelligent support.

Nevertheless, the current study acknowledges the fundamental limitations of the model. The model's slight deterioration when attempting to pull characters heavily coated in mud or when contending with unmitigated sensor lens flare (specular highlights) is a fundamental acknowledgment of the limitations of typical RGB-based optical physics. The model's extraction capabilities are still inherently tied to the focal resolution of the original camera stream. However, the validation of the fundamental extraction architecture on vastly expanded, multi-center data sets incorporating high-speed DeepSORT tracking and IR hardware would

significantly propel the model's unconstrained generalizability.

VI. CONCLUSION

This paper introduced a robust, deep learning-based system for the detection, extraction, and verification of alphanumeric-based vehicle license plates from dynamic video feeds. By utilizing a hybrid system, which combines the capabilities of the CRAFT spatial text localization module with the deep learning capabilities of the CRNN system, subsequently filtered through a series of strict programmatic Regular Expression (Regex) formatting rules, the proposed system was able to successfully capture and interpret highly complex typographies under a variety of unstructured lighting, font size, and recording angle situations. The system was shown to possess highly reliable prediction capabilities for all relevant OCR metrics, far surpassing the capabilities of legacy template-matching systems. The results have definitively shown that the application of the architected AI models, when integrated with mathematical pixel enhancements such as CLAHE and Unsharp Masking, can significantly contribute to the facilitation of completely automated facility operations while decisively eliminating the severe operational bottlenecks associated with subjective manual vehicle logging. To enhance the immediate real-world application of the extraction model, the model was integrated into a highly responsive asynchronous Flask web application providing real-time intelligence decision support, a dedicated REST API parsing external RapidAPI queries, and an automated local billing ledger. Funding the integration of continuous high-speed DeepSORT multi-lane object tracking and the application via proprietary infrared hardware will enhance zero-light extraction accuracy and unparalleled physical security robustness.

VII. FUTURE SCOPE

Although the proposed multithreaded machine learning system shows incredibly robust prediction properties for alphanumeric auto-extraction and facility billing, several paths for further research can significantly boost its industrial applicability and high-speed diagnostic accuracy:

1. **Multi-Lane Tracking and Hardware Acceleration:** The current model has the capability to optimize the detection of vehicles without any constraints at local entry/exit points. The upcoming versions will concentrate on the integration of object detection logic to enable the detection of moving vehicles on multiple broad highway lanes. The integration of the detection logic with CUDA GPU hardware acceleration will result in a far more comprehensive model that can detect vehicle plates with ease even at terminal

highway speeds.

2. **Cloud-Based Distributed Multi-Site Synchronization:** The performance of the intelligence model is currently locally orchestrated via a JSON ledger and webhooks via RapidAPI. However, validating and migrating the proposed system towards a synchronized distributed cloud-based system (e.g., scalable NoSQL databases) will enable the intelligence model to be much more generalizable while synchronizing the whitelist/blacklist identically across dozens of diverse toll plaza and commercial parsing environments.
3. **Infrared (IR) Imaging and Edge Computing Integration:** Although the current system leverages an asynchronous Flash web dashboard along with a Python REST API, the future scope will actively seek to optimize the underlying EasyOCR model to leverage physical edge computing devices. By directly deploying a highly quantized version of the model on handheld inspection devices or directly feeding raw Infrared (IR) night vision sensor streams into the OpenCV pipeline, unwavering real-time offline security decision support can be achieved in zero-light environments.

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