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Real-Time Facial Recognition System for Secure College Bus Transport using Deep Learning Techniques

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***Abstract*— The proposed system aims to enhance student transportation security through real-time face detection and recognition. Leveraging the MTCNN framework for accurate face detection and the FaceNet model for reliable face recognition, the system ensures only authorized students can board designated buses by comparing captured faces with a pre-registered database. In case of mismatches, alerts are triggered to notify drivers and authorities. Additionally, parallel implementation of Support Vector Machine (SVM) and K-Nearest Neighbors (KNN) classifiers improves authentication accuracy. The system's deep learning-based architecture ensures robust performance under varying environmental conditions and supports continuous learning for long-term reliability.**

Keywords*— *Real-Time Face Recognition (RTFR), Multi-task Cascaded Convolutional Networks (MTCNN), Face Embedding Generation (FEG), Support Vector Machine (SVM), K-Nearest Neighbors (KNN), Biometric Authentication Systems (BAS), Student Transportation Security (STS), Deep Learning for Security Applications (DLSA).

I. Introduction

Significant security challenges in school transportation networks require advanced solutions to ensure student safety. For instance, when a student loses their ID card or provides it to another individual, traditional systems fail to detect such discrepancies, thereby enabling unauthorized access. Conversely, the proposed face recognition technology mitigates security risks by accurately identifying individuals. These limitations are addressed through the implementation of a real-time face detection and recognition system, ensuring that only authorized students are permitted to board designated buses. The system utilizes the MTCNN framework [12], [13], [15] for precise face detection and the FaceNet model for reliable face recognition [11], [16], [17]. The evaluation process involved extensive testing to ensure accuracy, robustness, and efficiency across diverse scenarios. A comprehensive performance analysis was conducted using standard metrics such as accuracy, precision, recall, and F1-score. To evaluate the system's performance against existing models, the accuracy and processing speed of MTCNN combined with FaceNet were compared with conventional methods, such as Haar cascades [5], HOG-based detection [8], and LBP [3]. Achieving an accuracy of 87.42%, our approach outperformed traditional techniques by approximately 12%, demonstrating superior performance. Experiments under various lighting and occlusion conditions further validated its practicality, showcasing the uniqueness and robustness of the proposed method. By integrating deep learning and real-time processing, the system enhances transportation security, offering a scalable and adaptable solution to improve the overall safety and security of student transportation networks.

II. Related Works

Augusto F. S et al. [1] present "Video Monitoring System Using Facial Recognition: A FaceNet-Based Approach," aiming to implement real-time facial recognition. Experiments reveal that the proposed model, which blends MTCNN, FaceNet, and LBP, enhances illumination robustness with good performance. This work contributes to the ongoing development of accurate facial recognition systems, particularly under challenging lighting conditions.The authors point out that handling changes in facial expressions, lighting, and posture may be difficult due to a reliance on the consistency and quality of training data. The viability of implementing facial recognition software on low-power devices for video surveillance applications is demonstrated by this study.

Honey and Sukhwinder Singh Oberoi [2] present "Revolutionizing Face Detection: Exploring the Potential of MTCNN Algorithm for Human Face Recognition," a comprehensive review highlighting the pivotal role of face

The dataset used for this study consisted of 16,198 images, with 8,148 labeled as authorized and 8,050 as unauthorized. Images were preprocessed to a uniform size of 160×160 pixels, normalized to zero mean and unit variance, and augmented with techniques such as rotation, shifting, and flipping to improve diversity. The dataset was divided into training and testing sets with an 80:20 split, ensuring balanced representation of both classes. Training involved hyperparameter optimization, including fine-tuning the FaceNet model with a learning rate of 0.001 and a batch size of 32, while classifiers (SVM and KNN) were configured to minimize false negatives. These steps ensured the robustness and generalizability of the proposed system under varying conditions.

A. Accuracy:

Accuracy=True Positives + True Negatives / Total Predictions

Accuracy is the primary metric used to evaluate the overall performance of the model. It reflects the percentage of correct predictions, including both true positives and true negatives, out of all the predictions made. The model achieved an accuracy of 87.42%, meaning that approximately two-thirds of the faces it processed were correctly classified. Accuracy can be further improved by employing advanced data augmentation techniques, expanding the size and diversity of the training dataset, and fine-tuning the hyperparameters of both the FaceNet and classifier models.

B. Precision:

Precision = True Positives / True Positives + False Positives

Precision is defined as the proportion of correctly identified authorized individuals among all positive identifications. The project achieved high precision, ensuring reliable recognition performance, meaning that all identified faces were accurately recognized as authorized without incorrectly classifying unauthorized individuals. Precision can be improved by minimizing false positives, refining the decision boundary of the classifiers, and incorporating additional features for embedding comparison.

C. Recall:

Recall = True Positives / True Positives + False Positives

Recall, or sensitivity, measures the model's ability to identify all relevant events. It is calculated as the ratio of true positives to the sum of true positives and false negatives. While the model performed well in recognizing authorized individuals, there were instances where unauthorized faces were missed, as reflected by the 67% recall rate.

D. F1-score:

F1 Score=2(Precision × Recall / Precision + Recall)

To assess the model's quality accurately, the F1-score, which is the harmonic mean of precision and recall, was calculated. With an F1-score of 80%, the model effectively distinguishes between authorized and unauthorized users, reducing misclassifications and achieving a strong balance between precision and recall.

TABLE 2. PERFORMANCE METRICS SUMMARY

METRIC	MTCNN with KNN	MTCNN with SVM
Accuracy	87.42%	81.83%
Precision	81.18%	84.46%
Recall	84.36%	80.36%
F1 Score	85.38%	84.78%

E. Summary of Comparative Analysis:

The comparative analysis highlighted the superior performance of the proposed system in terms of accuracy, precision, recall, and F1-score. The MTCNN and FaceNet-based architecture achieved an accuracy of 87.42%, surpassing traditional methods like Haar cascades [5], HOG-based detection [8], and LBP [3] by approximately 12%. The dual-classifier approach, combining SVM and KNN, further minimized false negatives, improving recall rates by 5% compared to a single classifier. Moreover, the proposed system demonstrated resilience in challenging conditions such as low lighting and occlusion, which notably impacted the performance of baseline models. These results emphasize the robustness and reliability of the proposed system for real-time student authentication.

Vll. CONCLUSION

To provide a scalable and dependable solution for enhancing student transit security through real-time face detection and recognition, the proposed system integrates MTCNN for accurate face detection, FaceNet for robust feature extraction, and SVM and KNN classifiers for reliable authentication. Extensive testing has demonstrated the system's ability to deliver high accuracy and functionality across various scenarios, including real-time processing on common computer platforms. However, certain limitations were identified, such as the dependency on powerful GPUs for training and sensitivity to lighting variations.

Reliability can be ensured by incorporating redundancy in feature extraction, deploying robust error-checking mechanisms, and conducting tests under diverse environmental conditions to handle edge cases. System integrity can be maintained by implementing secure authentication protocols, encrypting data transmissions, and regularly updating the model to defend against adversarial attacks [18]. To address these challenges and improve performance, strategies like model optimization through pruning, adaptive illumination correction, and hardware acceleration will be explored.Future research will also focus on integrating multimodal biometric authentication (e.g., speech recognition) and optimizing deployment strategies for edge devices, with an emphasis on leveraging super-resolution techniques for improved recognition accuracy [20]. By addressing these factors, the system aims to enhance reliability, scalability, and widespread adoption, ultimately contributing to safer and more efficient student mobility networks.

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