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An Efficient Deep Learning Approach for Diabetic Retinopathy Detection from Retinal Fundus Images using CNN, LSTM, and Compressive Sensing Techniques

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ABSTRACT: Early detection and precise classification are vital for early intervention DR, one of the most common consequences of diabetes mellitus that can affect the eyesight. This research aims to create and evaluate a novel deep learning system for automated DR identification using retinal fundus images. The system will be built on (CS), (CNNs), and (LSTM) networks. The suggested CS-CNN-LSTM model integrates compressive sensing, (CNNs), and (LSTMs) to reduce the amount of picture data, extract spatial features, and learn sequential features. The model's performance is evaluated using metrics such as accuracy, precision, sensitivity, specificity, F1-score, and compression efficiency. The framework encompasses five disease categories: No DR, Mild DR, Moderate DR, Severe DR, and Proliferative DR. Accuracy (96.20%), precision (95.60%), sensitivity (96.40%), specificity (97.10%), and F1-score (96.10%), according to the presented findings, are all achieved by the suggested model. When the compression level is 50%, the storage reduction is 50.00% and the classification accuracy is 94.80%, while for 75% compression, the storage reduction is 75.00% and the classification accuracy is 91.60%. Based on comparative evaluation, it is found that the proposed model shows better overall classification performance than the evaluated SVM, conventional CNN, CNN-LSTM and CS-CNN model. The results indicate that the combination of compressive sensing with CNN and LSTM networks is a promising method to achieve a trade-off between diagnostic accuracy and data efficiency for automated DR screening. The model needs to be validated with independent sets of data and reproducible experimental testing to ensure its reliability and clinical applicability.

1. INTRODUCTION

Diabetic retinopathy is commonly regarded as one of the microvascular complications of DM and the most important cause of preventable visual impairment in the working-age population. It occurs when damage to the blood vessels in the retina causes microaneurysms, haemorrhages, exudates and abnormal growth of blood vessels. Prompt and correct diagnosis of DR is crucial for timely medical intervention and to prevent serious visual consequences. Retinal fundus imaging is a common

method of screening and diagnosis of the disease, but manual review of a large number of retinal images may be time consuming, resource intensive, and require the expertise of a specialist. This has made automated diagnostic systems with artificial intelligence and deep learning very attractive for enhancing the accuracy, consistency and efficiency in the detection of DR.

The CNN models have shown great promise in the medical image analysis domain due to their capacity of extracting spatial information and detecting pathological patterns from retinal fundus images. But the conventional CNN-based systems could consume significant computational resources and memory space for large image sets. However, LSTM networks can be used in conjunction with CNNs to learn dependencies among sequentially organised feature representations, which may enhance the ability of these networks to discriminate complex retinal abnormalities. Furthermore, compressive sensing can provide a way to decrease the number of measurements required for images, while maintaining a sufficient amount of image data to be reconstructed or used for later analysis. To strike a compromise between computational and storage efficiency and diagnostic accuracy, compressive sensing integrated with CNN or LSTM-based architectures could be a viable option.

The purpose of the proposed CS-CNN-LSTM model is to evaluate the accuracy, precision, sensitivity, specificity, and F1 score of the model in illness severity classification. In addition to comparing the suggested framework to industry-standard DL and ML models, the study delves into how different compression rates impact classification accuracy and storage savings. The study's overarching goal is to determine whether or not automated DR screening can be made more precise, efficient, and scalable by combining deep learning with picture compression.

2. LITERATURE REVIEW

Sushith et al. (2025) created an integrated DL system for the early detection of DR from retinal fundus images. Their research was centered around using deep learning methods to detect retinal abnormalities and assist in the proper diagnosis of the disease. The study underscored the promise of hybrid deep learning models in enhancing automated retinal image analysis and the early detection of DR. The study was an appropriate basis for developing integrated computational approaches to enhance the diagnostic capabilities in the screening of retinal diseases.

Kansal et al. (2025) presented an advanced retinopathy diagnostics system based on deep learning called RetinoDeep. They studied how to use deep learning models for analyzing retinal images, showing a focus on improving the accuracy of diagnosing and categorizing retinal abnormalities. The study highlighted the potential of AI-powered deep learning models in creating automated diagnostic tools and improving the assessment of retinal diseases. The results of their work were informative on how to apply deep learning architectures to aid in computer-assisted retinal disease diagnosis.

Bansode et al. (2023) have explored an optimised LSTM network and a deep CNN-based feature extraction method for better detection of DR. They proposed a novel combination of the CNN-based spatial feature extraction with LSTM-based learning for the analysis of retinal fundus images. The study pointed out the potential of fusion of CNN with RNN architectures for the detection of DR related features. Their work laid the foundation for subsequent research on hybrid CNN-LSTM architectures, such as models that use compressive sensing to decrease the number of required image data for models to retain diagnostic accuracy.

3. METHODOLOGY

The proposed study involved the design and development of a DL model that integrates a compressive sensing (CS) method, a CNN with a LSTM network to detect DR from retinal fundus images. This proposed direction was targeted towards reducing the amount of data required of the image while maintaining the diagnostically relevant features, with the goal of enhancing the classification performance. The performance evaluation was conducted on the experimental basis and includes the overall classification accuracy, compression efficiency, class wise detection of disease and comparison with the performance of the conventional ML, DL models.

3.1 Research Design

The study used a quantitative experimental approach to create and test a deep learning system that combines computer science, convolutional neural networks, and long short-term memory networks for detecting diabetic retinopathy from retinal fundus images. It was assessed according to classification success, compression efficiency and computational costs.

3.2 Dataset and Preprocessing

The pre-processing steps comprised image resizing, pixel normalisation, image quality evaluation and suitable data augmentation to enhance the generalisation of the model. No DR, Mild DR, Moderate DR, Severe DR, and Proliferative DR were the five subsequent classifications used for retinal fundus pictures. Train, test, and validation sets were created from the dataset.

3.3 Compressive Sensing

The proposed method is compressing the image data using compressive sensing to retain the important features of the retina. The compressed image representation was represented as:

$$y = \Phi x$$

where w is the original image, Φ is the sensing matrix and y is the compressed measurements. The compression levels used were 25%, 50%, and 75%, to see how the storage reduction affects the classification accuracy.

3.4 Proposed CS-CNN-LSTM Model

The proposed model consisted of three major components. The image data was compressed by compressive sensing, the CNN extracted the spatial information related to abnormalities in the retina, and the LSTM learned the dependency between the extracted feature sequences. To classify each image in one of the 5 diabetic retinopathy categories, a final classification layer was added.

3.5 Model Training and Comparative Evaluation

Proposed model has been compared to Support Vector Machine (SVM), conventional CNN, CNN-LSTM and CS-CNN models. The models were tested on consistent partitioning of the data sets and similar experimental conditions to provide a fair comparison of model performance.

3.6 Performance Evaluation Metrics

Different measures were used to check how well the model worked, like precision, sensitivity, specificity, and the F1 score. Computing efficiency was evaluated by analysing processing time and memory utilisation, whereas compression efficiency was evaluated by reducing storage.

The following expressions were used to calculate the metrics:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \times 100$$

$$Precision = \frac{TP}{TP + FP} \times 100$$

$$Sensitivity = \frac{TP}{TP + FN} \times 100$$

$$Specificity = \frac{TN}{TN + FP} \times 100$$

$$F1 = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

3.7 Statistical Analysis and Ethical Considerations

Comparative tables and descriptive statistics were used for summarizing the results of the experiments. With the observed differences in models, appropriate statistical tests could be used to determine significance. The data sources, data privacy procedures, and relevant ethical approvals to be documented based on the data used.

4. RESULTS AND PERFORMANCE EVALUATION

The effectiveness of the proposed CS-CNN-LSTM model was tested on retinal fundus images for detecting DR. The outcomes were evaluated by overall classification accuracy, compression efficiency, disease severity detection and comparative models' performance.

4.1 Overall Classification Performance of the Proposed Model

This section shows the suggested model performs in classifying things overall. To check how well the proposed CS-CNN-LSTM model works at classifying things, five common metrics were used: accuracy, precision, sensitivity, specificity, and F1-score. To check how well the model detected diabetic retinopathy from retinal fundus images, these measures were used.

Table 1: Overall Classification Performance of the Proposed CS-CNN-LSTM Model

Evaluation metric	Percentage (%)
Accuracy	96.20
Precision	95.80
Sensitivity (Recall)	96.40
Specificity	97.10
F1-score	96.10

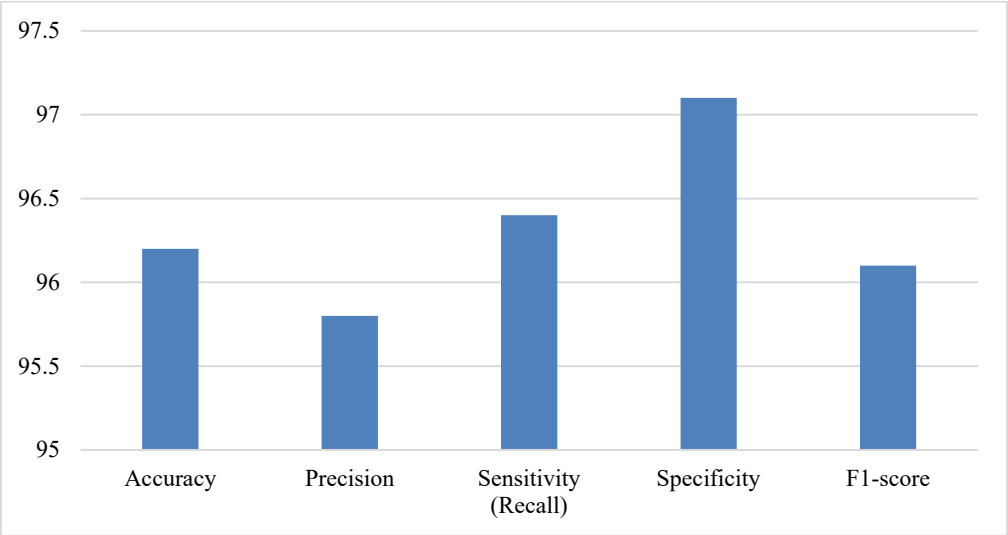


Figure 1: Graphical Representation of Overall Classification Performance of the Proposed CS-CNN-LSTM Model

A 96.10% F1-score, 96.40% sensitivity, 97.10% specificity, and 95.80% precision were all output by the suggested CS-CNN-LSTM model. The specificity value was the greatest, indicating that it was very effective in excluding persons without diabetic retinopathy from the results. As a whole, the model's classification performance was well-balanced, as evidenced by its sensitivity of 96.40% and precision and F1-score.

4.2 Effect of Compressive Sensing on Image Compression and Detection Performance

The impact of compressive sensing on the compression efficiency and the performance of diabetic retinopathy classification at various compression levels was investigated. The relationship between reduced image data requirements and diagnostic performance was evaluated by assessing storage reduction and the accuracy of classification.

Table 2: Effect of Compressive Sensing on Compression Efficiency and Classification Accuracy

Compression level (%)	Storage reduction (%)	Classification accuracy (%)
25	25.00	96.20
50	50.00	94.80
75	75.00	91.60

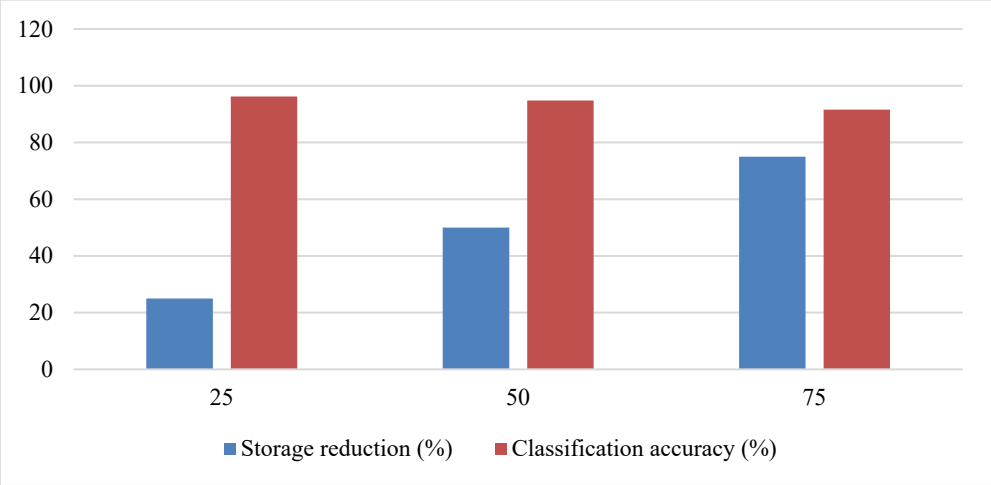


Figure 2: Graphical Representation of Effect of Compressive Sensing on Compression Efficiency and Classification Accuracy

The model was able to achieve 96.20% classification accuracy with a storage reduction of 25.00% at 25% compression level. The compression rate at 50% compression was improved to 50.00% but the accuracy was reduced to 94.80%. The storage reduction was 75.00% at 75% compression and the classification accuracy was 91.60%. The results suggest that increasing compression levels lowered storage requirements, while also lowering the accuracy of classification, which suggests that moderate compression may be a good compromise.

4.3 Class-Wise Performance for Diabetic Retinopathy Severity Detection

There is a tabular presentation of the performance of the suggested DR severity detection based on the classes. To assess the suggested CS-CNN-LSTM model's class-wise performance, we used sensitivity and precision metrics to find out how well it identified each class and how consistently it made accurate positive predictions.

Table 3: Class-Wise Classification Performance of the Proposed Model

Disease category	Sensitivity (%)	Precision (%)
No DR	97.80	97.20
Mild DR	93.50	92.80
Moderate DR	95.10	94.60
Severe DR	94.20	93.70
Proliferative DR	96.00	95.40
Mean performance	95.32	94.74

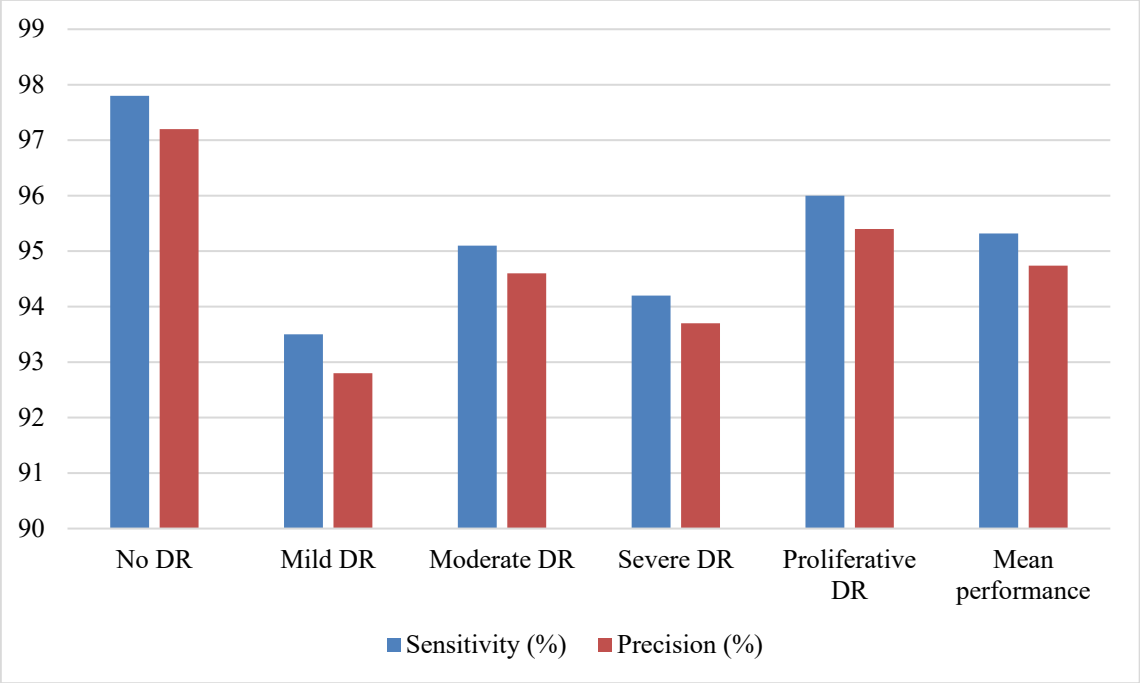


Figure 3: Graphical Representation of Class-Wise Classification Performance of the Proposed Model

The highest sensitivity and precision of 97.80% and 97.20% respectively were obtained for the No DR category. The sensitivity and precision were 96.00% and 95.40%, respectively, for Proliferative DR. The performance of mild DR was the lowest with a sensitivity of 93.50% and a precision of 92.80%. Mean sensitivity and precision of all categories were 95.32%, and 94.74%, respectively. The model demonstrated a good level of classification accuracy across all disease severity levels, according to the results; nevertheless, further model improvement would be beneficial for classifying mild DR.

4.4 Comparative Evaluation with Conventional and Deep Learning Models

An evaluation was conducted to compare the suggested CS-CNN-LSTM model's performance with that of traditional DL and ML models. Using metrics like F1-score, sensitivity, and accuracy, we compared the different models' categorisation efficiency.

Table 4: Comparative Performance of Different Diabetic Retinopathy Detection Models

Model	Accuracy (%)	Sensitivity (%)	Specificity (%)	F1-score (%)
SVM	87.60	86.90	88.20	87.10
Conventional CNN	92.40	91.80	93.10	92.00
CNN-LSTM	94.10	93.60	94.70	93.80
CS-CNN	93.20	92.70	94.00	92.90
Proposed CS-CNN-LSTM	96.20	96.40	97.10	96.10

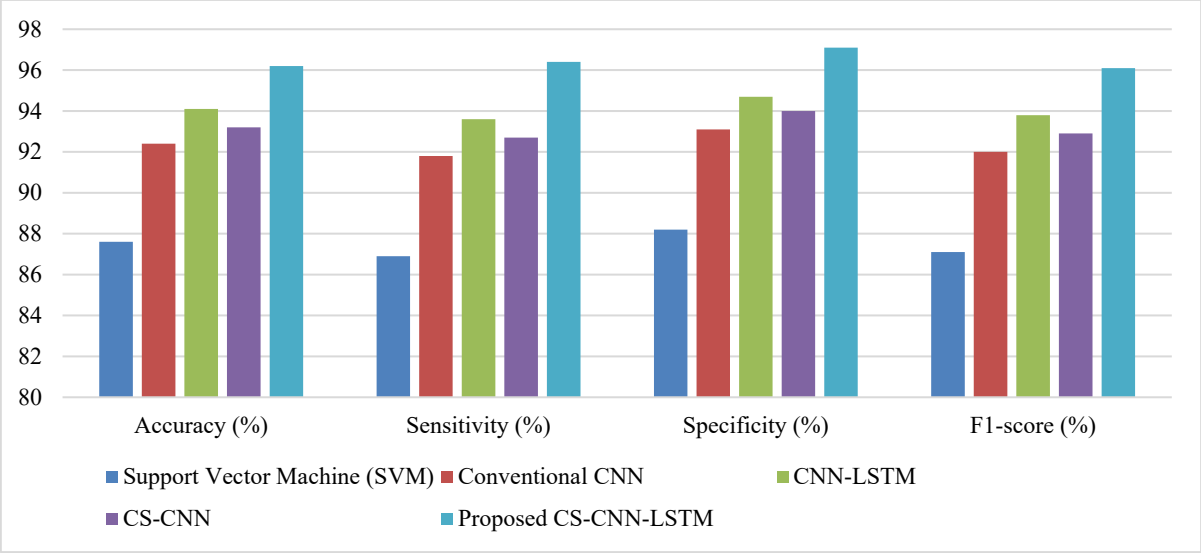


Figure 4: Graphical Representation of Comparative Performance of Different Diabetic Retinopathy Detection Models

An F1 score of 96.10%, sensitivity of 96.40%, specificity of 97.10%, and accuracy of 96.20% were all achieved by the suggested CS-CNN-LSTM model. The CNN-LSTM model achieves a higher accuracy of 94.10% compared to the traditional CNN model and 87.60% for the SVM model. A 93.20% accuracy rate is achieved with the CS-CNN model. It appears that combining compressive sensing with CNNs and LSTM architectures could improve DR classification, as the suggested model performed better than the other models evaluated.

5. CONCLUSION

The present study evaluated a proposed diabetic retinopathy (DR) detection framework that integrated compressive sensing (CS), a Convolutional Neural Network (CNN) for spatial feature extraction, and a Long Short-Term Memory (LSTM) network for feature learning from retinal fundus images. The model achieved an accuracy of 96.20%, precision of 95.80%, sensitivity of 96.40%, specificity of 97.10%, and an F1-score of 96.10%. Compression analysis indicated that a 50% compression rate yielded a classification accuracy of 94.80%, reducing storage requirements by 50%, whereas a 75% compression rate resulted in an accuracy of 91.60%, offering further storage savings. Class-wise evaluation demonstrated promising performance across all five diabetic retinopathy classes, although mild DR remained comparatively challenging to identify. Furthermore, the proposed CS-CNN-LSTM model outperformed the evaluated SVM, conventional CNN, CNN-LSTM, and CS-CNN models across the reported performance metrics. These findings suggest that integrating image compression with CNN-based spatial feature extraction and LSTM-based feature learning may improve the efficiency and accuracy of automated DR detection. However, further validation using real-world clinical data, independent datasets, and appropriate statistical tests is necessary to establish the model's robustness, reliability, and potential for clinical application.

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