"It always seems impossible until it's done"

- Nelson Mandela

Chapter 9

CONCLUSIONS AND FUTURE DIRECTIONS

9.1 OVERVIEW

Although, lot of efforts have been carried out for the development of handwritten Devanagari character recognition system in offline mode, however very few work exist for the development of the offline handwritten Devanagari word recognition framework. Therefore, the present work is an attempt in this regard/direction. Since there is the lack of publicly available benchmark/standard dataset in Devanagari (words) script, so 48,000 samples of handwritten Devanagari words have been gathered for experimental/research purposes. Also, various approaches for the recognition of handwritten Devanagari words considering the combination of various features and classifiers have been proposed which gives comparable recognition results with the available state-of-the-art techniques. Using combination of Gradient and structural-based features, maximum recognition accuracy of 90.10% has been obtained by exploring XGBoost classification approach.

To recognize handwritten Devanagari words, the recognition accuracies of 88.06% (with the combination of intersection & open-end points based features, elliptical based features and Arnold transform based directional features), 89.12% (with the combination/concatenation of uniform zoning, peak extent and Gabor filter-based features) and 94.53% (with the combination/ concatenation of uniform zoning, diagonal and centroid-based features) are obtained using majority voting classification, adaptive boosting and Gradient Boosted Decision Tree (GBDT) approaches, respectively. To the best of present knowledge, these considered combinations are the first of its type for

the recognition of offline handwritten Devanagari words. Moreover, an efficient approach for offline handwritten Devanagari word recognition has been proposed/developed using VGG16 as feature extractor (deep features) and XGBoost approach which results in 95.00% of recognition accuracy.

This chapter is divided into four sections. Section 9.2 highlights the brief contributions of the work. Section 9.3 provides major conclusions to the present work, while Section 9.4 discusses the future scope of the work.

9.2 BRIEF CONTRIBUTIONS OF THE WORK

This study has made significant contributions to the field of offline handwritten Devanagari word recognition system by presenting the following key findings and advancements.

9.2.1 OHDW Recognition System Based on Gradient and Structural Features

Gradient and structural features based on contour-directional histogram has been extracted from the scanned images of handwritten words. Three different classifiers namely SVM (Support Vector Machine), NB (Naive Bayes) and XGBoost (eXtreme Gradient Boosting) are explored for the recognition tasks. Experiments are also carried out using combined feature vectors resulted from gradient and structural features as input to various classifiers. The combination of these two features improved the performance of the proposed system in terms of recognition accuracy (%). The work is evaluated on the corpus of 20,000 words of 50-different word-classes of handwritten Devanagari script. The presented work is subjected to performance evaluation in terms of Recognition Accuracy (%), FAR (False Acceptance Rate) (%), FRR (False Rejection Rate) (%) and Precision (%). The experimental results are presented in the Tables 4.1 to 4.4.

It has gathered from experimental work that combination of feature vectors resulted from gradient and structural features along XGBoost classifier perform better as compared with individual features itself. Using eXtreme Gradient Boosting (XGBoost) classification, a maximum Recognition Accuracy (RA) of 90.10%, minimum False

Acceptance Rate (FAR) of 0.20% and False Rejection Rate (FRR) of 9.89% has been obtained with a concatenation of gradient and structural features. However, structural based features along with XGBoost classifier attained maximum Precision (PR) of 90.65%. Overall, it has gathered from experimental work that combination of feature vectors resulted from gradient and structural features along with XGBoost classifier perform better as compared with individual features itself. But, still there is a scope for improving the recognition results.

9.2.2 Recognition Scheme for OHDW based on Majority Voting Methodology

The analytical study of different combination of features and classifiers in holistic manner so as to recognize handwritten Devanagari words has been carried out using in-house corpus of 48,000 Devanagari words. From the experiments, recognition accuracy of 88.06%, False Acceptance Rate (FAR) of 0.10%, False Rejection Rate (FRR) of 11.93%, precision of 88.83%, F1-Score of 88.20%, Matthew's Correlation Coefficient (MCC) of 0.882 and Area Under the Curve (AUC) of 93.98% have been obtained using combination of intersection & open-end points features, elliptical-based features and Arnold transform-based features along with majority voting classifier. We have taken 80% of the corpus as training (38,400 words) and 20% of corpus as testing samples (9,600 words). Experiment results are presented in the below Tables 5.1 to 5.7.

Moreover, the experimental results have been compared with the available state-of-the-art techniques. It has been gathered that the presented system achieved better or comparable performance with existing systems developed so far for the recognition of offline handwritten words.

9.2.3 OHDW Recognition System using Adaptive Boosting Approach

In this, the performance of three feature extraction approaches namely uniform zoning-based, peak extent-based and Gabor filter-based are analyzed considering three classification techniques namely Support Vector Machine (SVM), Naive Bayes (NB) and Random Forest (RF) for recognition of handwritten words (Devanagari). Thereafter, to enhance the recognition results and the system performance, we have proposed efficient concatenation of different feature extraction as well as classification

approaches followed by adaptive boosting technique. The system performance has been evaluated taking a corpus of 48,000 handwritten Devanagari words using 80:20 partitioning scheme, where 38,400 words are used as training samples (i.e. 80% of data) and whereas, 9,600 words are used as testing samples (i.e. 20% of data).

It has observed that maximum recognition accuracy of 89.12%, FAR of 0.09%, FRR of 10.87%, F1-Score of 89.22% and Area Under the Curve (AUC) of 94.51% have been achieved using concatenation of various features followed with adaptive boosting approach. Recognition results in terms of Recognition Accuracy (%), FAR (%), FRR (%), F1-Score (%) and AUC (%) are depicted in the Tables 6.1 to 6.5. Furthermore, recognition results of some available state-of-the-art techniques are compared with proposed approach. It has gathered that the presented system gives comparable performance with prevailing systems developed for the recognition of handwritten words.

9.2.4 Recognition of OHDW using Gradient Boosted Decision Tree (GBDT) Approach

Various statistical features extraction techniques based on uniform zoning, diagonal and centroid are explored for the recognition handwritten Devanagari words (written in offline mode) considering various classifiers namely K-Nearest Neighbor (KNN), Decision Tree (DT), Random Forest (RF). Feature vector sets (features) have been obtained to describe each handwritten word (Devanagari) in the feature space through extraction of the above mentioned features from the corpus of images (handwritten words). The performance of the system has been evaluated taking a corpus of 20,000 handwritten Devanagari words (50-word classes) using 70:30 partitioning scheme, where 14,000 words are used as training samples (i.e. 70% of data) and whereas, 6,000 words are used as testing samples (i.e. 30% of data). Furthermore to improve the performance of the system, concatenation of both the above mentioned features along with Gradient Boosted Decision Tree (GBDT) approach is suggested. Recognition results in terms of Recognition Accuracy (%), FAR (%), FRR (%), F1-Score (%), MCC and AUC (%) are depicted in the Tables 7.1 to 7.6.

In this way, proposed framework gained maximum recognition accuracy of 94.53% and the achieved competent results which are comparable with exiting state-of-the-art

approaches. Moreover, the proposed framework has obtained F1-Score of 94.56%, FAR of 0.11%, FRR of 5.46%, MCC of 0.945 and AUC of 97.21%. Overall, proposed framework performed well and competent as compared with other existing state-of-the-art systems for handwritten word recognition (Devanagari).

9.2.5 VGG16: An Efficient Approach for OHDW Recognition using Deep Features and XGBoost

We have proposed a holistic approach for the recognition of offline handwritten words written in Devanagari script using VGG16 (Visual Geometry Group) as a feature extractor because of its versatility. Three classifiers namely Gaussian Naive Based (Gaussian NB) classifier, eXtreme Gradient Boosting (XGBoost) classifier and Random Forest (RF) classifier have been considered to classify these word images. Based upon extracted features and above mentioned classifiers, words have been classified as belonging to one particular class out of the total 50-word classes. The experiments have been carried out using 15,000 word samples written in Devanagari script. For this work, handwritten Devanagari word datasets is divided into three strategic schemes namely X, Y, and Z; as depicted in the following Table 3.23. In X strategic-scheme, training datasets (words) are considered as 90% of the dataset whereas 10% of datasets are considered as testing datasets (words). For Y strategic-scheme, 80% of the corpus is considered as the training dataset (words) and 20% of the corpus is taken as a testing dataset (words). In the Z strategic-scheme, 70% of the corpus is taken as a training dataset (words) and while, 30% of the corpus is considered as a testing dataset (words).

Various performance evaluators viz. Recognition Accuracy (%), Precision (%), Recall (%), F1-Score (%) and AUC (%) are taken in consideration to evaluate the effectiveness of the proposed system/framework. Performance analysis based on of above mentioned performance evaluators are depicted in the Tables 8.2 to 8.6. It has been observed that Random Forest (RF) based classification technique achieved the maximum recognition accuracy of 95.00%, precision of 95.23%, recall of 95.00% and F1-Score of 94.99% and while XGBoost based classification scored maximum AUC of 99.94% in this work. Thus, an efficient offline handwritten Devanagari word recognition system using deep features (VGG16) which results in better recognition accuracy is proposed. This is due

to the recognition ability of an HWR system depending on the quality of extracted features.

9.3 MAJOR CONCLUSIONS

To develop an offline handwritten Devanagari word recognition framework, initially a dataset/corpus of handwritten Devanagari words have been gathered for experimental purpose. Thereafter, an offline HWR system has been developed for Devanagari script which find its application in recognition of city name for postal automation, form processing, handwritten notes reading, signature verification etc. We have considered majority voting classification, adaptive boosting and gradient boosted decision tree approaches and achieved recognition accuracies upto 88.06%, 89.12% and 94.53%, respectively. To boost the system performance, an efficient approach for the recognition of offline handwritten Devanagari words has been proposed using VGG16 as feature extractor (deep features) and XGBoost approach which results in 95.00% of recognition accuracy.

9.4 FUTURE SCOPE OF THE WORK

The present work on offline handwritten Devanagari word recognition has opened up several avenues for future research and development. Some potential directions for further exploration are as follows:

- Although 48,000 samples of handwritten Devanagari words were gathered for this research work due to non-availability of benchmark dataset of Devanagari words. Future, work can focus on curating a larger and more diverse dataset to improve the generalizability of the recognition system.
- The proposed approaches in this work involved combining various features and classifiers to achieve competitive recognition results. Further investigations can be conducted to explore additional feature combinations and classifiers. Evaluating the performance of different combinations using various classification approaches can lead to further improvements in recognition accuracy.
- The use of deep learning models, such as VGG16 as a feature extractor, has shown promising results in offline handwritten Devanagari word recognition,

achieving a recognition accuracy of 95.00%. Further exploration can focus on exploring other deep learning architectures and techniques, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), to extract high-level representations from handwritten Devanagari word images. This can potentially lead to even higher recognition accuracy and improved system performance.

- Expanding the scope of the research to recognize other Indic scripts, such as Gurumukhi or other North Indic scripts, can be an interesting direction. Investigating the similarities and differences between these scripts and exploring transfer learning techniques can help in developing robust multilingual recognition systems.

Overall, the present work lays a solid foundation for future research in offline handwritten Devanagari word recognition. By addressing the challenges specific to Devanagari script and exploring advanced techniques, the recognition accuracy and performance of the system can be further improved, paving the way for practical applications in document processing, text recognition and other related domains.