ABSTRACT

Handwritten Word Recognition (HWR) has gained significant attention as a research field in pattern recognition, which focuses on the recognition of words through computer-based systems using online and or offline approaches. Online HWR utilizes tablet-like surfaces and specialized pens, while offline HWR relies on paper surfaces and subsequent scanning for digitization. This thesis aims to develop an offline handwritten Devanagari word recognition framework for various applications, including city name recognition, form processing, handwritten notes reading, signature verification and writer verification. Devanagari, a widely used script in India, consists of vowels, consonants, modifiers and composite characters formed by merging basic characters. The work include generating a corpus of handwritten Devanagari words for experimentation and exploring various features, classifiers and their combinations for offline handwritten Devanagari word recognition.

This thesis comprises a total of nine chapters, which are succinctly outlined as follows:

Chapter 1 offers an in-depth analysis of the classification of handwritten word recognition systems, including their applications, advantages and disadvantages. It provides an extensive overview of the Devanagari script and elaborates on the different phases involved in the offline handwritten word recognition system. The chapter also explores the various application areas of the proposed system. Moreover, it presents the objectives of the proposed work, highlights the major contributions and discusses the achieved milestones.

Chapter 2 presents a widespread survey on various feature extraction and classification methods considered so far for the recognition of online and offline handwritten characters and or words. Moreover, the latest studies, research gaps, challenges and future perspectives have been identified in the Devanagari text recognition domain.

Chapter 3 delves into the detailed phases of the offline handwritten Devanagari word recognition system encompassing data collection, image acquisition, digitization and pre-processing. The data collection involved obtaining 48,000 samples of handwritten words in Devanagari script, specifically comprising 120 place names of different states in India that were acquired from 400 distinct writers. Thereafter, the handwritten

documents were scanned to generate digital images. Subsequently, the digitized images underwent three crucial operations: binarization, normalization and thinning. These operations aimed to achieve uniform-sized thinned word images, facilitating subsequent analysis and recognition. Moreover, an evaluation was conducted to assess the suitability of three thinning algorithms, namely Zhang-Suen [ZSu], Guo-Hall [GHa] and Lee-Kashyab-Chu [LKC], for skeletonizing offline handwritten Devanagari words.

Chapter 4 provides a comprehensive discussion on the extraction of Gradient and structural features based on contour-directional histogram from handwritten word images. Subsequently, three distinct classifiers, namely Support Vector Machine (SVM), Naive Bayes (NB) and eXtreme Gradient Boosting (XGBoost), are explored for the recognition tasks. Experimental evaluations are conducted using combined feature vectors derived from gradient and structural features as input to various classifiers. The integration of these two features yields improved recognition accuracy in the proposed system. The evaluation is performed on a corpus of 20,000 words (50 word-classes) in handwritten Devanagari script. The system's performance is evaluated in terms of Recognition Accuracy (RA), False Acceptance Rate (FAR), False Rejection Rate (FRR) and Precision (PR). Experimental results indicate that the combination of feature vectors derived from Gradient and structural features with the XGBoost classifier outperforms individual features alone. Using XGBoost classification, the system achieves a maximum Recognition Accuracy (RA) of 90.10%, a minimum False Acceptance Rate (FAR) of 0.20%, and a False Rejection Rate (FRR) of 9.89% with the concatenation of Gradient and structural features. Moreover, structural-based features combined with the XGBoost classifier achieved a maximum Precision (PR) of 90.65%.

Chapter 5 gives the analytical study of different combination of features and classifiers in holistic manner so as to recognize handwritten Devanagari words using in-house corpus of 48,000 Devanagari words (120 word-classes). From the experiments (with 80:20 partitioning strategy), Recognition Accuracy (RA) of 88.06%, False Acceptance Rate (FAR) of 0.10%, False Rejection Rate (FRR) of 11.93%, Precision (PR) of 88.83%, F1-Score (FS) 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 features and Arnold transform based features along with majority voting classifier. It has been gathered that the presented

system achieved better and comparable performance with existing systems developed so far for the recognition of offline handwritten words.

Chapter 6 analyzes the performance of three feature extraction techniques (uniform zoning-based, peak extent-based and Gabor filter-based) and three classification techniques (Support Vector Machine (SVM), Naive Bayes (NB) and Random Forest (RF)) for the recognition of handwritten Devanagari words. To enhance system performance, an effective concatenation of feature extraction and classification techniques have been proposed, followed by an adaptive boosting approach. The performance evaluation is conducted using a corpus of 48,000 handwritten Devanagari words (120 word-classes) with an 80:20 partitioning scheme. The evaluation reveals that the proposed system achieves a maximum Recognition Accuracy (RA) of 89.12%, a False Acceptance Rate (FAR) of 0.09%, a False Rejection Rate (FRR) of 10.87%, an F1-Score (FS) of 89.22% and an Area Under the Curve (AUC) of 94.51% through the concatenation of various features followed by adaptive boosting. 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.

Chapter 7 explores various statistical feature extraction techniques namely uniform zoning-based, diagonal-based and centroid-based along with various classifiers namely K-Nearest Neighbor (KNN), Decision Tree (DT) and Random Forest (RF) for the recognition of offline handwritten Devanagari words. Feature vector sets have been generated to describe each word in the feature space by extracting above mentioned features from the corpus of 20,000 handwritten Devanagari words (50-word classes) using 70:30 partitioning scheme. Furthermore to enhance the system performance, combination of above mentioned features along with gradient boosted decision tree algorithm is proposed. In this way, proposed system achieved maximum Recognition Accuracy (RA) of 94.53% and the attained competent results are comparable with exiting state-of-the-art methods. Moreover, the proposed system has achieved F1-Score of 94.56%, FAR of 0.11%, FRR of 5.46%, MCC of 0.945 and AUC of 97.21%. Overall, proposed system performed good and competent as compared with other existing similar state-of-the-art systems for recognizing the handwritten words.

Chapter 8 proposes a holistic approach to recognize 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), eXtreme Gradient Boosting (XGBoost) and Random Forest (RF) 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 (15,000 word samples). For this work, handwritten Devanagari word samples are divided into three strategic schemes namely X (90:10), Y (80:20) and Z (70:30). It has been observed that Random Forest (RF) based classification technique achieved the maximum Recognition Accuracy (RA) of 95.00%, Recall (RC) of 95.00%, Precision (PR) of 95.23% and F1-Score (FS) of 94.99% and while XGBoost based classification scored maximum Area Under the Curve (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.

Chapter 9 concludes the results derived from the various experiments conducted in this study. Additionally, a concise overview of potential future directions is provided, serving as a guide for further research endeavors.

Thus, in order to develop an offline handwritten Devanagari word recognition framework, a dataset of handwritten Devanagari words was initially collected for experimental purposes. Subsequently, various systems for offline handwritten word recognition in the Devanagari script were developed which finds practical applications in recognizing city names for postal automation, form processing, handwritten notes reading, signature verification and many more. The majority voting, adaptive boosting and gradient boosted decision tree classification approaches have been considered and achieved recognition accuracies upto 88.06%, 89.12% and 94.53%, respectively. To boost the system performance, an efficient approach for offline handwritten Devanagari word recognition using VGG16 as feature extractor (deep features) and XGBoost classification approach has been proposed which results 95.00% of recognition accuracy.