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Online Handwritten Text Recognition for Indian Scripts

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Abstract: *Online Handwriting Recognition has been a rigorous research area for the last few decades. Substantial amount of work has been reported on the online handwriting recognition of Western, Chinese, Japanese, Korean and Arabic Scripts, but few related to Indian scripts. In this paper a review of online HCR work on almost all popular Indian scripts such as Devanagari, Gurmukhi, Bangla, Tamil, Telugu, Malayalam, Urdu, Kannada, Oriya, and Gujarati is presented. The review is organized into 7 sections. Section 1 covers introduction. Properties of Indian scripts and general architecture of online HCR is given in section 2 and 3. In section 4, research work done on online handwriting for Indian scripts is summarized. Challenges of online HCR are discussed in section 5. The scope of future work and further steps needed for Indian script based online HCR development are discussed in section 6. Conclusions are given in section 7.*

Keywords: *Online Handwritten text Recognition, Indian Scripts, Character Recognition, OCR, HCR.*

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I. Introduction

With the development of technology and portable computing devices such as PDAs and handheld computers, Non-Keyboard methods are providing an efficient and natural way for man machine interface. Most promising options are voice based and pen based inputs. Online handwriting refers to writing through a special pen on an electronic surface and recognition of online handwriting is the tracking of hand movements, the way user writes. Practical applications of online handwriting recognition are: (i) Pen based form filling, (ii) Word processing, (iii) Natural language processing, and (iv)Usage of online handwriting recognition in conjunction with speech synthesis, to empower people with vocal disability to communicate with others [46]. Various Designers have been actively involved in developing online Handwritten character recognition systems for Indian scripts (N Joshi et al.[6,27]; A Sharma et al. [11,51], R.K Sharma et al.[11,14,15,16], Sachan and Lehal et al.[12,13] ,U. Bhattacharya et al.[17,19,20], A G. Ramkrishnan etal.[6,27,30,31,32,33,34,43,44,46], R. Kunwar et al.[30,31,44]). Little work has also been reported for bilingual Online HCR(S Lakshami et al.[7, 35], A.Arora and Namboodiri et al.[38]) and HCR for Mobile Devices (A Sharma et al.[52]). In this paper an overview of online handwritten character recognition for Indian scripts is reported. Most of the articles are published from the year 2004 onwards. The comparison of all reported methods is presented in tabular form and is done with respect to pre processing, feature set, classifier, post processing, and reported accuracy.

II. Properties Of Scripts

India is a Multi-Lingual, Multi-Script country. Devnagari, Gurmukhi, Bangla, Tamil, Telgu, Urdu, Oriya, Gujarati, Kannada and Malayalam are 10 official Indian scripts. Most of these scripts are originated from an ancient script called Brahmi. Examples of these scripts are shown in figure1. These Indian scripts differ by variety of visual characteristics; and also share some important similarities.

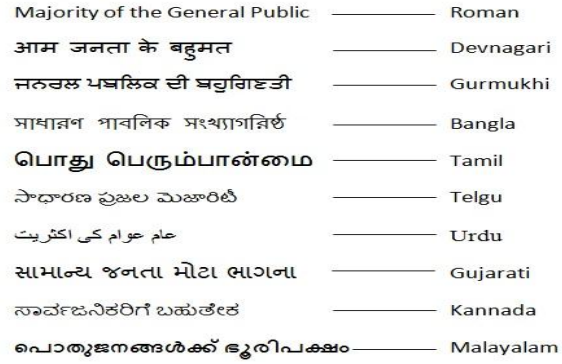

Figure 1 : Examples of Indian Scripts.

A brief overview of General Structural properties of these scripts is discussed below:

- Character set of most scripts is divided into two categories: Basic and Compound Characters. (i) Basic Character is collection of vowels and consonants. Devnagari has 11 vowels and 33 simple consonants, Gurmukhi has 9 vowels and 41 consonants, Bangla has 11 vowels and 39 consonants, Tamil has 12 vowels and 23 consonants, Telgu has 14 vowels and 34 consonants, Kannada has 14 vowels and 34 consonants, Gujarati has 11 vowels and 34 consonants, Malayalam has 18 vowels, 36 consonants, and 5 half consonants, Oriya has 12 vowels and 35 consonants; (ii) In most Indian scripts (except Tamil and Gurmukhi) there are compound character, which are formed by combining two or more basic character. The shape of combined characters is usually more complex than basic character [1].
- There is no concept of upper and lower case in Indian scripts.
- Writing style of Devnagari, Gurmukhi, Kannada, Tamil and Telgu, Malayalam, Bangla, Guajarati is from Left to Right whereas, Urdu is written from Right to Left.
- In some Indian scripts (like Devnagari, Bangla, Gurmukhi etc.) many characters have a horizontal line at the upper part called headline.
- In most Indian scripts the text is partitioned into three zones- the upper zone, Middle zone and lower zone.

III. Steps In Online HCR Systems

Online HCR system converts user handwritten information into text. The recognition of online handwritten characters includes following phases: data acquisition, pre processing, feature extraction, classification, recognition and post-processing. The output obtained from one phase becomes input for the next phase. These phases are illustrated in figure 2.

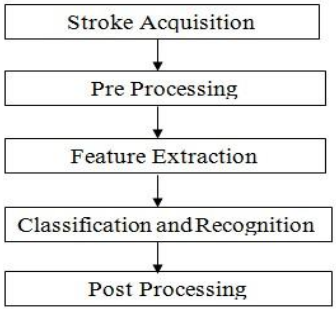

Figure 2: General steps in Online Handwritten Text Recognition System

Writing on mobile phone, tablet, PDA or any online input device, generate a sequence of strokes. These Strokes are pre processed to extract useful features. Pre processed strokes are then sent to recognition engine which then accept or reject the stroke based on pre defined rules. Each script has its own writing rules depending upon the properties of the script. Steps involved in online Script recognition are:

I. ***Data Acquisition****:* Data is collected during the input. Parameters related to pen tip like position, acceleration, velocity and sometimes pressure on the writing surface are used for data acquisition.
II. ***Pre processing*****:** In this step, noise and other undesirable effects are reduced to improve the data for the recognition process. Typically, Normalization, Smoothing, Resampling, Dehooking, Thinning, Noise Reduction is applied.
III. ***Feature Extraction*****:** The relevant information from the input is extracted for further processing. The challenge in this phase is to extract a minimal set of features with maximum data recognition. Typically Shape, Directional, Length, Angle features are extracted. High recognition performance could be achieved by selecting suitable set of features.
IV. ***Classification and Recognition*****:** Methods such as SVM, MQDF, DWT, HMM, Neural Networks are often used for handwriting recognition. The goal is to find the optimal letter for a given handwritten input. The letter corresponding to the maximum probability is reported as the recognized letter.
V. ***Post processing:*** Post processing is performed in order to improve the performance of the system. It includes the procedure of correcting misclassified results by applying linguistic knowledge [7]**.**

IV. Online HCR Systems For Indian Scripts

4.1 Recognition of Devanagari Script

Devanagari is the most widely used Indian writing system. The first system on online recognition of devanagari script was introduced by Connel et al. [5]. They have used combination of Hidden Microwave Model and Nearest Neighbor Classifier for classification and capturing different levels of offline and online features yielding a classification accuracy of 86.5%.

Table 1. Existing Devnagari Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_ Processing	Training Set	Test Set	Recognition Rate
Scott D Connell et al.[5] (2000)	Online Handwritten Character	Size Normalization , Quantization	Local Online Features, Global Offline Features	HMM and Nearest neighbour Classifier	-	-	1600 characters	86.5%
Niranjan Joshi et al.[6] (2005)	Online Handwritten Character	Resampling and low pass Filtering	Stroke level features such as mean(x, y) value , Length, Offline features, Positional cues and Directional codes	Structural Recognition, Feature based Recognition and Output Mapping	_	1487 characters	441 characters	94.49%
Swehta Lakshami et al.[7] (2008)	Online Handwritten Strokes	Normalization , Smoothing, Interpolation	Spatiotemporal features,, Spectral Features, Spatiostructural Features	Support Vector machine	Disambiguation and Regroupping	16764 examples	8769 examples	90.86% (Spatiostructural), 95.14% Spatiotemporal
Bhushan C Bhokse, Bhushan S. Thakare et al.[6] (2012)	Online Handwritten Character	Stroke Joining, Scaling and Shifting, Down sampling and Quantization	Character Pattern, Length, Directional Code, Vertical Line and Half Vertical Line, Horizontal Line and Half Horizontal Line	Dynamic Time Wrapping Algorithm	-	-	-	64%
Deepika Wadavan et al.[9] (2012)	Handwritten Devnagari Numerals	Size normalization, Interpolation, Resampling, Smoothing, Slant Correction	Direction Angles, Curvature	Support Vector Machine	-	-	-	98.90%
Sharuti Kabatur et al.[10] (2012)	Online Handwritten Character	Smoothing and De-noising, Normalization	Speed of Writing, angular Velocity and order of Strokes.	Neural Network	-	2760 Samples	2760 samples	96.268%(with 2 neural Network) 97.283%(with 2 neural network)

Joshi et al. [6] have developed a system for automatic recognition of isolated handwritten devanagari character obtained by linearizing consonant conjuncts. Resampling and low pass filtering are used as pre-processing techniques. The recognition methodology used is broadly divided into three modules: Structural Recognition, Feature Based Recognition, and Output Mapping. In sequential data testing, the system recognition accuracy of 94.49% is reported.

System for Online Handwritten Character Recognition of Devanagari and Telugu Characters has been proposed by Swethalakshmi et al. [35] where, Support vector machines are used for constructing the stroke recognition engine. Also a study has been done by Swethalakshmi et al. [7], stroke based HCR systems, which use SVMs for stroke classification and a rule based approach for character identification, are proposed for two major Indian writing systems, Devanagari and Tamil. Pre processing steps: Normalization, Smoothing, and Interpolation are performed to remove variations and noise and a uniform representation of input strokes is obtained. Spatiotemporal, Spectral, and Spatiostructural features are used for obtaining three different representations of stroke, and classification accuracy of 95.13% for spatiotemporal, 95.29% for spectral, and 90.86% for spatiostructural features is reported for devnagari script. Post processing steps: Disambiguation and Regrouping are performed to resolve the ambiguities among confusable strokes and to identify non-proximal units. Bhokse et al. [8] have presented a recognition system using DTW technique. The down sampled and quantized input character pattern are preprocessed to extract structural features. An adequate accuracy of 64% is reported. Deepika et al. [9] have developed an online handwritten Devanagari Numeral recognition system using SVM. The recognition task is divided into 4 phases namely: Data collection, Pre processing, Feature Extraction, and Recognition. Recognition is done using four kernel functions (linear, polynomial, RBF, sigmoid) of SVM by dividing the data into six schemes depending on the features extracted. Results obtained are reasonably good when the linear kernel is used as compared to the other kernels. The highest accuracy reported by the linear kernel is 98.90%. Sharuti et al. [10] have proposed a Neural Network based system for recognition of online handwritten devanagari characters, where the mode of character input is through computer mouse. The recognition rate of 97.2% is achieved after testing of algorithm on 2760 characters. Table 1gives an overview of the online handwritten recognition systems for devanagari characters and numerals.

4.2 Recognition of Gurumukhi Script

Gurumukhi script is 14th most widely used script in the world. Sharma et al. [11] introduced a writer independent system for online Gurumukhi script recognition. New recognition method, Small Line Segment was introduced based on chain code rule and elastic matching technique. Recognition rate of 94.59% is reported using small line segments method. Post processing phase is also discussed which includes verification of recognized strokes through features of character in the script.

Table 2. Existing Gurmukhi Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_ Processing	Training Set	Test Set	Recognition Rate
Anuj Sharma et al.[11] (2009)	Online Handwritten Characters	Size normalization and centring of strokes, Smoothing of stroke, Slant correction of stroke & resampling of points in stroke, Interpolating missing points in stroke.	High Level Features- Loop, crossing, dots, straight line and headline. Low Level Features- Position of stroke ,area, length, curliness,slope	Small Line Segment Method Based on Elastic Matching and chain code Technique	Verification of recognized strokes through features of characters in script	-	2460 characters from 60 users	94.59% Using Small Line Segmentation
Manoj K Sachan et al. [12,13] (2011)	Online Handwritten Words	Rescaling, Duplicate Point Removal	Distributed Directional Features	(a)Extraction of strokes based on position , pressure, button & time (b) Merging of Sub strokes	-	-	2150 words from 50 users	76%
Shivali et al.[14] (2011)	Online Handwritten Numerals	Size normalization and centring, interpolating missing points, resampling, smoothing	Points Generated after pre-processing phase is used as feature for recognition	Support Vector Machine	-	80% of Data	20% of Data	97.5% (with 40 resampled points Using linear kernel)
R. Aggarwal et al.[15] (2012)	Online Handwritten Strokes	Size Normalization and Centring, Interpolating Missing Points, Smoothing, Resampling	Points Generated after pre processing phase is used as feature for recognition	Support Vector Machine	-	-	300 words from 3 users	98.45% (without pre processing) 98.92%(with preprocessed strokes)
Dushyant Khurana et al.[16] (2013)	Online Handwritten Characters	Removal of duplicate points, Size Normalization & Centring, Missing point Interpolation, Resampling	Points Generated after pre processing phase is used as feature for recognition	Support Vector Machine	Database of Rules for Creating a Character is used.	75% of Data	25% of Data	94.4%

Sachan et al. [12, 13] proposed a system for online Gurumukhi script recognition. Pre-processing steps rescaling and duplicate point removal are performed on input data. The segmentation algorithm consist of two phases namely extraction of strokes and merging of strokes. Segmented shapes are processed to extract Distributed directional features. Feature data is fed to the recognition engine which is nearest neighbour classifier. Average accuracy of 76% is achieved by the system.

Shivali et al. [14] has reported work for recognition of Online Handwritten Punjabi Numerals using Support Vector Machine. Recognition accuracy of 97.5% is achieved with 40 resampled points using linear kernel. Work for recognition of Online Handwritten Gurmukhi Strokes using SVM has been done by Aggarwal et al. [15]. An overall accuracy of 98.45% without applying pre-processing and 98.92% with pre-processing phase has been reported. Khurana et al. [16] has also reported work for online Gurumukhi text recognition by using SVM with accuracy rate of 94.4%. Table2 gives an overview of the online handwritten recognition systems for Gurumukhi characters and numerals.

4.3 Recognition of Bangla Script

Bangla script is used by more than 200 million people of India and Bangladesh. Online Bangla cursive words recognition system was proposed by Bhattacharia et al. [17]. An analytic recognition approach is proposed. 8-directional feature vector along with the Modified Quadratic Discriminant Function is used for recognition of segmented strokes. Overall word level recognition accuracy 82.34% is reported. System for online recognition of handwritten Bangla character is presented by Bandopadhyay et al. [18]. A DTW based classifier is used to identify strokes. Overall recognition accuracy of 97.33% is reported for writer dependent system. Parui et al. [19] presented a system where, Recognition of the strokes forming the shape of an unknown character sample is done by the HMM classifier. The classification rate reported by the proposed scheme is 87.7% whereas classification accuracy at the stroke level is 84.6%.

Table 3. Existing Bangla Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_ Processing	Training Set	Test Set	Recognition Rate
U Bhattacharya et al.[17] (2008)	Online Handwritten Words	Noise Removal , Shift of Origin , Smoothing and Resampling of points	Width and height of stroke, angle , directional features, coordinates of the center of gravity	8 directional feature vector along with the Modified quadratic discriminant function MQDF) classifier.	_	-	_	82.34%
Asok Bandopadhyay et al.[18] (2008)	Online Handwritten Characters	Resampling, Smoothing and Normalization of Strokes	Directional Features , Shape Based Features	DWT Classifier	-	-	-	97.33%
S K Pauri et al.[19] (2008)	Online Handwritten Characters	Snoothing , Normalization	Shape and size of sub stroke, Points forming the strokes, distance between points, angle, Direction, Length, Height of Stroke.	HMM	-	-	-	87.7%(Classification rate)
Gernot A.F et al.[20] (2010)	Online Handwritten Words	Size Normalization, Smoothing and Resampling	For each sub-stroke 8 scalar feature value representing its shape, size and relative position are computed.	-System was developed using open source environment ESMERALDA - Semi-continuous HMMs	-	-	-	93.1%(Context Dependent)
Chandan Biwas et al.[21] (2012)	Online Handwritten Characters	Normalization , Remove Local Noise, Resampling, Smoothing	8 stroke features (Computed on the basis of angle, centre of gravity and length of stroke)	-HMM Classifier - Dirichlet Distributer for stroke classes	-	29951 character samples	8616 Samples	91.85%
K Roy et al.[22] (2012)	Online Handwritten Characters	Smoothing	Structural Features, Point based futures	Multi Layer Perceptron Neural Network based scheme	-	¼ of data	¾ of data	96.85% (isolated strokes) 88.23 % (character)
Sumanta Daw et al.[24] (2013)	Online Handwritten Compound Words	Segmentation	Point Based Features(90), Structural features (15), Directional Features(128)	Multilayer perception Neural Network Based Scheme	-	-	4200 Compound Words	73%

Online Bangla word recognition system was built using Open-Source development environment ESMERALDA by Fink et al. [20]. Sub-Stroke Level Features and Hidden Markov Models are used for recognition. A quite satisfactory recognition rate of more than 93% is achieved. HMM Based Online Handwritten Bangla Character Recognition using Dirichlet Distributions was developed by Biswaset al. [21]. The character level recognition accuracy of 91.85 % is reported.

Roy et al. [22] has proposed a Multi Layer Perception Neural Network based system for recognition of online handwritten Bangla characters. The sequential and dynamical information obtained from the pen movements on the writing pads is used as features in system. Features computed from the strokes are fed to the MLP classifier for recognition. The recognition rate of 96.85% for isolated strokes and 88.23% for overall system is reported.

A system for Stroke Segmentation and Recognition for Bangla Online Handwritten Text is given by Bhattacharya et al. [23]. Directional features were used in SVM for recognition and correct stroke recognition rate of 97.68% is reported. Sumanta et al. [24] has presented a system for online Bangla handwritten compound word recognition based on segmentation of word into its constituent characters. Segmentation rate of 87% and the overall recognition rate of 73% is reported.

Rajib et al. [25] has proposed a technique for segmentation of Online Bangla handwritten word by extracting basic features of different strokes as well as basic features of writing style of handwriting. Also another approach of Segmentation of Online Bangla Handwritten Word using busy zone concept has been proposed to segment Online Bangla handwritten word into its constituent basic strokes.

Table 3 gives an overview of the online handwritten recognition systems for Bangla characters.

4.4 Recognition of Tamil Script

Tamil is a popular classical language used by a significant population in South East Asian Countries. Joshi et al. [27] introduced a Tamil Handwriting Recognition system using Subspace and DTW based Classifiers. They compared both methods in writer dependent, independent and adaptive scenarios. Error rate of 11.15%(PCA) and 8.52%(DTW) in writer independent, 5.23%(PCA) and 3.30%(DTW) in writer dependent, and 5.41%(PCA) and 3.60%(DTW)is reported in writer adaptive testing.

Table 4. Existing Tamil Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_Processing	Training Set	Test Set	Recognition Rate
N. Joshi, G. Sita et al.[27] (2004)	Online Handwritten Character	Smoothing, Normalization	Pre processed x,y coordinates are used as feature for recognition	Subspace base classification, DTW Based Classification	-	19440 samples	4860 samples	Error Rate 11.15%(PCA), 8.52% (DTW)
Aparna et al.[28] (2004)	Online Character Data	Interpolation, Smoothing and Normalization	Set of 18 Shape Features	Shape Feature database, Rule List, Finite State Automation	-	-	-	NA*
Toselli et al.[29] (2007)	Online Handwritten Character	Repeated Point Elimination, Noise Reduction , Speed and Size Normalization	- Set of 7 Time Domain Features, -Set of 8 Frequency Domain Features	HMM's	-	39618 Samples	26926 Samples	Error Rate 9.3%
Swehta Lakshami et al.[7] (2008)	Online Handwritten Strokes	Normalization ,Smoothing, Interpolation	Spatiotemporal features,, Spectral Features, Spatiostructural Features	Support Vector machine	Disambiguation and Regroupping	19398 Examples	9048 examples	90.77%(Spatiostructural), 91.92%(Spatiotemporal)
Rituraj Kunwar et al.[30] (2009)	Online Handwritten Words	Smoothing, Normalization, Resmapling	Normalized x,y 1st Derivatives , Normalized x,y 2nd derivatives, Curvature	HMM	-	-	-	84% (at symbol level)
Suresh Sundaram et al.[32] (2009)	Online Handwritten Character	Smoothing, Dehooking, Resampling, Normalization	Normalized x,y coordinates of points, Distance, Angle, Length, Position of sample point with respect to its neighbours.	NN + 2DPAC Classifier	Disambiguation	270 training samples for each character	26926 random Samples	86.5% 87.5%(with post-processing)
Bhargava Urala et al.[34] (2013)	Online Handwritten Words	Smoothing, Normalization, Resampling	X,y coordinates of Normalised Symbols and their first derivatives as Local Features, Truncated Fourier Coefficients as global features	SVM with Radial Basic Function(RBF)	N best choices of symbol for a given word are generated using Viterbi Lattice. String is then converted to Unicode string using FST.	-	-	NA*

*NA: Not Available – Recognition result is not given in the terms of numeric value

A system for Online Recognition of Handwritten Tamil characters is presented by Aparna et al. [28]. Shape feature database, Rule list and Finite State Automata are used for character recognition. Work on On-Line Handwriting Recognition System for Tamil Handwritten Characters is reported by Toselli et al. [29]. The system is based on continuous density Hidden Markov Models and characterized time and frequency domain feature extraction. 10.0% classification error rate for 16 Gaussian densities is the best result reported. As discussed earlier, Swethalakshmi et al. [7], proposed a stroke based HCR systems, which use SVMs for stroke classification and a rule based approach for character identification, for two major Indian writing systems, Devanagari and Tamil. Classification accuracy of 91.92% for spatiotemporal, 92.13% for spectral, and 90.77% for spatiostructural features is obtained for Tamil script. Also post processing steps: Disambiguation and Regrouping are performed to resolve the ambiguities among confusable strokes and to identify non-proximal units. Kunwar at al. [30] developed HMM Based Online Tamil Word Recognizer where, Each Tamil symbol is modeled using a separate HMM. Training of the models is performed using the Baum Welch Estimation. The Bayesian approach is adopted for recognizing the label for the test symbol. An accuracy of 84% at the symbol level is reported. Kunwar et al. [31] have also present a fractal coding method to recognize online handwritten Tamil characters and proposed a novel technique to increase the efficiency in terms of time. This technique exploits the redundancy in data, thereby achieving better compression and usage of lesser memory. A recognition accuracy of 90% has been reported by using DTW as compared to 78% using nearest neighbour classifier. Sundaram et al. [32] have proposed a script-specific post processing schemes for improving the recognition rate of online Tamil characters. At the first level, features derived at each sample point of the preprocessed character are used to construct a subspace using the 2DPCA algorithm. Recognition of the test sample is performed using nearest neighbour classifier. Based on the analysis of the confusion matrix, multiple pairs of confused characters are identified. At the second level, script specific cues are used to sort out the ambiguities among the confused characters. Recognition accuracy of 86.5% is achieved using 2DPCA+NN classifier, however with the post-processing scheme the performance is improved by approximately 1%. Also, they have proposed a Bigram language model and re-evaluation strategy for improved recognition of online handwritten Tamil words with recognition accuracies of 93.0% at the symbol and 81.6% at word level [33]. A system for Identification of Tamil script on Tablet PC is proposed by Urala et al. [34]. They used support vector

machine with radial basis function (RBF) as kernel. In post processing, statistics of co-occurrence of Tamil symbols estimated from the Emille corpus of Tamil text along with SVM confidence levels are used to generate N-best choices of symbol strings for a given handwritten word, using a Viterbi lattice. The symbol string is then converted to a Unicode string using a finite state transducer. Table 4 gives an overview of the online handwritten recognition systems for Tamil characters.

4.5 Recognition of Telugu Script

Telugu script is used by 100 million population in southern part of India. Rao et al. [35] have presented a system for online recognition of Telugu characters. In this approach, Individual strokes are identified by comparing the unknown stroke with a database of strokes. Combinations of strokes are then mapped onto ISCII codes of Telugu Characters.

Table 5. Existing Telgu Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_ Processing	Training Set	Test Set	Recognition Rate
Lakshami et al.[36] (2006)	Online Handwritten Strokes	Normalization, Smoothing, Interpolation	Coordinates of Points, Curve Length	SVM	-	33726 samples	4091 samples	NA*
Prasanth et al.[37] (2007)	Online Handwritten Symbols	Resampling, Normalization	Pre-Prosessed x,y Features, Shape Context Features, Tangent Angle Features, Generalised Shape Context Features, Normalised Derivative Features, Curvature Features.	Elastic Matching with Local Features	-	29174 samples	9215 samples	87.22(with L7 features)
Babu and Prasanth et al.[38] (2007)	Online Handwritten Symbols	Duplicate Point Elimination, Smoothing, Size Normalization, Resampling	Time Domain Features, Frequency Domain Features	HMM	-	29158 training samples	9235 Test Sample	91.6% (Top 1 accuracy) 98.7% (top 5 accuracy)
Amit Arora et al.[39] (2010)	Online Handwritten Strokes	Normalization, Resampling	Raw x,y Coordinates of resampled points, Moments of strokes, Overall direction and Curvature of Stroke Length of the Stroke, Aspect Ratio, Area of Stroke, Number and Direction of points in different sub windows, projection histograms, Fourier coefficients of x,y sequences	SVM classifier using a DDAG(Decision Directed Acyclic Graph), Discriminating classifier	Akshara recognizer using FSA(Finite State Automation)	57669 samples	-	75.70% (telgu)
K Vijay Kumar et al.[40] (2013)	Online Handwritten Character	Binarization, Smoothing and Noise Removal, Normalization, Thinning, Segmentation, Skew Detection, Slant Correction	x,y coordinate points, Fourier Transforms, Hilbert transform logarithm of spectral density, Wavelet Features	SVM	-		-	96.69%

*NA: Not Available – Recognition result is not given in the terms of numeric value

Swethalakshmi et al. [36] developed a system for Online Handwritten Character Recognition of Devanagari and Telugu Characters. Support vector machines have been used for constructing the stroke recognition engine. System for Online Handwritten Tamil and Telugu Scripts is presented by Prasanth et al. [37] using Elastic matching with local features. Nearest neighbour classifier with DTW distance was used as the classifier. For Telugu data an accuracy of 87.22% is reported using L7 features.

HMM-based Online Handwriting Recognition System for Telugu Symbols is developed by Babu et al. [38]. They introduced a cost-effective and natural data collection procedure based on ACECAD Digimemo. The combination of time-domain and frequency domain features is used in the system. Top-1 accuracy of 91.6% and top-5 accuracy of 98.7% on a dataset containing 29,158 train samples and 9,235 test samples is reported. A Hybrid Model for Recognition of Online Handwriting for two Indian Scripts, Telugu and Malayalam is presented by Arora et al. [39]. The recognition is based on a generative model of handwriting formation, coupled with a discriminative model for classification of strokes. In post processing akshara recognizer using FSA is used to estimate the most likely sequence of aksharas. For telugu data set word level accuracy of 75.70% is reported.

Kumar et al. [40] have presented a system for Online Handwritten Character Recognition for Telugu Language Using Support Vector Machines. Overall stroke recognition accuracy of 96.69% is reported.
Table 5 gives an overview of the online handwritten recognition systems for Telugu characters.

4.6 Recognition of Gujarati Script

Gujarati language is used in the western state of Gujarat. Because of script peculiarities, Character Recognition becomes difficult. Character Recognition of Gujarati script becomes difficult because of lack of use of ‘‘Shirolekha’’. Like many Indian languages, many modifiers are used in Gujarati, and sometimes these modifiers change even the shape of the basic alphabet. Very less work has been done in the area of Optical Character Recognition for Guajarati Language. However, online handwritten character recognition for Gujarati language remained untouched.

4.7 Recognition of Kannada Script

Kannada is one of the scheduled languages of India and the official language of the South Indian state of Karnataka. The recognition of isolated Kannada characters was first introduced by Kunte et al. [41]. Wavelet feature extracted from the character contour and Multi-layer feedforward neural networks with a single hidden layer are used for recognizing the characters.

Table 6. Existing Kannada Online Handwritten Character Recognition System

Author	Input	Pre-processing	Features	Method	Post-Processing	Training Set	Test Set	Recognition Rate
Parsad et al.[42] (2009)	Online Handwritten Data	Noise removal, Resampling, Normalization	Size Normalized Horizontal and Vertical Coordinates	Divide and Conquer for segmentation, K-NN Classifier	-	11952 samples	5229 samples	81%
Rituraj Kunwar et al.[43,44] (2010)	Input Handwritten Character	Normalization , Smoothing, Arc Length Resampling	Pre-Processed x,y Coordinates, 1st derivative of x,y coordinates (estimate 1 & estimate 2)	Statistical Dynamic Time Wrapping(SDTW)	-	Total 295 classes and 40 samples for each class	29 samples for each class	85.2%(estimate 1) 87.9%(estimate 2)
A G Ramkrishnan et al.[46]	Online Handwritten Symbol	Smoothing, Normalization ,Resampling	Number of dominant points, Inter Stroke Features, Symbol Size, Arc-length of Each Stroke	SVM Classifier	-	-	44772 words	62%(symbol recognition) 18.2% (word recognition)
MM Parsad et al.[47] (2013)	Online Handwritten Data	Noise removal, Resampling, Normalization	Normalized x,y coordinates, Trajectory features,first derivative feature, second derivative features, deviation features, Estimate features	2D-LDA	-	3750 samples	1550 samples	86% to 88.3%

Prasad et al. [42] proposed Divide and Conquer Technique for Online Handwritten Kannada Character Recognition. The structural and the spatiotemporal information of handwritten Kannada characters are exploited to segment a compound character into three distinct stroke units. The subspace features of each class of stroke groups are fed to their respective nearest neighbour (NN) classifiers for classification. The results from these classifiers are then combined to generate the output character. Maximum recognition accuracy attainable from the proposed system is around 81%.

System for unrestricted Kannada online HCR is proposed by Kunwar et al. [43]. Statistical dynamic time warping (SDTW) has been employed to classify Kannada characters with x-y coordinates of the trace and their first order derivatives as features. 46 times faster classification rate is achieved Using SDTW over DTW with comparable accuracy of 88%. Kunwar et al. [44] also developed a system to perform recognition of entire word. Writer independent word level recognition of 80% is reported using SDTW as classifier with estimate 2 of first derivatives as features.

Online HCR system for Kannada using Principal Component Analysis Approach is proposed by Parsad et al. [45]. System is implemented on mobile device using two different approaches namely Principal Component Analysis (PCA) and Dynamic Time Wrapping (DTW), an average recognition accuracy of 88% for the PCA and up to 64% is achieved for DTW approach. Ramakrishnan et al. [46] developed an online handwritten system for kannada characters. In addition to basic characters, 9 Kannada numerals, 9 Hindu Arabic numerals and 22 special symbols used in poetry, shlokas and Kannada grammar are also considered for recognition. AFS method is used to segment the online Kannada word into its constituent symbols.

2D-LDA based system for Online Handwritten Kannada Character Recognition is developed by Prasad et al. [47]. Feature combinations extracted from the size normalized characters are fed to 2D-LDA for dimensionality reduction and nearest neighbor classifier is used for classification. Reported average recognition accuracy varies between 86% and 88.3%. Table 6 gives an overview of the online handwritten recognition systems for Kannada characters and numerals.

4.8 Recognition of Malayalam Script

Malayalam script is used by millions of people in the state of Kerala and in the Lakshadweep Islands. System for online recognition of handwritten Malayalam characters is presented by Shankar et al. [48]. Soft matching strings are used to recognize new characters.

Table 7. Existing Malayalam Online Hand written Character Recognition System

Author	Input	Pre-processing	Features	Method	Post_ Processing	Training Set	Test Set	Recognition Rate
Gowari Shankar et al.[48] (2003)	Online Character Data	Normalization and Smoothing of strokes	A set of 8 Shape Based Features is Used	String Matching Algorithm	-		-	90.75% approx. (for 4 data sets)
Amit Arora et al.[39] (2010)	Online Handwritten Strokes	Normalization, Resampling	Raw x,y Coordinates of resampled points, Moments of strokes, Overall direction and Curvature of Stroke Length of the Stroke, Aspect Ratio, Area of Stroke, Number and Direction of points in different sub windows, projection histograms, Fourier coefficients of x,y sequences.	SVM classifier using a DDAG(Decision Directed Acyclic Graph), Discriminating classifier	Akshara recognizer using FSA(Finite State Automation)	7348 samples	-	78.07% (malayalam)
Seeraj M et al.[49] (2010)	Writer Independent Handwritten Character	Dot detection, Dehooking, Smoothing, Thinning, Loop Detection, Normalization, Equidistant Resampling	Time Domain Features, Directional Features, Curvature	Nearest Neighbour Classifier(K-NN)	-	2591 samples	-	98.125%
R. Ravinder Kumar et al.[50] (2011)	Online Handwritten Character	Dehooking, size Normalization, Resampling, Smoothing and Removal of Duplicate points	Geometric Features, Ink related Features , Directional Features, Global Features, Local Features	Elastic Matching	Stroke correction, Stroke Concatination, Linguistic Rules		-	82% (at word level) 94% (at character level)
Amritha Sampath et al.[51] (2012)	Online Handwritten Character	Noise Removal	Low level Features(width, height, curliness, aspect ratio), High Level Features (number and position of loops, straight lines, headlines, curves), Directional Features	Back Propagation Neural Network	Representation of output in Unicode formate, Disambiguation of confusing paires		-	NA*

***NA**: Not Available – Recognition result is not given in the terms of numeric value

As discussed earlier, Online HCR system for two Indian Scripts, Telugu and Malayalam is presented by Arora et al. [38]. The recognition is based on a generative model of handwriting formation, coupled with a discriminative model for classification of strokes. In post processing akshara recognizer using FSA is used to estimate the most likely sequence of aksharas. For Malayalam data set word level accuracy of 78.07% is reported.

Sreeraj et al. [49] presented k-NN based On-Line Handwritten Character recognition system. A novel feature extraction method, a combination of time domain features and dynamic representation of writing direction along with its curvature is used for recognizing Malayalam characters. This writer independent system gives an accuracy of 98.125% with recognition time of 15-30 milliseconds.

Online handwriting recognition system for Malayalam using elastic matching technique is presented by Kumar et al. [50]. Two-stage classification scheme using nearest neighbour classifier is adopted. Post processing steps 1) Stroke correction 2) Stroke concatenation 3) Linguistic rules are performed to improve the recognition accuracy. The post processing stage also makes use of a spellchecker to identify the word written is valid or not. For invalid words, suggestions from the dictionary are provided. With DTW- classifier and spellchecker, an average recognition rate of 94% at character level and 82% at word level is reported. Sampath et al. [51] presented a Neural Network based model for handwritten character recognition. Back propagation Neural Network is used for classification of characters. Additional disambiguation technique is used in post processing stage to identify confusing pairs. Table 7 gives an overview of the online handwritten recognition systems for Malayalam characters.

4.9 Recognition of Oriya Script

Oriya script is used to write the Oriya language which is spoken in Odisha state situated in the eastern part of India. During the last decades, intensive research studies have been made for recognition of handwritten characters and numerals in various Indian and foreign languages, but a few work has been reported on Oriya character recognition. Few literatures available for printed and offline handwritten character recognition but, no work has been done on online handwritten character recognition. The field of character recognition in Oriya language still needs an in depth study. Researchers tried to explore the possibilities of directional, structural,

zonal, statistical topological, morphological, wavelet features. The majority of the researchers have used neural network, K-NN and SVM, MLP, PCA, Fuzzy, Binary Tree, LDA, HMM, DTW based classifiers. There is lack of availability of benchmarking databases for research. From the literature, it is clear that many of the researchers have used their own databases for evaluating their techniques. So it is very difficult to compare the various techniques and methods proposed by the researchers.

V. Challenges Of Online Hcr

Recognition of handwritten Indian scripts is difficult because of the presence of numerals, vowels, consonants, vowel modifiers and compound characters. The structure of the scripts and the variety of shapes and writing styles pose challenges that are different from other scripts and hence require customized techniques for feature representation and recognition [3]. The Online Handwriting recognition for Indian scripts is a greater challenge because of the following reasons:

- The structure of the scripts and the variety of shapes. The same character may take different shapes and two or more character may take a similar shape.
- Presence of large number of characters.
- Handwriting style variations, Handwritings vary from person to person and also for a person it may vary from time to time according to his/her mood, urgency, etc.
- Two-Dimensional Structure of scripts, in most Indian scripts matras or vowels diacritics occurs to left, right, bottom, top or even as multiple components around the base consonant.
- Complexity of the characters & Inter-class Similarity
- Poor reliability of extracted stroke features due to variance in handwriting
- Due to limitations of the device or speed of writing, it is possible for a single character to be broken into different parts, hence creating confusion in recognition.

Challenging problems in online hand writing recognition are different character sizes, stroke number/order variation and duplicate pixels produced by hesitation in writing or interpolated non-adjacent pixels caused by fast writing [53]. Vocabulary is also a major factor in determining the difficulty of handwriting recognition task. (i) Closed-vocabulary tasks refer to recognition of words from a predetermined dictionary; (ii) Open-vocabulary tasks refer to recognition of any words without the constraint of being in a dictionary. Closed-vocabulary tasks are easier than open-vocabulary ones because only certain sequences of letters are possible when limited by a dictionary [15]. There are several other script dependent issues, for example, Malayalam text is written mostly in clockwise direction and consists of loops and curves, presence of shape modifiers in Gujarati etc. Most recent progress in this concern has been made either through improved pre-processing or through advances in language modeling. Relatively little work has been done in the development of basic recognition algorithms, in depth study needed in concern.

VI. Scope And Future Work

The work reported on Online HCR for Indian scripts may be extended in various directions. Some of them are listed below:

- Little (or no) Literature is available for Online HCR system for Oriya and Gujarati scripts, the task of script identification can be explored.
- Extension of online handwriting recognition to the recognition of large or very large vocabularies.
- Spelling and semantic checks can be incorporated to correct error at stroke, character and word level.
- Widening of the domain from on-line handwriting recognition systems to the composition of on-line composite documents containing handwriting, graphics, drawings and symbols.
- Incremental learning can be incorporated so that a new stroke or character can be incorporated without the requirement of retraining the entire system.
- Development of bilingual and multi lingual online HCR.
- Ink management in documents, i.e. edition of documents by graphic gestures, annotation of documents.
- Idea of on-line construction and understanding of composite documents.
- Online Handwritten character recognition for Mobile devices.

Recently, interest has occurred concerning the biometric applications of online handwriting, namely for writer authentication and signature verification. Recognition of unconstrained handwriting with open-vocabulary is clearly the end objective of Online HCR research.

VII. Conclusion

In this paper work on Online HCR for Indian Scripts paper has been summarized. Majority of the research work reported for Indian languages either dealt with a subset of characters such as only the base characters or approaches based on limited vocabulary lexicon based recognizers. Although much research in the

field of HCR has been done, recognition algorithms still do not achieve 100% of the high recognitions. Many of the researchers do research for a short period of time as a part of their academic courses. As a result there is a great amount of redundancy in the work related to Indian script OHR. The above discussed approaches have their own applicability, but they are having limited domain.

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