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Marathi Numeral Recognition Using Statistical Distribution Features

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***Abstract* — Optical character recognition (OCR) is very old topic of research still needs much improvement. OCR system deals with the machines, so the new methodologies are to be found out to increase the overall performance of the character recognition system. This paper deals with the recognition of Devanagari (Marathi) numerals. After preprocessing the image and converting it to binary the statistical features for individual numeral can be calculated. Based on these features the numerals are classified into appropriate groups. In classification method using histogram feature matching, the numbers like three and six can be misclassified as they are having similar histogram. In the proposed system overall performance of classification can be improved if more number of features are compared. The system used in this paper is better as compared to simple histogram matching criteria.**

Keywords—Devanagari; Marathi; Decision tree; OCR; Numerals

I. INTRODUCTION

Optical Character recognition deals with the conversion of scanned character images into text which can be stored in the digital format, can be edited or can be converted into Audio or speech. OCR is the field of research which is having applications in various areas that aim in automation so that the human efforts can be reduced and error free work can be done like postal automation system [1], [2], bank automation system [3], form filling etc. and also the handwritten character recognition for Indian scripts [4]. In India there are multiple languages in different regions and the script the script is also different. The research started with off-line character recognition of printed characters, and then extended to the recognition of handwritten numbers and characters in many Indian scripts [5], [6], [7], [8] including Devanagari [9].

The main study about off-line handwriting recognition has been done by researchers [10], [11] most of in English, Chinese, Japanese, Latin and Arabic scripts. As the major Indian scripts have very large complexities, automatic handwriting recognition for these scripts have not yet been extensively studied. Although in recent decade researchers in India have shown some interest in off-line handwriting recognition for Indian scripts, a majority of them studied images of isolated handwritten characters such as in [12], [13], [14]. A very few studies are also done on offline handwritten Devanagari words include [15], [16], [17], [18].

Many of the systems have elaborated about variety of different techniques for text character segmentation but most of them are not proven reliable for the isolated character recognition. Zhong kang et al [19] have considered this problem as initial factor to propose their system. Their system uses rational B-spline representation of digit templates based on Pixel-to-Boundary Distance (PBD) maps then the neural network approach to extract B-spline PBD templates and also an evolutionary algorithm had been used to optimize these templates to resolve the unreliability. Off-line word-recognition system based on structural information in the unconstrained written word is invented by Buse [20]. Oriented features in the word are extracted with the Gabor filters. The two-dimensional fuzzy word classification system is introduced which had improved the word recognition accuracy.

In roman numeral system, the number system and the representation is very difficult for the larger numbers. The great mathematician from India, Aryabhata used the place-value system. This system was seen used in the 3rd-century within the Bakhshali Manuscript. The knowledge of zero was underlying Aryabhata's place-value system as a vicinity holder for the powers of ten with null coefficients. Aryabhata did not use the script numerals. It is not sure about whether Aryabhata was known zero or not. As the inventions by him contains square and cubic roots which may require the place value system and the zero also.

II. RELATED WORK

Adaptive approach for off-line handwritten character or word recognition invented by Park [21] in which it uses measurements of evaluation of the absolute confidence using shape features along with pattern confidence, and lexical confidence for recognition of the word. A Modular system to recognize the numerical strings is proposed by Oliveira et al [22] It uses a

segmentation-based recognition approach and a recognition and verification strategy. The approach combines the outputs from different levels such as segmentation, recognition, and post processing in a probabilistic model. Text retrieval from document images without the use of OCR is invented by Chew et al [23]. Documents are segmented into character objects. Image features, namely the vertical traverse density (VTD) and horizontal traverse density (HTD), are extracted. An n-gram-based document vector is constructed for each document based on these features. Text similarity between documents is then measured by calculating the dot product of the document vectors.

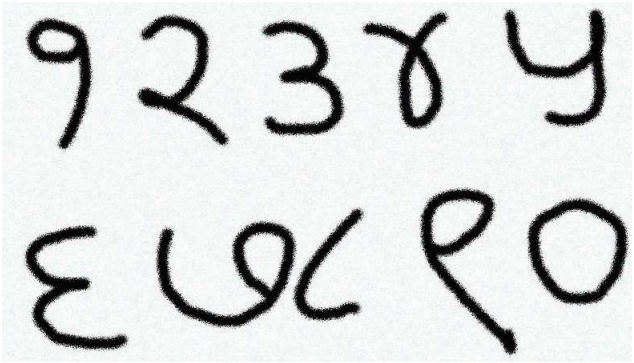

Fig. 1 Handwritten Marathi digit set showing 10 classes

Marathi numeral database is used in this paper. Marathi is very ancient language spoken mainly in Maharashtra and also the numeral representation of Marathi are quiet similar to that of Hindi language. There are ten different numerals representation in Marathi as shown in figure 1.

TABLE I. MARATHI NUMERALS REPRESENTATION FROM 0 THROUGH 9

Numeral	Marathi Number	Trans-literation	Numeral	Marathi Number	Trans-literation
०	शून्य	śūnya	५	पाच	Pāch
१	एक	ek	६	सहा	Saḥa
२	दोन	don	७	सात	sāt
३	तीन	tīn	८	आठ	āṭh
४	चार	chār	९	नऊ	nau

I. DATABASE CREATION AND USE

A database of approximate 6000 numerals were created by scanning different pages containing handwritten Devanagari Marathi numbers from zero to nine. The documents were scanned by Samsung Laser-jet Scanner using 600 dpi.

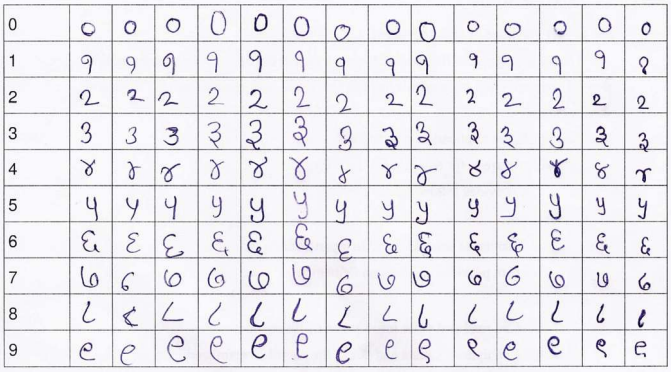

Fig. 2 Scanned Documents for database creation

Every scanned document contains nearly 560 handwritten Marathi digits. Thus in eleven scanned pages contain the numerals handwritten by different students of school. These scanned documents are then segmented after preprocessing using simple segmentation algorithm like horizontal projection and vertical projection method or by simple identifying the horizontal and vertical lines as every box has same length and width. After segmentation the separate single numerals are stored to obtain the features. Thus the computed feature values are used for classification of numerals in ten different classes.

II. REDUCED COMPUTING COMPLEXITY USING STATISTICAL BINARY PIXEL DISTRIBUTION FEATURES

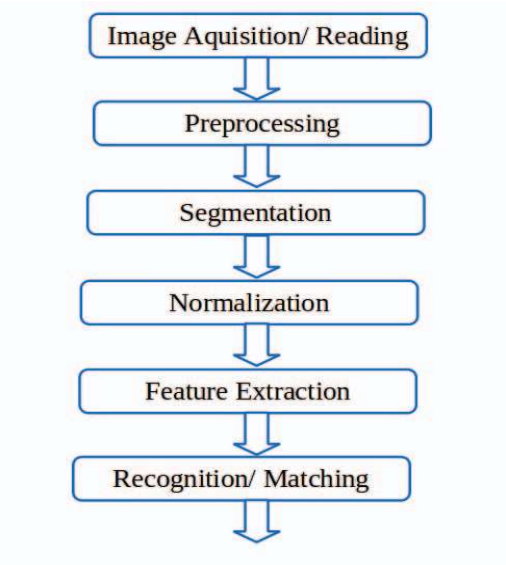

Fig. 3 Numeral Recognition system

In this paper the results of Marathi numeral classification based on horizontal, vertical projections and diagonal summation vectors in two directions are calculated and combined together to increase the performance of the system.

Using divide and conquer method, the best features or attributes can be selected in the training. Thus reducing the search time and the size of feature. First image is scanned or captured using any digital device connected to the machine. The captured image may have different format and the color scheme. The image is then preprocessed to make the image features easy and better understandable. The segmentation algorithms can be applied to catch only required part of interest from the whole image. The segmentation is followed by normalization to add uniformity in the extracted numerals.

A. Pre-processing

First, After acquiring the image from different sources, the image is to be preprocessed. In this step Noise reduction and Image enhancement algorithms are applied to get a good quality image. Also if the image is not in proper format or color scheme, it is to be converted to readable format. If the image is in any other color format like RGB or other, it is converted into the Gray scale format.

B. Segmentation

In Segmentation process the individual digits which make up a number are separated out. For typewritten, printed or neatly written numbers it is a straightforward task and need no extra modification as the size and orientation of the number is similar but while dealing with handwritten numbers, it can be quite difficult as every person is having different writing style. The main reason for this is that handwritten characters often overlap and, in some cases, may be disjointed. Also, the wide variations in handwriting styles make it very difficult to make generalizations for making segmentation heuristics. In this paper, the basic processes common to any system dedicated to handwritten numeral segmentation and the assumptions on which they are based is explored. Thus the numerals are segmented using fixed block size and cropping the image using crop function as the numbers are written in fixed size of boxes as shown in figure 2.

C. Normalization

After segmentation of Numerals, the size is to be calculated. If the size of segmented image vary the feature space also vary and the required results will not be obtained. To minimize the this problem of scaling the segmented characters/ numerals are resized to the standard size used in the training and testing phase. Thus any size numeral recognition is possible with minimum error. The size selected has greater impact on performance of the overall system. If the size is large the recognition error is reduced, but the time complexity will have adverse effect. Therefore 32 x 32 pixel size is selected to optimize the performance.

D. Feature Extraction

The traditional feature extraction method using histogram cannot be used on binary images as it uses only two different shades/colors, and the graph plotted will contain only two bars/spikes. A binary image of size m × n (where m, n ∈ N) is a rectangular array consisting of m rows and n columns, its elements are called pixels (or points or positions) which can take two possible values (black and white) can also be represented by a binary matrix of size m × n where the 1s/0s of the matrix stand for the black/white pixels, respectively [27]. Any binary image $\mathbb{I}$ can be partitioned into components $\mathbb{I}1$, $\mathbb{I}2, \ldots, \mathbb{I}k$ ($k \geq 1$) in a uniquely determined way.

Histogram of an image is a graphical representation of the distribution of pixel data in an image. It is an estimate of the probability distribution of a continuous variable introduced by Karl Pearson. Image Histogram gives a rough estimate about the density and distribution of the pixel data, and used mainly for density estimation of total pixels and estimating the probability density function PDF of the underlying variable [26]. The total area of a histogram used for probability density is always normalized to one (1). Using simple histogram features, the Marathi numerals like three and six can be misclassified as they are mirror image of each other having similarity in terms of no of pixel and their distribution.

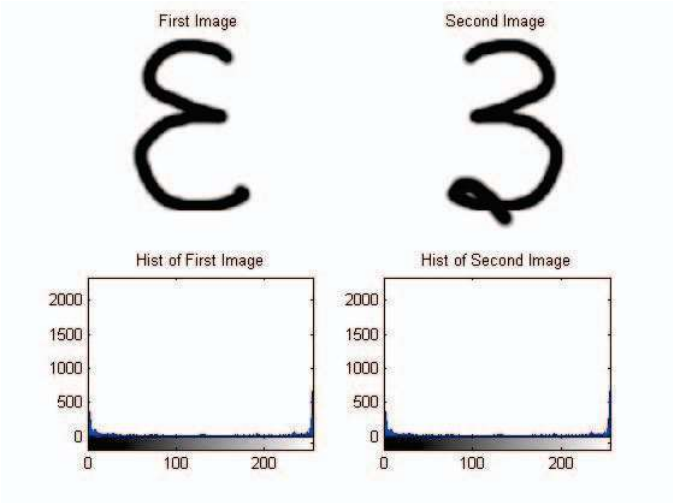

Fig. 4 Histogram Features of Marathi digits 3 and 6

To overcome this drawback of simple histogram, statistical features of pixels in horizontal, vertical and diagonal backslash and diagonal forward slash directions are calculated which will be used for further classification.

$$\mathbb{H}(j) = \text{Sum } i \text{ from 0 to n-1 on Image(n,n)} \quad (1)$$

$$\mathbb{V}(i) = \text{Sum } j \text{ from 0 to n-1 on Image(n,n)} \quad (2)$$

$$\mathbb{D}(i) = \text{Sum } i = 0 \text{ to n, } j = 0 \text{ to } i \text{ on Image(n,n)} \quad (3)$$

$\mathbb{D}'(j)$ = *Sum j = 0 to n, i= 0 to j on Image(n,n)* *(4)*

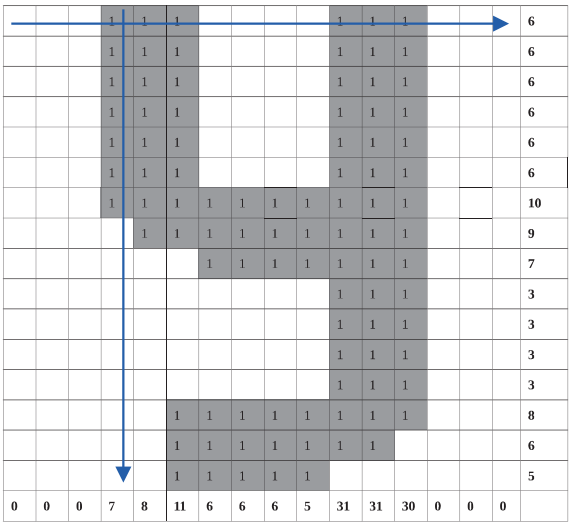

Fig. 5 Horizontal and Vertical summation features

If the horizontal $\mathbb{H}(i)$, vertical $\mathbb{V}(j)$, forward slash (\) diagonal $\mathbb{D}(i)$ and backward slash (/) diagonal $\mathbb{D}'(i)$ summation are considered separately for statistical feature manipulations, the computation complexity for calculations will be more.
Therefore the horizontal and vertical directions pixel summation values are combined together to form a single vector likewise forward slash diagonal and backward slash diagonal summation values are also combined together to for a single vector.

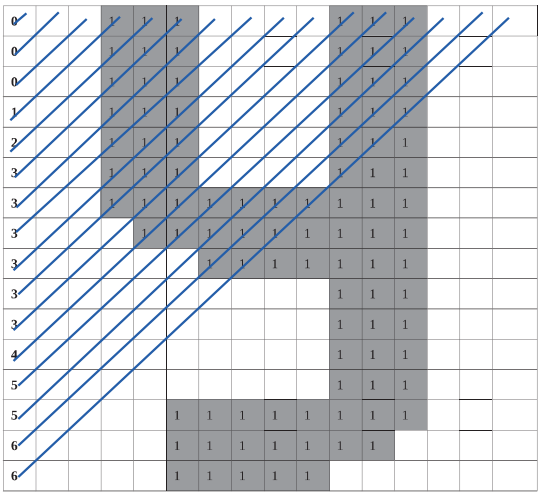

Fig. 6 Diagonal forward slash and backslash features

The statistical features of this concatenated vector are calculated like mean, median, skew, variance and sums of the absolute deviation from the mean and median for clustering and classification.

Mean can be calculated using simple equation

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{or} \quad \mu = \frac{\sum x}{N} \tag{5}$$

Median can be calculated using

$$median = L_1 + \left(\frac{n/2 - (\sum f)l}{f_{median}}\right)c \tag{6}$$

Standard deviation σ and variance σ^2 can be calculated using

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{n}(x_i - \mu)^2 = \frac{1}{N}\sum_{i=1}^{n} x_{i^2} - \mu^2 \tag{7}$$

Skew can be calculated using

$$Skew = \frac{(Mean - Median)}{\sigma} \tag{8}$$

E. Classification and Recognition

Use of Decision tree is possible to classify the Marathi Numerals. A decision tree is a tree structure, where each internal node (nonleaf node) denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (or terminal node) holds a class label and is represented in hierarchical levels. Rectangles are used to denote Internal nodes and ovals are used to denote leaf nodes. Some decision tree algorithms produce only binary trees (where each internal node branches to exactly two other nodes), whereas others can produce nonbinary trees, where each internal node branches to one or more nodes [28].

The attribute values of a given tuple, X, are tested against the decision tree for which the associated class label is unknown. Starting from the root node, a path is traced towards a leaf node, which holds the similar features or class prediction for that tuple. Decision trees can easily be converted to classification rules. As decision tree classifiers have very good accuracy they can be used for Marathi Numeral Recognition system.

Statistical data for all four vectors obtained from horizontal, vertical forward slash (\) diagonal and backward slash (/) diagonal summation is analyzed and the features are calculated by statistical measures like mean, median, skew, variance and sums of the absolute deviation from the mean and median. These features are used along with different conditions for generating or creating a decision tree. Minimum distance can be calculated by comparing the database features with the features of new pattern. Based on the leaf nodes of decision tree the numerals are classified. As multiple features are used for classification of ten different patterns, the decision tree may be formed using binary or multiary tree. Thus using decision

tree the numerals get classified using 12 different features calculated on the binary image.

III. Experimental Results

Experiments have been conducted on Marathi Devanagari Numerals scanned pages. The text pages contain different persons' handwritten numerals starting from zero up to nine. Then pages are scanned using Samsung SCX3401 LaserJet scanner, an example of the scanned page is shown in Fig. 2. From the scanned pages, numerals are segmented using projection profile method to obtain total 6000 numerals.

These numerals are divided into training and testing sets. The training set contains 50% of the data and testing set contains 50 % of scanned data samples. As the scanned data contains equal number of sample of each class, each set training and testing contains equal number of sample for each class.

By using training set of scanned samples, the decision tree is trained and then the testing set is used to evaluate the performance and accuracy of decision tree. The percentage of classification rate and misclassification rate is observed for the decision tree are shown in tabular format. The overall classification rates of 94.16% on test set are observed. If the scanned document is not having proper inclination the system performance and will degrade. Table – II given represents confusion matrix for recognition of Devanagari Marathi numerals. A confusion matrix is a simple methodology to display the classification results.

TABLE II. Confusion Matrix of the System on the Base of Marathi Numerals

०	१	२	३	४	५	६	७	८	९	Num	Accuracy
293	0	1	0	0	0	0	0	1	5	०	97.66
0	288	3	0	0	1	0	4	2	2	१	96.00
0	6	278	8	0	0	0	0	4	4	२	92.66
0	0	5	284	4	0	4	3	0	0	३	94.66
3	0	0	0	283	7	0	2	0	5	४	94.33
0	0	11	0	5	274	0	6	4	0	५	91.33
0	0	5	9	0	3	277	0	6	0	६	92.33
13	0	0	2	5	0	7	273	0	0	७	91.00
3	0	0	0	0	1	8	0	289	0	८	96.33
7	0	1	2	0	4	0	0	0	286	९	95.33
										Average	94.16

The confusion matrix is the combination of the desired classification and the predicted classifications results on the rows and the columns respectively. For each exemplar, a (one) 1 is added to the cell entry defined by (desired classification, predicted classification). For complete correct classification the predicted classification is to be the same as the desired classification, such that all the exemplars end up on the diagonal cells of the matrix (the diagonal connecting the lower right corner to the upper-left). Thus for 100% rate of classification, confusion matrix of size [M x M] should be a diagonal matrix with M output classes.

1.

IV. Comparison with Other DCR Systems

The results of various feature extraction methods are compared with the proposed method. The work done by different researchers in past is compared.

TABLE III. Comparison Results for Devanagari Numerals

Sr. No.	Work done by	Methodology	Accuracy
1.	S. K. Parui and B. Shaw[16]	Chain code based HMM	80.20
2.	N. Sharma, U. Pal[12]	Chain code Quadratic	80.36
3.	B. Shaw, S. K. Parui and M. Shridhar[18]	Segmentation based	84.31
4.	S. Arora, D. Bhatcharjee [29]	Two stage classification	89.12
5.	R.J. Ramteke, S.C. Mehrotra[30]	Moment based	92.28
6.	Hanmandlu and Ramana Murthy[31]	Fuzzy model based	92.65
7.	Proposed method	Statistical pixel distribution	94.16

Accuracy of the recognition system Using fuzzy model [31] the results of classification of Devanagari characters are better as compared to chain code HMM [16] or two stage classification [29]. it can be observed from the from Our proposed method is very simple for implementation and gives better results as compared to the previous methods.

V. Conclusion and Future Scope

In the proposed research work different features of numeral binary image are calculated and combined approach is implemented to decrease the time complexity of the algorithms used for feature extraction. The features that are having better gain ratio are used to develop a decision tree. In proposed method the number of attributes are reduced thus reduced comparisons which leads to faster processing. Using numeral sub-images the classification is performed in a hierarchical manner by partitioning the numerals into different classes. Experiments have been conducted on scanned pages containing Numeral for which an overall classification rate of 94.16% is observed.

In future work the classification rate also can be improved by applying other clustering or classification techniques like fuzzy neural network, genetic algorithm and artificial intelligence. Also other feature extraction methodologies can be applied for better accuracy. Better Segmentation methods can be employed as it plays very vital role in recognition process. The system can be extended to multi-oriented numeral recognition.

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REFERENCES

[1] K. Roy, S. Vaidya, U. Pal, B. B. Chaudhuri and A. Belaid, “A System for Indian Postal Automation”, *Proceeding 8th International Conference Document Analysis and Recognition, Seoul, Korea, Aug. 31-Sep. 1, 2005*, pp.1060-1064.

[2] U. Pal, R. K. Roy, K. Roy and F. Kimura, “Indian Multi Script Full Pin-code String Recognition for Postal Automation”, *Proceedings 10th International Conference Document Analysis and Recognition, Barcelona, Spain*, pp. 456-460, Jul. 26-29, 2009

[3] Lawrence D. Jackel, David Shaman and Charles E. Stenard, B. Ivan Strom and Derek Zuckert, “Optical Character Recognition for Self Service Banking”, *AT & T Technical Journal, July/August 1995.*

[4] U. Pal and B. B. Chaudhari, “Indian Script Character Recognition: a Survey”, *Elsevier Journal on Pattern Recognition, vol. 37*, pp. 1887-1899, 2004.

[5] Nibaran Das, Jagan Mohan Reddy, Ram Sarkar, Subhadip Basu, Mahantapas Kundu, Mita Nasipuri and Dipak Kumar Basu, “A statistical–topological feature combination for recognition of handwritten numerals”, *Elsevier Journal on Applied Soft Computing, vol. 12*, pp. 2486-2495, 2012.

[6] A. Pujari, C. Dhanunjaya Naidu, M. Sreenivasa Rao and B. C. Jinaga, “An Intelligent Character Recognizer for Telugu scripts using Multiresolution Analysis and Associative Memory”, *Image and Vision Computing, vol. 22*, pp. 1221-1227, 2004.

[7] Umapada Pal, Partha Pratim Roy, Nilamadhaba Tripathy and Josep Llados, “Multi-oriented Bangla and Devanagari text recognition”, *Elsevier Journal on Pattern Recognition, vol. 43,* pp. 4124-4136, 2010.

[8] H.L. Premaratne, E. Jarpe and J. Bigun and S. K. Parui, “Lexicon and hidden Markov model-based optimisation of the recognised Sinhala script”, *Elsevier Journal on Pattern Recognition Letters, vol. 27,* pp. 696-705, 2006.

[9] R. Jayadevan, S. R. Kolhe, P. M. Patil and U. Pal, “Offline Recognition of Devanagari Script: A Survey”, *IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews, vol. 41, no. 6*, pp. 782-796, Nov. 2011.

[10] N. Arica and F. Yarman-Vural, “An overview of character recognition focused on off-line handwriting”, *IEEE Transactions on Systems, Man, and Cybernetics – Part C: Applications and Reviews, 31(2),* pp. 216–232, 2001.

[11] R. Plamondon and S. N. Srihari, “On-line and off-line hand-writing recognition: a comprehensive survey”, *IEEE Transactions Pattern Analysis & Machine Intelligence, 22(1),* pp. 63–84, 2000.

[12] N. Sharma, U. Pal, F. Kimura, and S. Pal, “Recognition of off-line handwritten Devanagari characters using quadratic classifier”, *Proceedings of ICVGIP 2006. editor(s) P. K. Kalra, and S. Peleg, Lecture Notes in Computer Science, vol. 4338*, pp. 805–816, Springer, 2006.

[13] Ujjwal Bhattacharya and B.B. Chaudhuri, “Handwritten Numeral Databases of Indian Scripts and Multistage Recognition of Mixed Numerals”, *IEEE Transaction on Pattern recognition and Machine Intelligence, vol. 31, no. 3,* pp. 444– 457, 2009.

[14] U. Bhattacharya, M. Shridhar, S. K. Parui, P. K. Sen and B. B. Chaudhuri, “Offline recognition of handwritten Bangla characters: an efficient two-stage approach”, *Pattern Analysis and Applications, vol. 15, no.4,* pp 445–458, 2012.

[15] Utpal Garain and Bidyut B. Chaudhuri, “Segmentation of Touching Characters in Printed Devanagari and Bangla Scripts Using Fuzzy Multifactorial Analysis”, *IEEE transactions On Systems, Man, and Cybernetics—Part C Applications and Reviews vol. 32, no. 4,* pp. 449–459, 2002.

[16] S. K. Parui and B. Shaw, “Offline handwritten Devanagari word recognition: An HMM based approach”, *Proceedings of 2nd International Conference on Pattern Recognition and Machine Intelligence (PReMI), Kolkata, India, LNCS, 4815*, pp. 528–535, 2007.

[17] R.M. Suresh and S. Arumugam, “Fuzzy technique based recognition of handwritten characters”, *Elsevier Journal on Image Vision Computing, vol. 25*, pp. 230-241, 2007.

[18] B. Shaw, S. K. Parui and M. Shridhar, “Offline handwritten Devanagari word recognition: A segmentation based approach”, *Proceedings of International Conference on Pattern Recognition(ICPR), Tampa, Florida, USA*, pp. 1–4, 2008.

[19] Zhongkang Lu; Zheru Chi and Wan-Chi Siu, "Extraction and optimization of B-spline PBD templates for recognition of connected handwritten digit strings", *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.24, no.1*, pp.132-139, Jan 2002.

[20] Buse, R.; Zhi-Qiang Liu and Bezdek, J., "Word recognition using fuzzy logic", *IEEE Transactions on Fuzzy Systems, vol.10, no.1,* pp.65-76, Feb 2002.

[21] Park J., "An adaptive approach to offline handwritten word recognition", *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.24, no.7,* pp.920-931, Jul 2002.

[22] Young Oliveira, L.S.; Sabourin, R. and Bortolozzi, F.; Suen C.Y., "Automatic recognition of handwritten numerical strings: a recognition and verification strategy", *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.24, no.11*, pp. 1438- 1454, Nov 2002.

[23] Young Chew Lim Tan; Weihua Huang; Zhaohui Yu and Yi Xu, "Imaged document text retrieval without OCR", *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.24, no.6*, pp.838-844, Jun 2002.

[24] Young Cannon M.; Fugate, M.; Hush D.R. and Scovel C.; , "Selecting a restoration technique to minimize OCR error", *IEEE Transactions on Neural Networks, vol.14, no.3*, pp. 478- 490, May 2003.

[25] Young Shi, D.; Gunn, S.R. and Damper, R.I., "Handwritten Chinese radical recognition using nonlinear active shape models", *IEEE Transactions on Pattern Analysis and Machine Intelligence, vol.25, no.2*, pp. 277- 280, Feb 2003.

[26] Gonzalez and Woods, “*Digital* Image *Processing”, second Edition 2002.*

[27] S.W. Golomb, Polyominoes, Charles Scriber’s Sons, NewYork, 1965.

[28] Jiawei Han And Micheline Kamber, “Data Mining Concept and Techniques”, Copyright 2006, Second Edition.

[29] S. Arora, D. Bhatcharjee, M. Nasipuri, and L. Malik, “A two stage classification approach for handwritten Devanagari characters,” *Proceedings of International conference Computer Intelligence Multimedia Application,* pp. 399–403, 2007.

[30] R.J. Ramteke, S.C. Mehrotra, “Feature extraction based on moment invariants for handwriting recognition”, *Proceedings of International IEEE conference of Cybernetics Intelligent System (CIS2006), Bangkok*, pp. 1-6, June 2006.

[31] M. Hanmandalu, O.V.R. Murthy and V.K. Madasu, “Fuzzy model-based recognition of handwritten Hindi numerals”, *Pattern Recognition, vol. 40, no. 6*, pp. 1840-1854, 2006.

[32] R. Bajaj, L.Dey, and S. Chaudhuri, "Devanagari numeral recognition by combining Decision of multiple connectionist classifiers", Sadhana, vol. 27, no. 1, pp. 59-72, 2002.