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Handwritten Text Recognition System Based on Neural Network

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Abstract
Handwritten text recognition is still an open research issue in the domain of Optical Character Recognition (OCR). This paper proposes an efficient approach towards the development of handwritten text recognition systems. 3-layer Artificial Neural Network (ANN) is utilized in this Paper using supervised learning approach. The choice of optimal feature vectors greatly the accuracy of any text recognition system therefore bit map representation of input samples are utilized as feature vector. The feature vectors are first pre-processed and then applied to the ANN along with the generated target vectors; that are generated on the basis on input samples. 55 samples of each English alphabet are used as a ANN training process in order to make sure the general applicability of system towards new inputs. Two different learning algorithms are utilized in this paper. Additive image processing algorithms are also developed in order to deal with the multiple characters input in a single image, tilt image and rotated image. The trained system provides an average accuracy of more than 95 % with the unseen test image.

Keywords
OCR, Image Processing, Handwritten Text Recognition, Artificial Neural Network, English Alphabet Recognition, Supervised Learning

I. Introduction

Intelligence of humans makes them different from computers. The human can do various tasks that are still impossible for machine to do by their own. One of such tasks is handwritten text recognition. Even though, Text recognition in the handwritten documents has been studied as one of the prominent research areas by different researchers during the last few decades [1] and because of that many automatic handwritten systems are developed by different researchers in past [2-12]. However, the recognition algorithm and its efficiency is still an open research issue. Due to the vast inconsistency in handwriting styles, frequently the state-of-the-art handwriting recognition systems gets fail to provide satisfactory performance on various types of handwriting samples.

Available approaches to handwriting recognition usually consist of various steps which mainly include 1.preprocessing, 2.feature extraction, 3.classification, 4. post processing. However, feature extraction and classifier design are the two major steps of any recognition system [3, 5]. Many researchers made different type of handwritten text recognition systems for different languages such as English [4, 8, 10], Chinese [11], Arabic [9], Japanese [12] Bangla [6], Malyalam [7] etc. Still the recognition problems of these scripts cannot be considered to be entirely solved.

ANN can be proved to a life savior in the development of an efficient and accurate handwritten text recognition system. One of the principal means by which computers are skilled with humanlike aptitudes is through the utilization of ANN in the design. Neural networks work on the design of human brain and they are particularly very useful for solving such problems that cannot be stated as a series of simple steps, such as patterns recognition, classification of objects into different classes, data mining and series prediction.

The most common use of neural networks is perhaps pattern recognition. The neural network is presented with a different class of target vectors and also with the respective input vectors (a vector which contains the pattern information). The input can be ranges from simple one dimension (1-D) data to multiple dimensional data. Once the ANN get trained with the help of train data (just like human brain), it can be used to determine the patterns/class in the unseen data (new inputs) [27-33].

The main objective of this study is to develop an efficient handwritten character and numbers recognition system for English characters based on ANN. The handwritten characters may contain mix case (capital and small letters) of English characters so 52 classes (26 for capital and 26 for small) are included in this study for the classification. The reader should note that the recognition of their English symbols is out of our study. The Neural network provides a pretty decent average accuracy of more than 95%. Two different learning mechanisms (Resilient Back-propagation, and Scaled conjugate gradient) are tested in order to train the ANN. Rest of the paper is organized as follows: Section 2 presents the literature review in the domain of handwritten text recognition. Section 3 presents the proposed framework in detail. Section 4 is dedicated to the discussions on the results obtained in the proposed work. Section 5 provides the final remarks on the present study along with the suggestions of future work that can be addressed in this field.

II. Related work

Since a very long time, human used to write their thoughts in the form of letter, transcripts etc.; in order to convey them to others. But since the development of computer technology the format of handwritten text changed rapidly to computer generated digital text and so people feel a need of such method that can transform the handwritten text to digital text as it makes the processing of such data very fast and easy.

Many researches tried to develop such system in past. Though, there is still a need of much more research in this field. Many recognition studies have been made for offline and online handwritten characters of major languages used worldwide: like English, Chinese, Indian scripts such as Devanagari, Malayalam and Bangla [2-12] but they all suffer with some sort of drawback: like low conversion speed, low accuracy, higher false detection rate and poor performance with noisy input etc. Thus, recognition studies of handwritten character image samples still remain relevant because of their enormous application potentials.

A comparative performance study of several classifiers on handwritten digit recognition can be found in Liu et al. [4]. Features providing the state-of the- art accuracies in handwritten character recognition tasks are gradient, curvature [13] features. In a few character recognition studies, Gabor transform [14] and

statistical/structural features [15] have also been successfully used. In a recent study [16] on handwritten Devanagari and Bangla character recognition, the wavelet transforms of input character image were subjected to three layer approach.

Rajib et al. [17] proposed a handwritten English character recognition system based on the Hidden Markov Model (HMM). This method made use of two different feature extractions namely global and local feature extraction. Global feature includes many features like gradient features, projection features and curvature features in the numbers of four, six and four respectively. Whereas local features are calculated by dividing the sample image into nine equal blocks. Gradient feature of each block is calculated using four feature vector, which makes the total number of local features as 36. This resulted into fifty features (local + global) for each sample image. Then, these features are fed into HMM model in order to train it. Data post processing is also utilized by this method in order to decrease the cross classification of different classes. This method takes a lot of time in training and feature extraction. Moreover, it performs poor in case of such inputs, when many characters are combined in a single image.

Velappa Ganapathy et al. [18] proposed a recognition method based on the multi scale neural network training. In order to improve the accuracy, this method used selective threshold, which is calculated based on minimum distance technique. This method also involves the development of GUI, which can find out the character throughout the scanned image. This method provides an accuracy of 85% with moderate level of training. This method used large resolution images (20 × 28 pixels) for training with lesser training time.

T. Som et al. [19] used fuzzy membership function to improve the accuracy of hand written text recognition system. In this method, text images are normalized to 20 × 10 pixels and then fuzzy approach is used to each class. Bonding box is created around the character in order to determine the vertical and horizontal projection of the text. Once the image is cropped to a bounding box, it is re-scaled to the size of 10×10 pixels. Then, cropped images are thinned by the help of thinning operation. In order to create the test matrix, all these pre-processed images are placed into a single matrix; one after another. When new (test) images are presented by the user, it is tested for the matching against the test matrix. The method was fast but it provides a low accuracy.

Rakesh kumar et al [20] proposed a method in order to reduce the training time of system by utilizing a single layer neural network. Segmented characters are scaled to 80 X 80 pixels. Data normalization is performed on the input matrices to improve the training performance. But their result has a low accuracy rate.

Other notable work proposed by Zamora includes feature extraction using the diagonal method [21], an improved version of this work [22]. The others used zone based hybrid feature extraction from the text. Doing so, led to improvement in speed and accuracy. By using Euler number approach, speed and accuracy are improved. Many preprocessing like Thresholding, thinning and filtering operations are performed on the input image so that cross error rate can be minimized. Three techniques are utilized for better segmentation. After segmentation, the input image is resized to the size of 90 X 60 pixels. Then after, Euler number is calculated for each text and then they are divided into 54 zones, such that each contains 10×10 pixels. The average value of each zone (row and column wise) is used as the feature vector of the character. These features are fed in to a feed forward back propagation neural network (FF-BP-NN), which have a configuration of 69-100-100-26. This system classified the data into 26 different English letters. This method performs well but it did not include includes the classification of small English letters.

Anshul Mehta at el [23] proposed their work based on the heuristic segmentation algorithm. Their system performs identification of valid segmentation points between handwritten letters quite well. Fourier descriptors are used in this approach for feature extraction. After a successful segmentation, Discrete Fourier Coefficients are calculated (a[k] and b[k]) for the input image. Here k varies from zero to (L-1) and L represents the boundary points of input image. This method tried to provide classification of total 52 characters (26 upper case English letters and 26 lower case English letters). It also provides a comparative analysis of different classification methods. The method also incorporates post processing in order to reduce the error rate but it suffers with a low accuracy and high cross classification rate; because of the non-optimal choice of features.

Serrano et al. [24] proposed a novel interactive approach for handwritten character recognition. The system requires human suggestion for only those inputs for which the system gets confuse. Although It keep the accuracy to high level, it increases the human lead. The only problem was that the system was not fully automatic and requires human intervention for operation.

Amma et al. [25] proposed a wearable input system such that one can change the texts that are drawn in the sir itself. It was a 3D integration method for handwriting recognition. The handwriting gestures were caught wirelessly by the help of motion sensors, accelerometers and gyroscopes, which are placed strategically to the back of the human hand. The proposal was good but it was unable to perform the same for already written data.

In this paper, a bit map version of input image sample is used as feature vector. The optimal feature vector selection is an integral part of any recognition system. The aim of proposed feature extraction algorithm is to help in classification of the pattern correctly by means of minimum number of features that are effective in discriminating pattern classes. The bit map version contains all the major information of parent image in a small neighborhood. The proposed also involves the study of the change come in the system due to different learning mechanisms. it also shows the effect of different parameter use like number of hidden layer, size of hidden layer and epochs etc. The Preprocessing of proposed method involves thee like noise removal, segmentation of characters, normalization and De-skewing. In this work an effort is made towards recognition of English characters with on accuracy up to 95%. Due to its logical simplicity, ease of use and high recognition rate, proposed system may turn out to be very useful for practical use.

III. The Proposed System

The purpose of this study is the development of system that takes handwritten English characters as input, process the input, extract the optimal features, train the neural network using either Resilient Back-propagation or Scaled conjugate gradient, recognize the class of input text, and finally generate the computerized form of input text. The complete system is divided into two major sections: Training of ANN with image database and testing of ANN with test images. Figure 1 is showing the block diagram of training part of ANN and Figure 2 is showing the block diagram of testing part of ANN.

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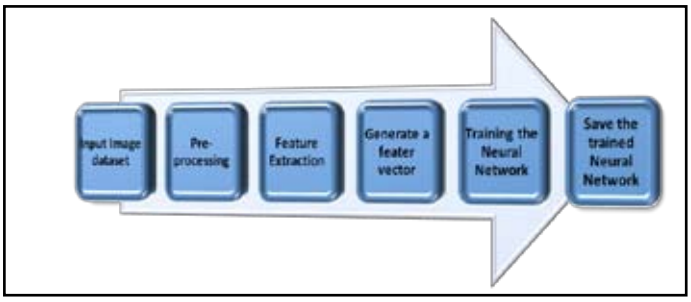


Fig. 1: Block diagram of training part of ANN

The training part of proposed work involves: creation of dataset, preprocessing of that dataset, feature extraction from pre-processed dataset, generation of a feature vector and test vector, training of ANN and saving of trained ANN for testing purpose.

The testing part involves some extra pre-processing steps as here we need to figure out the number of characters in the input image but it does not includes any training of ANN. On the contrary, it uses trained ANN directly after the feature vector generation. The segmentation is an important step of test procedure as it helps to figure out number of characters.

The detailed explanation and working of each block involved in training and testing procedure is shown in figure (1) and figure (2) respectively :

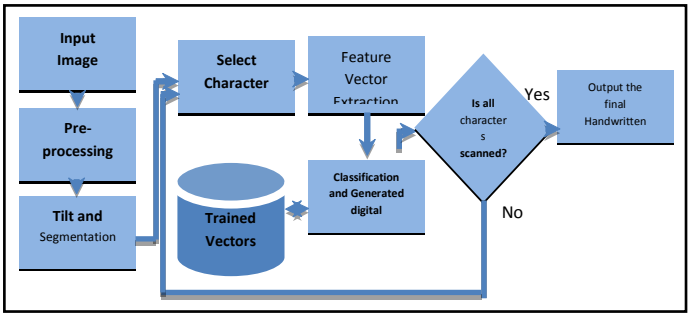


Fig. 2: Block diagram of testing part of ANN

A. Pre-processing

A series of operations are performed on the input image (In testing as well as training stage) during the pre-processing. It helps in enhancing the image rendering and makes the image suitable for segmentation. The main objective of pre-processing is to remove the background noise, enhance the region of interest in image and make a clear difference between foreground and background. In order to achieve these goals: noise filtering, conversion to binary and smoothing operations are performed on the input image. Figure 3 is showing an example of image normalization.

(a)

(b)

Fig. 3: (a) Tilt input image and (b) Image after preprocessing is performed

The pre-processing also involves a compressed representation of the input image. The edge detection is also performed in order to select the region of interest. The conversion to binary insures a very good difference between foreground and background. Dilation of edges is also performed in the pre-processing step itself.

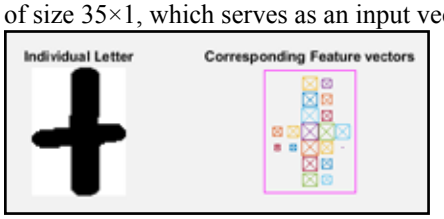
B. Segmentation

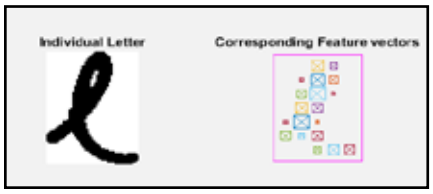
Segmentation of image is done in the testing stage only. In this, a complete image is decomposed into a sequence of text/sub-images of individual text. The segmentation is done on the basis of edge detection and gap between the different characters. After segmentation, the sub-divided parts are labeled and then processed further one by one. This labeling is done in order to find out the number of characters in the entire image. Each sub image is then resized (70×50) and normalized with respect to itself. This helps in extracting the quality features from the image. The scanned image is identified for valid segmentation points by the help of minima or arcs locations in between the characters, which is very easy to find in handwritten texts. The segmentation points are also checked for any error point inclusion by checking all points against the average distance between two segmentation points in complete image (will be shown later).

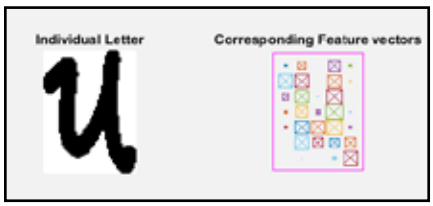
C. Feature Extraction

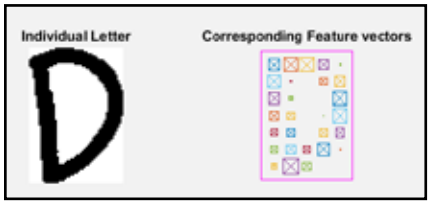
The feature vector is calculated by converting the pre-processed image into bit mapped version of size 7×5. Figure 4 show few examples of the bit map version of different characters utilized in the proposed system. The bit map version preserve the major features of input image in shorter space/ data length. Such that reduces the time elapsed in NN Training without affecting the accuracy of correct character recognition.

After that, The bit map images are converted into a single vector of size 35×1, which serves as an input vector to the ANN.









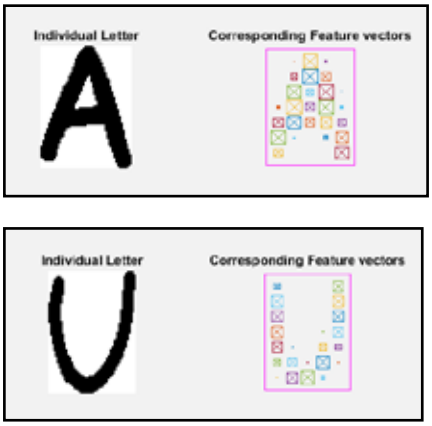


Fig. 4: examples of the bit map version for different characters

D. Learning Algorithms

Two different learning Algorithms are utilized in this Research study.

1. Resilient Back-propagation

Resilient back-propagation, is a learning Algorithms for supervised learning methodology of feed forward ANN it was proposed by Martin Riedmiller and Heinrich Braun in 1992 [26]. Likewise the Manhattan update learning rule, Resilient back-propagation considers the sign of partial derivative irrespective of the magnitude and it works on each weight independently. This rule updates each weight by a factor of η− or η+ depending of the sign change of the partial derivative. Here η represents the update factor. A detail description of Resilient Back-propagation can be found in [26].

2. Scaled conjugate gradient

Scaled Conjugate Gradient (SCG) is a supervised learning algorithm of second order. It based on the principal of gradient decent algorithm, which is a very old guided search method. The advantage of SCG lies in the facts that it needn't user defined parameter for ANN while training. The step size gets adjusted with each epoch automatically, which results into faster convergence and better accuracy. A detailed description of Scaled Conjugate Gradient can be found in [27].

3. ANN Train and Test

The training of ANN involves specifying the hidden layers and choice of learning algorithm. The input vector and target vector are also normalized in the range of [-1 to 1], so that the training can be done efficiently. During training, gradient is set as e-10 and maximum number of iteration as 1000. 55 samples of each character are used for creating of training dataset.

Now, New test images are created in order to check the validity of our designed system. figure (6) show a sample of handwritten document.

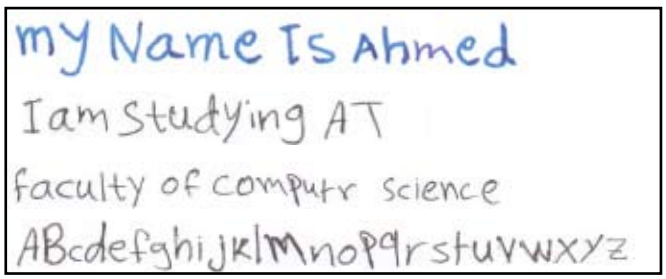


Fig. (6): samples of handwritten documents

IV. Results

The Handwritten Character Recognition system was tested on several different scanned handwritten images is proposed with different styles. The results were highly encouraging. The proposed system performs pre-processing on the image in order to remove the noise. Feature extraction is performed from the bit map image representation, which gives pretty decent classification of around 95%. The proposed system is advantageous as it uses fewer features to train the neural network, which results into faster convergence (less time for training). The advantage also lies in less computation involved in feature extraction, training and testing. The Feature comparison chart of proposed system with earlier systems is shown in table (1).

Table (1): Feature comparison of proposed system with other systems

Description	Training Time	Accuracy	English Character (Capital / Small)	Performance (can extract many characters in single image?)	Can Perform Tilt?	Automatic Extraction	Treat with symbols
Velappa et al. [18]	Low	Medium	Only Capital	Able to extract	No	Yes	Yes
Rajib et al. [17]	High	High	Only Capital	Unable to extract	No	Yes	Yes
Rakesh et al. [20]	Medium	Medium	Only Capital	Unable to extract	No	Yes	Yes
Anshul et al. [23]	Low	High	Both	Unable to extract	Yes	Yes	No
Serrano et al. [24]	Medium	High	Only Capital	Unable to extract	Yes	No	Yes
Proposed	Medium	High	Capital and Small both	Able to extract	Yes	Yes	No

The proposed system given good results for images that contain handwritten text written in different styles, different size and alignment with varying background. It classifies most of the handwritten characters correctly even if the image contains noise in ether characters or background.

It shows that our system is really good in compression with other systems Except in treating with symbols .

It is quite evident from the table (2) and table (3) that the Scaled conjugate gradient learning algorithm out performs the Resilient Back-propagation algorithm in terms of both accuracy as well as training time. Table (2) and (3) also show that the more hidden layers are, the more training time because the involved weights (weights to be trained) also increased along with the hidden layers. The accuracy increases along with the hidden layer, But after some time it again starts decreasing. This happen because of the over saturation of available weights that needs to be trained with limited constraints. The process of choosing the number of hidden layers is always a heuristic problem. But most of research papers always user double the number of input layers. this situation is similar to mathematics problem where more than 'n' equations are available to figure out 'n' variables. These results into over training and it degrades the performance of the system. It is quite clear from table (2) and (3) that '80' is the optimal hidden layer that should be used in proposed system.

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Table (2): Resilient Back-propagation Results

Configuration of ANN (input-hidden-output) layers	Accuracy (%)	Training Time (second)
35-10-52	64.44	69.33
35-20-52	66.54	75.76
35-30-52	69.43	85.43
35-40-52	73.76	98.87
35-50-52	77.32	109.43
35-60-52	83.65	117.65
35-70-52	87.35	139.34
35-80-52	93.54	151.54
35-90-52	91.11	169.85
35-100-52	88.32	187.76
35-110-52	85.43	195.42

Table (3): Scaled conjugate gradient Results

Configuration of ANN (input-hidden-output) layers	Accuracy (%)	Training Time (second)
35-10-52	65.36	65.33
35-20-52	67.32	72.34
35-30-52	70.34	82.44
35-40-52	74.36	94.27
35-50-52	79.34	101.37
35-60-52	86.36	110.33
35-70-52	90.63	130.32
35-80-52	95.62	142.77
35-90-52	92.44	159.34
35-100-52	89.13	178.33
35-110-52	87.36	189.34

V. Conclusion

A proposed handwritten character recognition system has been designed and tested. A comparison with related work has been presented. ANNs have been trained for this purpose with various types of input samples and that's why the developed program has an ability to test and classify the input character into 52 different classes with an accuracy of more than 95%. Two different learning algorithms have been used. Scaled Conjugate Gradient algorithm has been turned out to be better learning algorithm than the Resilient Back-propagation algorithm in terms of accuracy and training time, while using the same configuration. In future work, hybrid feature extraction methods will be developed in order to enhance the accuracy. Also better classification methods will be investigated in order to minimize the miss classified image. Finally, the proposed work will be extended to identify the Arabic language.

References

[1] *N. Arica and F. Yarman-Vural, An Overview of Character Recognition Focused on Off-Line Handwriting, IEEE Trans. Systems, Man, and Cybernetics Part C: Applications and Rev., vol. 31, pp. 216-233, 2001.*

[2] *A . Amin and H. B. Al-Sadoun, Hand Printed Arabic Character Recognition System, Proc. of 12th Int. Conf. Pattern Recognition, pp. 536-539, 1994.*

[3] *R. Plamondon and S. N. Srihari, On-Line and Off-Line Handwriting Recognition: A Comprehensive Survey, IEEE Trans. Pattern Analysis and Machine Intelligence, vo1.22, pp.63-84, 2000.*

[4] *H. Liu and X. Ding, Handwritten Character Recognition using Gradient Feature and Quadratic Classifier with Multiple Discrimination Schemes, Proc. 8th Int. Conf. on Document Analysis and Recognition, pp. 19-25, 2005*

[5] *Pratap, Neeraj, and Dr Shwetank Arya. "A Review of Devnagari Character Recognition from Past to Future". International Journal of Computer Science and Telecommunications 3, no. 6 (2012): 77-82.*

[6] *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, vo1. l5(4), pp.445-458, 2012.*

[7] *John, Jomy, and Kannan Balakrishnan. "A system for offline recognition of handwritten characters in Malayalam script." International Journal of Image, Graphics and Signal Processing (IJIGSP) 5, no. 4 (2013): 53.*

[8] *Fischer, Andreas, Ching Y. Suen, Volkmar Frinken, Kaspar Riesen, and Horst Bunke. "A fast matching algorithm for graph-based handwriting recognition." In Graph-Based Representations in Pattern Recognition, pp. 194-203. Springer Berlin Heidelberg, 2013.*

[9] *Parvez, Mohammad Tanvir, and Sabri A. Mahmoud. "Arabic handwriting recognition using structural and syntactic pattern attributes." Pattern Recognition 46, no. 1 (2013): 141-154.*

[10] *Zamora-Martínez, Francisco, Volkmar Frinken, Salvador España-Boquera, Maria Jose Castro-Bleda, Andreas Fischer, and Horst Bunke. "Neural network language models for off-line handwriting recognition." Pattern Recognition 47, no. 4 (2014): 1642-1652.*

[11] *Tao, Dapeng, Lingyu Liang, Lianwen Jin, and Yan Gao. "Similar handwritten Chinese character recognition by kernel discriminative locality alignment."Pattern Recognition Letters 35 (2014): 186-194.*

[12] *Das, Soumendu, and Sreeparna Banerjee. "An Algorithm for Japanese Character Recognition." International Journal of Image, Graphics and Signal Processing (IJIGSP) 7, no. 1 (2014): 9.*

[13] *M. Shi, Y. Fujisawa, T. Wakabayashi, and F. Kimura, Handwritten Numeral Recognition Using Gradient and Curvature of Gray Scale Image, Pattern Recognition, vol. 35(10), pp. 2051-2059, 2002.*

[14] *Singh, Sukhpreet, Ashutosh Aggarwal, and Renu Dhir. "Use of Gabor Filters for recognition of Handwritten Gurmukhi character." International Journal of Advanced Research in Computer Science and Software Engineering 2, no. 5 (2012).*

[15] *Wu X-Q, Wang K-Q, Zhang D (2005) Wavelet energy feature extraction and matching for palmprint recognition. J Comput Sci Technol 20(3):411–418*

[16] *Bhattacharya, U. and B. B. Chaudhuri, Handwritten Numeral Databases of Indian Scripts and Multistage Recognition of Mixed Numerals, IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 31(3), pp. 444- 457, 2009.*

[17] *Rajib Lochan Das, Binod Kumar Prasad, Goutam Sanyal, "HMM based Offline Handwritten Writer Independent English Character Recognition using Global and Local*

Feature Extraction", International Journal of Computer Applications (0975 – 8887), Volume 46– No.10, pp. 45-50, May 2012.

[18] Velappa Ganapathy, Kok Leong Liew, "Handwritten Character Recognition Using Multiscale Neural Network Training Technique", World Academy of Science, Engineering and Technology, pp. 32-37, 2008.

[19] T.Som, Sumit Saha, "Handwritten Character Recognition Using Fuzzy Membership Function", International Journal of Emerging Technologies in Sciences and Engineering, Vol.5, No.2, pp. 11-15, Dec 2011.

[20] Rakesh Kumar Mandal, N R Manna, "Hand Written English Character Recognition using Row- wise Segmentation Technique", International Symposium on Devices MEMS, Intelligent Systems & Communication, pp. 5-9, 2011.

[21] J Pradeep, E Shrinivasan and S.Himavathi, "Diagonal Based Feature Extraction for Handwritten Alphabets Recognition System Using Neural Network", International Journal of Computer Science & Information Technology (IJCSIT), vol. 3, No 1, Feb 2011.

[22] Om Prakash Sharma, M. K. Ghose, Krishna Bikram Shah, "An Improved Zone Based Hybrid Feature Extraction Model for Handwritten Alphabets Recognition Using Euler Number", International Journal of Soft Computing and Engineering (ISSN: 2231 - 2307), Vol. 2, Issue 2, pp. 504-508, May 2012.

[23] Anshul Mehta, Manisha Srivastava, Chitralekha Mahanta "Offline handwritten character recognition using neural network" IEEE 2011 International conference on computer applications and Industrial Electronics.

[24] Serrano, Nicolás, Adrià Giménez, Jorge Civera, Alberto Sanchis, and Alfons Juan. "Interactive handwriting recognition with limited user effort."International Journal on Document Analysis and Recognition (IJDAR) 17, no. 1 (2014): 47-59.

[24] Amma, Christoph, Marcus Georgi, and Tanja Schultz. "Airwriting: a wearable handwriting recognition system." Personal and ubiquitous computing 18, no. 1 (2014): 191-203.

[25] Martin Riedmiller und Heinrich Braun: Rprop - A Fast Adaptive Learning Algorithm. Proceedings of the International Symposium on Computer and Information Science VII, 1992

[26] Møller, Martin Fodslette. "A scaled conjugate gradient algorithm for fast supervised learning." Neural networks 6.4 (1993): 525-533.

[27] Hazem M. El-Bakry, "A New High Speed Neural Model For Character Recognition Using Cross Correlation and Matrix Decomposition," International Journal of Signal Processing, vol.2, no.3, 2005, pp. 183-202.

[28] Hazem M. El-Bakry, "A Novel High Speed Neural Model for Fast Pattern Recognition," Soft Computing Journal, vol. 14, no. 6, 2010, pp. 647-666.

[29] Hazem M. El-Bakry, "An Efficient Algorithm for Pattern Detection using Combined Classifiers and Data Fusion," Information Fusion Journal, vol. 11, issue 2, April 2010, pp. 133-148.

[30] Hazem M. El-Bakry, "A New Neural Design for Faster Pattern Detection Using Cross Correlation and Matrix Decomposition," Neural Network World journal, 2009, vol. 19, no. 2, pp. 131-164.

[31] Hazem M. El-Bakry, and Nikos Mastorakis "New Fast Normalized Neural Networks for Pattern Detection," Image and Vision Computing Journal, vol. 25, issue 11, 2007, pp. 1767-1784.

[32] Hazem M. El-Bakry, "New Fast Time Delay Neural Networks Using Cross Correlation Performed in the Frequency Domain," Neurocomputing Journal, vol. 69, October 2006, pp. 2360-2363.

[33] Hazem M. El-Bakry, and Qiangfu Zhao, "Fast Normalized Neural Processors For Pattern Detection Based on Cross Correlation Implemented in the Frequency Domain," Journal of Research and Practice in Information Technology, Vol. 38, No.2, May 2006, pp. 151-170.