Automatic Recognition of Handwritten Bangla Courtesy Amount on Bank Checks

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Summary
In spite of rapid evolution of electronic techniques, a number of large-scale applications continue to rely on the use of paper as the dominant medium. This is especially true for processing of bank checks. This paper presents a recognition system of handwritten Bangla courtesy amount on a bank check. The system uses the scanned image of a blank check to read the amount written by the user. There are four main stages in the systems that focus on: the detection of courtesy amount block within the image; the segmentation of string into characters; the recognition of isolated characters; and the post-processing process that ensures correct recognition. The detection of courtesy amounts is performed using image-cropping methods. The segmentation of the courtesy amount is the most difficult part of the process because of the largely unconstrained nature of handwritten amounts on checks. The segmentation module has been implemented as a recursive process that interacts with the recognition module. The recognition of the isolated characters is based on neural a network that has been demonstrated to be very accurate and computationally efficient. A Backpropagation learning algorithm is used to train up the network. The performance of the system is tested in different sorts of numeral and the experimental result shows satisfactory performance.

Key words:
Bank Check. Courtesy Amount, Segmentation, Neural Network Recognition

1. Introduction

Automatic bank check processing is a field of interest in banking industry, as a large part of checks is still processed manually that involves the manual reading of the checks and keying their respective values into the computer. As huge numbers of bank checks are processed daily, this manual procedure involves high cost due to its labor-consuming operation. In Bangladesh, most of the information in bank check is written in Bangla language. Handwritten Bangla text in the bank check is an important obstacle towards the automation of the bank check processing. So, we are interested to recognize Bangla handwritten text from bank check.

The widespread use of bank checks in daily life makes the development of check-reading systems of fundamental relevance to banks and other financial institutions. Bank transactions involving checks are still increasing throughout the world in spite of the overall rapid emergence of electronic payments by credit cards. The information contained in a bank check is frequently handwritten in Bangladesh. Extraction of this information involves detection, localization, tracking, enhancement, and recognition of the text from a given image of bank check. However, variations of text due to differences in size, style, orientation, and alignment, as well as low image contrast and complex background make the problem of automatic text extraction extremely challenging task. Accordingly, the field of automatic check processing has witnessed sustained interest for a long time.

Moreover the Bank managements are interested in reducing the workload of the employees manually reading the paper check. Since employees also make mistakes reading or typing the amount of the checks, a single manual read rarely drives the whole process. A system that is able to read check automatically would be very helpful, especially if it is fast and accurate. Even if misclassification occurs, the mistake could be detected potentially during the recognition process; however it is more desirable that the system rejects a check in case of doubt so that it can be directed to manual processing from the beginning. All these factors motivated us to carry out an experiment for automatic recognition of handwritten courtesy amount on bank checks.

The recognition of machine-printed documents has been a very successful application [1, 2]. In contrast, it is more difficult for computer systems to read handwritten texts and numbers. In the processing of handwritten fields, computer systems are generally slower and yield less accurate results than humans [3, 7].

Recognition of the courtesy amount field is one of the most challenging tasks for the automatic bank check reading process. The difficulty is due to some factors like: great variability in handwriting styles, handwriting devices, a lack of patterns and symbols used by writers to prevent fraud. In some cases, the courtesy amount field may also exhibit noise, irregularities in the boundary of the components and part of the digits from other check fields.

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Thus, the major problem faced by the most of the automatic recognition systems is their limited accuracy due to the high level of variability with which they have to manage.

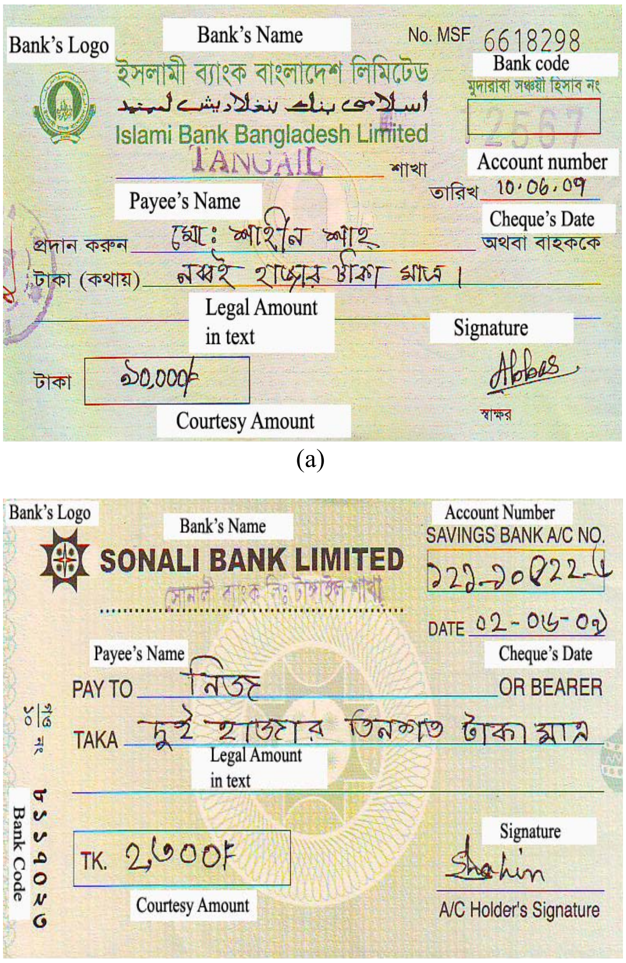
Segmentation of the courtesy amount into individual digits is the most critical task in check processing [6]. This includes the separation of touching characters and the merging of character fragments with other pieces. The segmentation of connected numbers is the main bottleneck in the handwritten numeral recognition system [8]. In case of Bangla, character segmentation is difficult because of some reasons: (i) there are about 300 basic, modified and compound character shapes in the script, (ii) characters are topologically connected in a word and (iii) Bangla is an inflectional language. Also, for the inflectional nature of this language, it is difficult to design a simple OCR error-correction module. Thus, Bangla OCR development is more difficult than that of any European language script.

There are studies in the literature on locating the courtesy amount block on bank checks [3, 9, 10] and segmentation of unconstrained handwritten connected numerals [11-15]. Several researches have been carried out in the field of Bangla character recognition system [16-21]. However, there are no precise methods to recognize handwritten Bangla text from bank check. For this reason, we attempt to make a system for Bangladeshi banks to make their daily management flexible and faster through automated recognition of handwritten courtesy amount on bank checks.

The structure of the paper is approximately as follows: Section 2 describes the problems to be solved. Section 3 discusses about the proposed system. Implementation of the proposed system and discussion of the result obtained is discussed in section 4. We finish by drawing some broad and necessarily speculative and personal conclusions about the proposed system with our future goal to extend the proposed system in section 5.

2. Problem Descriptions

A bank check image is formed by a set of fields which may be handwritten or printed. The amount written in numbers is supposed to be for courtesy purposes only and is therefore called the “courtesy amount”. The bank check also contains the name of the recipient, the date, the amount to be paid (textual format), the courtesy amount (numerical format) and the signature of the person who wrote the check as well as symbols and graphics [3-6]. The official value of the check is the amount written in words which is often called as the “legal amount”. However, the courtesy amount is more effective in the automation of bank check processing. There are many types of bank check used in Bangladesh; two types of them are shown in Figure 1.



(a)

(b)

Figure 1: General format of Bank checks used in Bangladesh.

The Bengali script has ten digits (graphemes or symbols indicating the numbers from 0 to 9), which are variants of Indian numerals (known as Arabic numerals in the West). Bengali digits have no horizontal head stroke [22]. Figure 2 shows Bangla and corresponding English numerals.

Numbers larger than 9 are written in Bengali using a positional base 10 numeral system (the decimal system), just as in English. A period or dot is used to denote the decimal separator, which separates the integral and the fractional parts of a decimal number. When writing large numbers with many digits, commas are used as delimiters to group digits, indicating the thousand (hajar), the hundred thousand or lakh (lakh or lokkho), and the ten million or hundred lakh or crore (koṭi or kror) units. In other words, going leftwards from the decimal separator, the first grouping consists of three digits, and the subsequent groupings always consist of 2 digits.

For example, the English number 17,557,345 will be written in traditional Bengali as ১,৭৫,৫৭,৩৪৫ (êk koti põchattor lakh, shatanno hajar, tin sho põetallish, "one crore, seventy-five lakhs, fifty-seven thousand, three hundred forty-five").

English Digits	0	1	2	3	4	5	6	7	8	9
Bangla Digits	০	১	২	৩	৪	৫	৬	৭	৮	৯
Bangla Names of Digits	shunno	êk	dui	tin	char	pãch	chhôe	shat	aṭ	nôe
	শুন্য	এক	দুই	তিন	চার	পাঁচ	ছয়	সাত	আট	নয়

Figure 2: Bangla and corresponding English numerals [22].

3. Proposed System

The system proposed in this paper is designed for automatic detection and recognition of courtesy amount on Bangladesh bank check. The system consists of three modules: (i) Image Preprocessing (ii) Extraction of courtesy amount (iii) Segmentation of digits (iv) Recognition using artificial neural network. Figure 3 shows the overall system architecture.

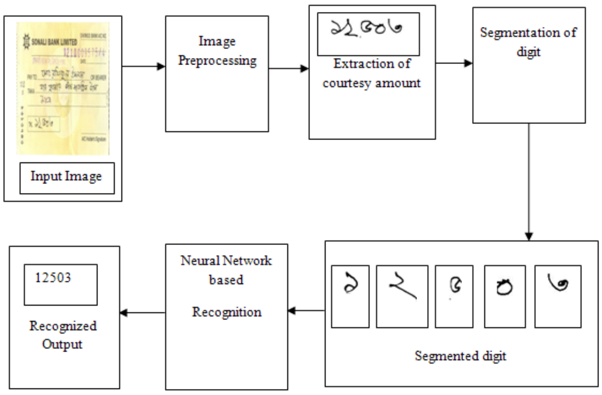


Figure 3: Block Diagram of the proposed system.

3.1 Image Acquisition

Image acquisition is the process of obtaining a digitized image from a real world source. Today, acquisition is usually done using different kinds of input devices such as scanner, digital camera, web camera, PDA, camcorder etc. Here we proposed to use scanner to acquire the image of the bank check. The scanned image is shown in Figure 4.

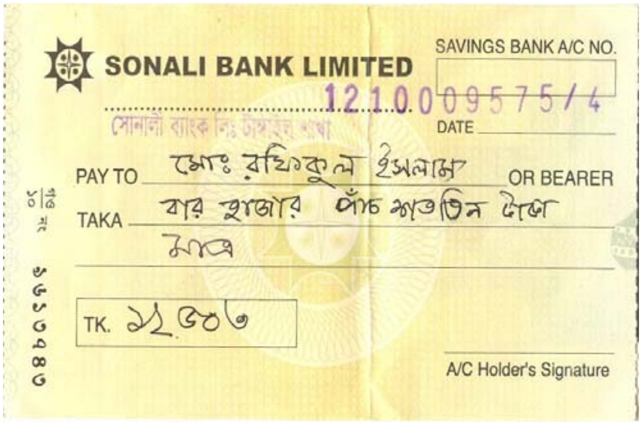


Figure 4: Scanned Image of Bank Check.

3.2 Image Pre-processing

Images that are acquired from documents containing Bangla text and numerical string, passed through the pre-processing steps. Preprocessing includes noise removal and the elimination of redundant information as far as possible. Images taken from camera are histogram equalized for better contrast. Figure 5 shows the block diagram of image pre-processing steps. This sub section describes each steps of image pre processing.

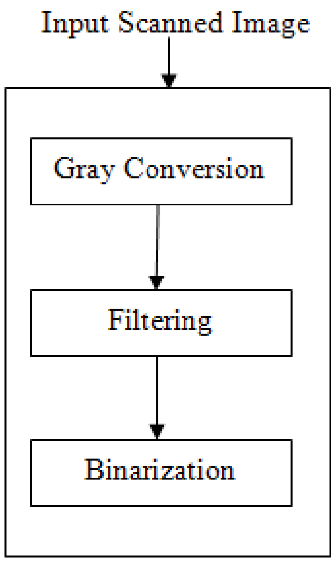


Figure 5: Block Diagram of image preprocessing steps

3.2.1 Gray Scale Conversion

RGB image is converted into gray scale image using NTSC gray scale conversion which is frequently used to convert RGB to gray scale conversion. The equation is given bellow:

Grayscale value= 0.3×Red+0.59×Green+0.11×Blue (1)

Grayscale image is shown in Figure 6.

Figure 6: Gray image

3.2.2 Filtering

A 3-by-3 median filter is used to blur the background. The characters are slightly blurred, but the background areas are more blurred in the image as in Figure 7.

Figure 7: Filtered Image

3.2.3 Binarization of Image

The image is converted from Gray scale to binary image that is an image with pixels 0's (white) and 1's (black). This conversion can take place because it conveys proper information of Bangla Numeral Structure.

- Covert into Binary image. Let f(x, y) is an input image. T is the threshold value and g(x, y) is the output image of thresholding process then the mathematical equation of this conversion is

  $g(x, y) = 1$ if $f(x, y) \geq T$ otherwise 0 (2)

To determine the threshold value we analyzed the histogram of the grayscale image. After histogram analysis we have defined the pixels with values over 160 (in a scale from 0 to 255) as one, and for pixels with values under this threshold as zero. Figure 8 shows a binary image of the bank check, where the ones are drawn in white and zeros are shown in black. In this figure, the superfluous information related to the background has been removed and the data related to the characters have been simplified into a set of black pixels.

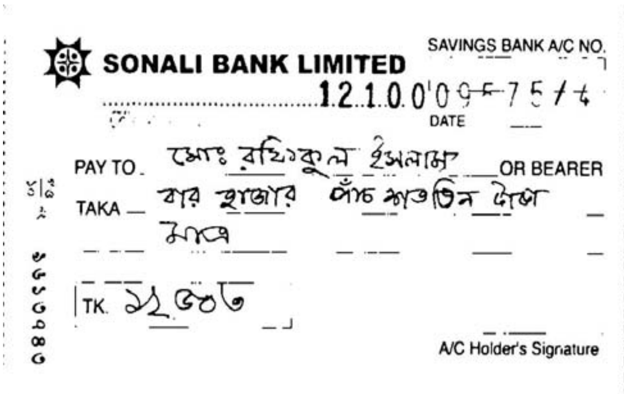


Figure 8: Binary Image

3.3 Detection of courtesy Amount

After Binarization of the image, either courtesy amount is selected by manually from binarized image or set the rectangular area in predefined function to auto select the courtesy amount. In Bangladesh, the courtesy amount is always located at the lower left corner and delimited by a rectangle box in the check. Since the size and the aspect ratio of this rectangle are fairly constant for a particular bank, the amount written in the box can be accurately determined. Figure 9 shows the cropped courtesy amount from the Check.

Figure 9: Cropped Image

3.3.1 Removal of unwanted portion of the cropped image:

After extracting the courtesy amount from the bank check, unnecessary background pixels (0) are removed from original image. This is done using the following algorithm:

Algorithm 1:

Step1*: Start from top-left corner; repeat for each column and row.*

If sum of all black pixels in row/column>0

Then save column and row

Step2: *Else delete the row and column.*

3.4 Segmentation Procedure

The challenge of a segmentation technique lies in the decision of the best cut path to localize an entity to be recognized as a correct isolated character by the recognition system. The literature usually shows three different strategies to perform the segmentation: Segmentation–Recognition, Segmentation-based Recognition and Segmentation Free systems.

This paper is based on the segmentation-based recognition strategy. The aim of this paper is to show how we define a new segmentation algorithm taking into account to complementary sets of structural features. The segmentation part of the scheme first detect whether a component of numeral(s) is isolated or connected. If it is connected, the touching numeral segmentation scheme is applied on it to get individual numerals. The touching numeral segmentation scheme detects the touching position using an algorithm. The flow chart for the segmentation of connected courtesy amount is presented in Figure 10.

The proposed image segmentation process includes three steps. (1) Separation of Connected Numeral (2) Numeral Separation (3) Segmentation of touching numerals.

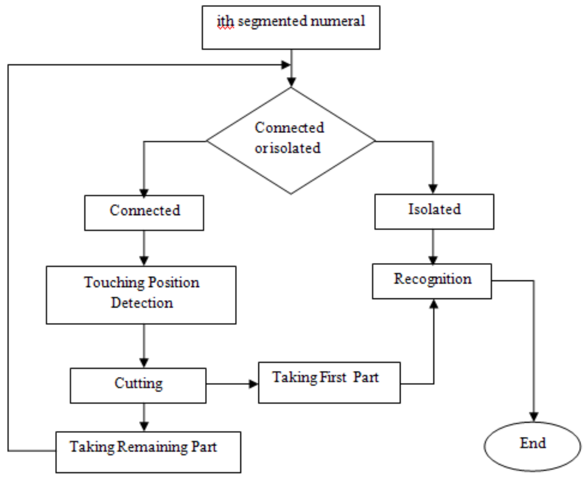


Figure 10: Segmentation procedure

3.4.1 Image separation

This step of the scheme classifies an input numeral into isolate and connected groups. The aspect ratio (width height ratio) of the component is used for the separation. If two or more numerals connected, then the width of the connected components should larger than its height. In principle, when two numerals get connected, one of the following happens in most case: (1) Two numerals create a larger width as shown in Figure 11, and (2) The projection of histogram at the connected points is almost equal in height.

Figure 11: Separation of connected or isolated numerals

Based on the projection histogram and aspect ratio of numeral isolated and connected numerals are identified as follows:

Let for a string of numerals N:
N_{CP}= Column pointer of the string
N_{IW}= Width of the string
N_{MH} = Maximum height of numeral in the string
$N_{MW=}$ Minimum width of the numeral in the string
P_{BC}= Black pixel counter
Also let C be a component of this string to be separated. Based on the above values the separation algorithm is as follows:

Step-1: Set ColumnCounter to zero
Step-2: Repeat while $N_{CP}< N_{IW}$
(i) Increment ColumnCounter and Set P_{BC} to zero

(ii) Repeat while i< N_{MH}

(a) If any Black pixel found in the i-th column then increment P_{BC}

[End of step (ii) loop]

(iii) If (($P_{BC=0}$) and (ColumnCounter <2* N_{MW}))

Then C is isolated

Otherwise C is connected

[End of step-2 loop]

Step-3: End

The above separation method is independent of the size of the numeral and there is no need of any normalization of the component.

3.4.2 Segmentation of touching digits by a line

Pairs of zero are frequently written for round values such as 1000 Tk. A random sampling of over 400 checks showed that about 50% of all connected digits consisted of a pair of zeros and 80-85% of successive zeros was connected together [23]. For this reason we took special care to detect and split these connected zeros. To separate the zeros or other digits connected at the top Figure 12(a), the string of the zeros is scanned horizontally from top to middle of the string as well as vertically from left to right and the number of black pixels are counted. Then the row(s) with maximum black pixels $R_{\max}$ and the column(s) with minimum black pixels C_{min} are selected. The pixels represented by the points ($R_{\max,}$ $C_{\min}$) are filled with white pixels. In this way the connected digits are separated Figure 12(b). After this, the procedure described in section 3.3.1 is applied to separate the disconnected digits (Figure 12(c)).

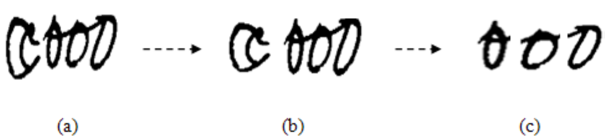


Figure 12: Segmentation of touching digits by a line

3.4.3 Segmentation of touching numerals

For the segmentation of connected numerals, at first the touching numerals are separated from the isolated numerals. The touching numeral segmentation algorithm extracts the feature points from touching numerals. The structural features of the numerals are used to detect the appropriate touching position of the connected numerals. Each connected numerals are inspected in a attempt to locate the characteristics representatives of segmentation points. Six major steps are executed to perform segmentation of touching numerals.

Step - 1: Average character width of the numerals is estimated.
Step – 2: Upper and lower word contours are examined to enable the location of possible ligatures.
Step – 3: Histogram of the vertical pixel density is calculated. Minima in the histograms are used to further confirm the location of possible segmentation points in each connected numerals.
Step – 4: Connected numerals are also scanned from left to right and the segmented portion is compared with a predefined structure to find an appropriate cutting position.
Step – 5: During the scanning process the backtracking may be required for proper segmentation position.
Step – 6: Segmentation of the numerals using best cut point.

Touching numeral separation according to the algorithm are described in Figure 13.

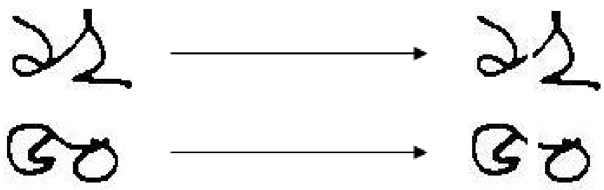


Figure 13: Touching numerals separation

3.5 Recognition of Numerals

A neural network is employed for Bengali digits recognition. A multilayer feed forward neural network with supervised learning method is more reliable and efficient for this purpose. The network applies back propagation learning algorithm that is a systematic method for training multiple layer ANNs. The objective of the training is to adjust the weight so that the input produce desired output. Recognition of numerals is shown in figure 14.

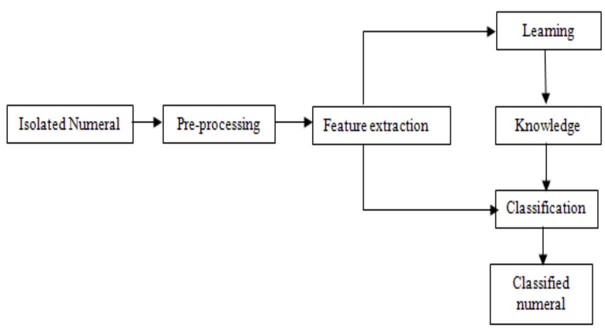


Figure 14: Recognition of Numerals

3.5.1 Neural Network Design

In this proposed system a fully connected Multi Layer feed-forward (MLP) network is used. Figure 15 shows a three-layered feed-forward model of the Artificial Neural Network. The simple structure of an MLP is shown in Figure 15. The neural network had three layers: an input layer consisting of 300 nodes (1 or 0 values corresponding to 300 pixels of the 20x15 normalized matrix), a hidden layer initially consisting of 50 nodes, and an output layer with 10 nodes (corresponding to the certainty that the image is digit '0', '1', …..,'9' respectively). The network is trained to output a 1 in the correct position of the output vector and to fill the rest of the output vector with 0's. The log-sigmoid transfer function at the output layer was used because its output range (0 to 1) is perfect for learning to output Boolean values (0 and 1).

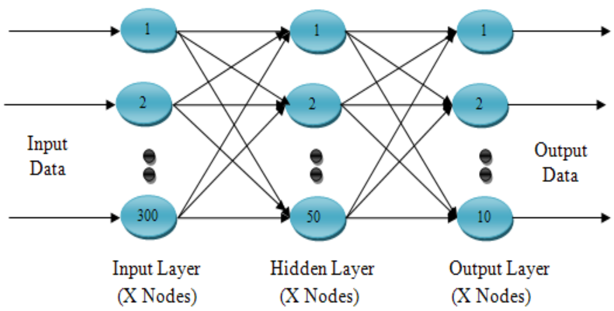


Figure 15: Multi Layer Feed-forward network.

3.5.2 Learning Process

Learning is a process by which the free parameters of a neural network are adapted through a process of stimulation by the environment in which the network is embedded. The type of learning is determined by the manner in which the parameter changes take palace [24]. Hence, training the network is equivalent to modifying the connection weights between the neurons and adjusts them to proper values so that the desired outputs can be obtained corresponding to a given set of input patterns. The inputs to the network are the feature matrices for each digit group. The training algorithm used to train the network is Backpropagation algorithm, also called generalized delta rule [25]. All training is done using this algorithm with both adaptive learning rate and momentum values. According to this algorithm, for each digit in the training set; weights are adjusted to proper values by:

1. Computing the discrepancy between the desired and actual output.
2. Back propagating this error from one layer to the previous one do as to interconnection weights is changed in proportion to their responsibility in producing the desired output.

3.5.3 Parameter Settings:

A Neural Network has several parameters i.e. learning Rate Parameter (η), Momentum (α), Weights. They are set during the network design. This setting must be done by a suitable combination.

Weights Initialization

The weights of the network to be adjusted by using Backpropagation algorithm must be initialized by some non-zero values. Initialize weights are randomly chosen, with typically value between [-0.5, +0.5] or [-0.1, +0.1].

Weight Adjustment

The weight adjustment is performed using the following equation [26]:

$$W_{kj}(t+1)=\alpha W_{kj}(t)+\eta\, \delta_{pk}(t)\, O_{pj}(t) \quad (3)$$

Here, $W_{kj}(t)$ denotes the weights from node k to j at time t, η is a learning rate parameter, α is positive number called momentum constant, $\delta_{pk}(t)$ is the error for pattern p on node k, and $O_{pj}(t)$ is the actual output on node j.

Minimizing the error measure with respect to the interconnection weights of the network then optimizes the network. The initialize value of the parameters is given in Table 1.

Table 1: Initialize value of Network parameters.

Parameter	***Value***
Input Layer	300
Hidden Layer	50
Output Layer	10
Learning Rate	0.0001
Total number of epochs	1000
Performance Goal	0.00000001
Momentum	0.9

4. Implementation and Performance Measurement

Experiments have been performed to test the proposed system and to measure the accuracy of the system. We simulated our software using MATLAB 7.1. The appropriate number of training examples is very important to get efficient response from the network. The system was trained and evaluated with different forms of handwritten digits provided by both male and female participants. Handwritten samples were obtained from 100 subjects, fifty males and fifty females. We have divided our system in three main phases: (i) Text Extraction, (ii) Segmentation and (iii) Training and Recognition. So the overall performance of the system directly depends on the performance of the three individual phases. The experiment results are summarized in this section.

4.1 Courtesy Amount Extraction

Image cropping technique was applied to locate the courtesy amount on the Bank check. In Bangladesh, the courtesy amount is always located at the lower left corner and delimited by a rectangle box in the check. Since the size and the aspect ratio of this rectangle are fairly constant for a particular bank, the amount written in the box can be accurately determined. As a result, accuracy of text extraction was 100%.

4.2 Segmentation

The proposed numeral separation algorithm was applied on the collected data set to separate the isolated and touching numerals. It was observed that the separation method had 98.99% accuracy. The rejection rate of the system was very small. During the numeral separation method we obtained the isolate numeral from touching numerals. The connected numerals separation algorithm was applied on the same data set to separate the touching numerals. The segmentation results obtained by this method was verified by manually and observed that 89.7% of the touching numerals. The rejection ratio of our segmentation scheme was 10%. The principle features for rejection where

1. The width of one of the segmented part was very small compare to the average with of a numeral.
2. The segmented part was very dissimilar of the original numerals.

4.3 Training and Recognition

Experiment was done to observe two things: the behavior of the neural network and the character recognition accuracy. After extraction and segmentation of scanned image, each digit was converted into 20 x15 binary images to be analyzed by the neural network. All the samples were split into two groups: the training set and the test set. The training set was comprised of 70% of the total genuine samples and rests are used for testing the system. We have simulated our system, using Image Processing Toolbox and Neural Network Toolbox of MATLAB (version 7.1).

The error term is presented here as Mean Square Error (MSE). The limit has been specified for training the network is less than or equal to 0.01. The number of hidden nodes and the value of the learning rate parameter had a significant effect on the MSE. The value of the parameters used in the neural network is shown in Table 2. The accuracy for MLP networks was 92% of correct readings with 1.7% of incorrect readings and 6.3% of rejections for low confidence. The performance of the system varies due to largely unconstrained nature of handwritten amounts on checks. The system performs better when all the digits are isolated in the courtesy amount rather than connected or overlapped digits. Table 2 summarizes the overall performance of the system.

Table 2: Overall recognition rate

Numeral	*Population*	*Recognition Accuracy %*	*Unrecognized Numerals %*
0	92	96	4
1	85	90	7
2	80	93	7
3	47	88	9
4	52	96	3
5	90	94	5
6	57	87	8
7	70	97	3
8	80	88	8
9	50	91	9
Total		92	6.3

This paper presents a system for the recognition of handwritten Bangla courtesy amount on bank-checks. The proposed technique was tested for accuracy using 100 segments from real checks and it is observed that 92.13% of the courtesy amounts were recognized correctly. From the experiment we noticed that most of the errors came from components having multi-touching points between two characters. However, the system rejects a check in case of doubt.

5. Conclusion

The proposed system can automatically detect, segment and recognize Bengali digits on Bank check properly. The system has been tested on different Bangladeshi hand written bank check and acquires good performance in segmentation and recognition parts. The system can properly segment digits from courtesy amount image if there is a single or normal touch exits. If there are multiple touches or overlapping between digits exits, it cannot segment full digits properly for recognition purpose. The future extension of this research work will be the recognition of hand written legal amount and date of the check and verification of signature of the client as well as develop a robust segmentation procedure for more complex handwritten connected numeral characters.

References

[1] S. Marinai, E. Marino, and G. Soda. Font adaptive word indexing of modern printed documents. IEEE Trans. on Pattern Anal. and Machine Intell., 28(8):1187–1199, 2006.

[2] C. Zanchettin, G. D. C. Cavalcanti, R. C. D´oria, E. F. A. Silva, J. C. B. Rabelo, and B. L. D. Bezerra. A neural architecture to identify courtesy amount delimiters. In Proc. of the Int. Joint Conf. on Neural Networks, pages 5849 5856, 2006.

[3] R. Palacios, A. Gupta, and P. S. Wang. Handwritten bank check recognition of courtesy amounts. Int. Journal of Image and Graphics, 4(2):203–222, 2004.

[4] C. Y. Suen, L. Lam, D. Guillevic, N. W. Strathy, M. Cheriet, J. N. Said, and R. Fan. Bank check processing system. Int. Journal of Imaging Systems and Technology, 7(4):392–403, 1996.

[5] L. L. Lee, M. G. Liz´arraga, N. R. Gomes, and A. L. Koerich. A prototype for brazilian bankcheck recognition. Int. Journal of Pattern Recognition and Artificial Intelligence, 11(4):549–569, 1997.

[6] R. Palacios, A. Gupta, and P. S. Wang. Feedbackbased architecture for reading courtesy amounts on checks. Journal of Electronic Imaging, 12(1):194– 202, 2003.

[7] S. Kelland and S.Wesolkowski. A comparison of research and production architectures for check reading systems. In Proc. of the Int. Conf. on Document Analysis and Recognition, pages 99–103, 1999.

[8] U. Pal, A. Belad, and Ch. Choisy. Touching numeral segmentationnext term using previous termwaternext term reservoir concept. Pattern Recognition Letters, 24(1-3):261–272, 2003.

[9] A. L. Koerich and L. L. Ling. A system for automatic extraction of the user-entered data from bankchecks. In Proc. of the Int. Symposium on Computer Graphics, Vision and Image Processing, pages 270–277, 1998.

[10] K. Liu, C. Y. Suen, and C. Nadal. Automatic extraction of items from cheque images for payment recognition. In Proc. of the Int. Conf. on Pattern Recognition, pages 798–802, 1996.

[11] Y.-K. Chen and J.-F. Wang. Segmentation of single - or multiple - touching handwritten numeral string using background and foreground analysis. IEEE Trans. Pattern Anal. Machine Intell., 22:1304–1317, 2000.

[12] J. Hu, D. Yu, and H. Yan. Construction of partitioning paths for touching handwritten characters. Pattern Recognition Letters, 20:293–303, 1999.

[13] E. Lethelier, M. Leroux, and M. Gilloux. An automatic reading system for handwritten numeral amounts on french checks. In Proc. of the Int. Conf. on Document Analysis and Recognition, pages 92– 97, 1995.

[14] L.S. Oliveira, E. Lethelier, F. Bortolozzi, and R. Sabourin. A new approach to segment handwritten digits. In Proc. of the Int. Workshop on Frontiers in Handwriting Recognition, pages 577–582, 2000.

[15] D. Yu and H. Yan. Separation of single-touching handwritten numeral strings based on structural features. Pattern Recognition, 31:1835–1847, 1998.

[16] Ahmed Asif Chowdhury, Ejaj Ahmed, Shameem Ahmed, Md. Shohrab Hossain and Chowdhury Mofizur Rahman, "Optical Character Recognition of Bangla Characters using Neural Network: A Better Approach", 2nd International Conference on Electrical Engineering (ICEE 2002), Khulna, pp. 145-152, 23-24 October, 2002.

[17] A.O.M. Asaduzzaman, M.K.I. Molla, M. Ganjer Ali, "Printed Bangla Text Recognition using Artificial Neural Network with Heuristic Method", 5th International Conference on Computer and Information Technology (ICCIT 2002), Dhaka, pp. 196-199, December 2002.

[18] M.A. Mehedi Hasan, M.A. Alim, M. Wahedul Islam, "A New Approach to Bangla Text Extraction and Recognition From Textual Image", 8th International Conference on Computer and Information Technology (ICCIT 2005), Dhaka.

[19] A.S. Mashiyat , A.S. Mehadi , K.H. Talukder, "Bangla off-line Handwritten Character Recognition Using Superimposed Matrices", 7th International Conference on Computer and Information Technology (ICCIT 2004), Dhaka, pp. 610-614, December 2004.

[20] Al Imran, M. Hossain, J. Dey, T. Debroy, B.K. Abir, A.H., OSDT: Outer Shape Detection Technique for Recognition of Bangla Optical Character, 12th International Conference on Computer and Information Technology (ICCIT 2009), Dhaka, pp. 384-389, December 2009.

[21] Mohammad Shabbir Hasan, A Fuzzy Based Approach to Recognize Optical Bangla Digit, 3rd International Conference on the Applications of Digital Information and Web Technologies 2010, Istanbul, Turkey, pp. 201-206, July 2010.

[22] Bengali Script, found at http://en.wikipedia.org/wiki/Bengali_script.

[23] J. Punnoose, "An Improved Segmentation Module for Identification of Handwritten Numerals", Master Thesis, Massachusetts Institute of Technology. 1999.

[24] Simon Haykin, "Neural Networks: A Comprehensive Foundation", Second edition, Pearson Education Asia, 2001

[25] N.K. Bose and P. Liang, "Neural Network Fundamentals with Graphs, Algorithms, and Applications", International edition, 1996

[26] R. Beale and T. Jackson, Neural Computing: An Introduction, IOP Publishing Ltd. 1990.

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