IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-6, June 2019 E-ISSN: 2347-2693

A Wide Scale Survey on Handwritten Character Recognition using Machine Learning

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DOI: https://doi.org/10.26438/ijcse/v7i6.124134 | Available online at: www.ijcseonline.org

Accepted: 11/Jun/2019, Published: 30/Jun/2019

***Abstract*—**In this paper, a comparative analysis of recent techniques for character recognition is done. Our purpose is to identify the impact of machine learning in the domain of character identification. Character recognition has a lot of applications in the fields of banking , healthcare and other fields for searchability , storability, readability, editability, accessibility, etc. to ease up various processes. Traditional machine learning techniques like a neural network, support vector machine, random forest, etc. have been used as classification techniques. Now with the advancement in the field of computer hardware and efficient research in artificial intelligence field have given emergence to deep learning algorithms. Recent articles are using deep learning for character identification. They also depict how various functions improve the performance in the filed of pattern recognition over time. The primary purpose of this paper is to encourage young researchers towards this domain and thus learn and work towards achieving novelty in the field.

***Keywords*—** Handwritten character recognition, Machine learning, Feature extraction, Deep learning.

I. INTRODUCTION

Handwritten recognition is a typical task because there exists a variety of writing ways. Due to the same situation, the computer program does not find good accuracy for the handwritten character recognition task. Literature focuses on English, Bangla, Marathi, Devanagari, Oriya, Chinese, Latin and Arabic languages.

Machine learning and deep learning algorithms have been widely used in past literature. At the same time, feature extraction is very crucial. Graph-based features, histograms, mathematical transforms, moment-based features are some popular techniques used for this task. Some necessary steps involved in handwritten character recognition are preprocessing, segmentation, representation, training, identification, and post-processing. As far as practical applications are concerned, a variety of mobile apps and web applications are providing character recognition features to their customers again end user wants better services that can technically be defined in terms of accuracy. Significance and challenges in character recognition are, and our purpose is to explore the solutions available in the past and explore the new possibilities to find out the resolution of the concerned problem. As discussed in the literature, one of the best ways to find the solution lies in the emerging domain of machine learning and deep learning algorithms. With this motivation, we are surveying handwritten character recognition using machine learning techniques.

The contribution of this study contains a comparative analysis of various machine learning and deep learning techniques for handwritten character recognition based on various factors like dataset and technique used. The organization of the paper is as follows: Section 2 gives a complete explanation of conventional and recent techniques in machine learning and deep learning field. Section 3 involves a comparative analysis of various techniques for different languages. Section 4 contains conclusion and future work. The section below describes the techniques used for past literature.

II. MACHIENE LEARNING AND DEEP LEARNING TECHNIQUES

Machine learning involves the process of designing a prediction algorithm based on experience. The important part is learning, and it requires data in the concerned domain after that prediction network organizes itself according to error. The current scenario has attained high complexity because the same field has attracted the attention of researchers. Various models are evolving, and some of them are as follows:

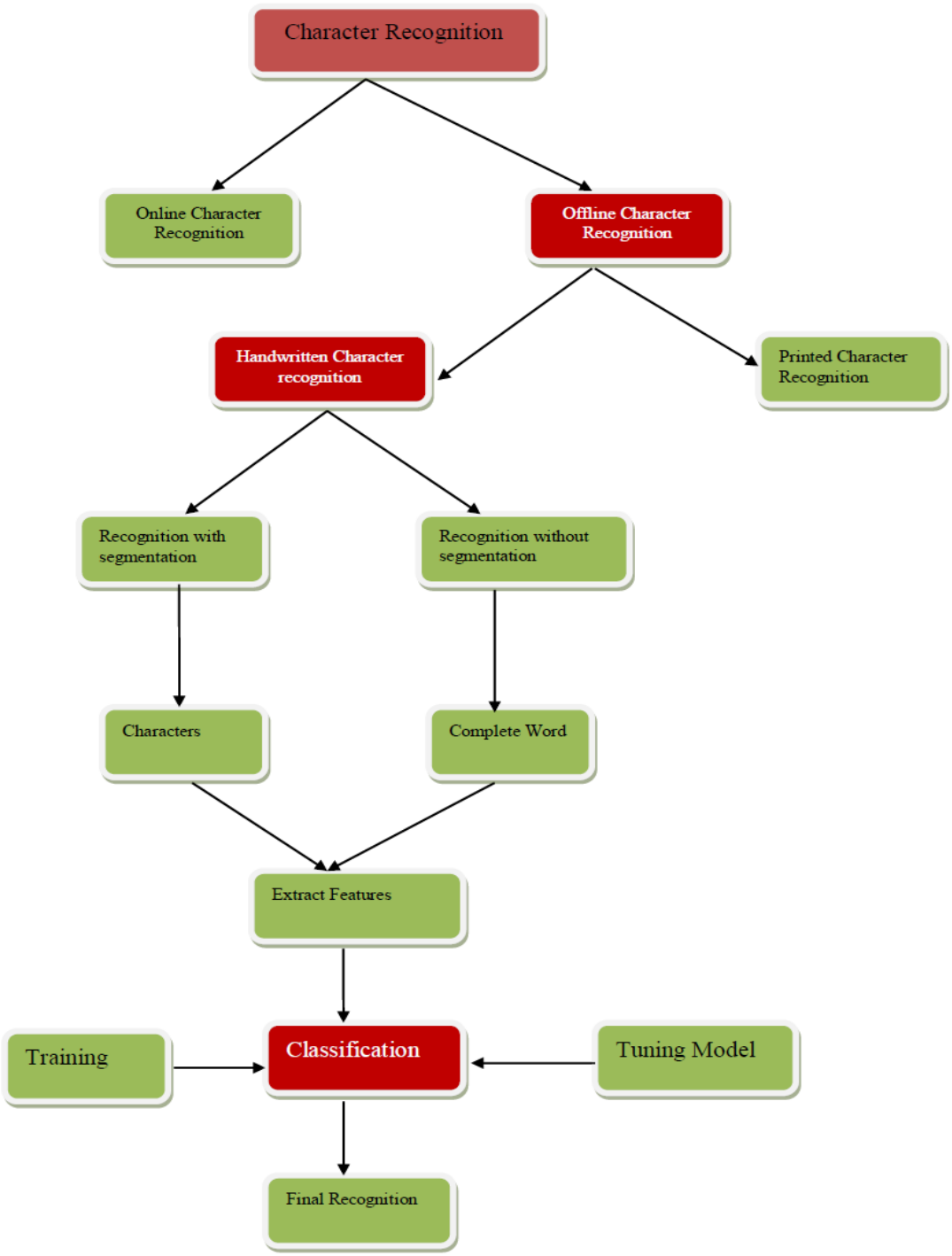

Figure1: General Steps of Character Recognition

1. Decision Trees
2. Nearest Neighbour
3. Random forest
4. Artificial Neural Network
5. Logistic regression
6. Linear Regression
7. Apriori Algorithm
8. Support Vector Machine

9. K-Means Clustering Algorithm
10. Naive Bayes Classifier
11. Neural Network

Deep Learning has attained pace due to various advancements of hardware and at the same time, algorithmic research that has been done on deep network information processing. Some of the essential algorithms of deep learning are:

a. Recurrent Neural Network
b. Autoencoder
c. Restricted Boltzmann Machine
d. Convolutional Neural Network
e. Deep Belief Network
f. Deep Neural Network
g. Deep Extreme Learning Machine
h. Localized Deep Extreme Learning Machine

III. CHARACTER RECOGNITION SYSYTEM

There is a variety of challenges in the handwritten character recognition system. Process of the handwritten recognition system is shown in Figure1. There are two categories in character recognition: online and offline character recognition. Online character recognition involves a digital pen and tablet. Offline recognition includes handwritten and printed characters. Handwritten characters have a lot of varieties. Segmentation and without segmentation is involved for written words. Further steps involve feature selection. Optimization can be used to speed up the process of classification. Subsequently, there is a requirement of a classification algorithm for reading features. Finally, a trained model is used for desired tasks.

IV. ANALYSIS OF LITERATURE

It should include important findings discussed briefly. Wherever necessary, elaborate on the tables and figures without repeating their contents. Interpret the findings in view of the results obtained in this and in past studies on this topic. State the conclusions in a few sentences at the end of the paper. However, valid colored photographs can also be published.

Overview of Bangla Script

Central characters, modifiers, diacritic and complex characters are the part of Bangla script. Figure2 represents handwritten Bangla script.

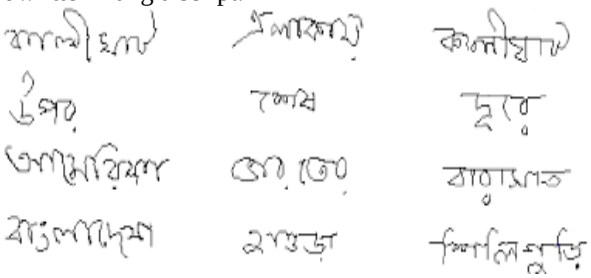

Figure2: handwritten Bangla Script

The Bengali language contains 50 central characters, 11 vowels, and 39 consonants. The complex character has made the task of pattern recognition complex. Table1 represents a comparative analysis of various techniques developed in past literature.

Table1. Comparative analysis of handwritten character recognition techniques for Bangla language

S.No.	Year	Title	Technique and Results
1.	2004	Recognition of Bangla handwritten characters using an MLP classifier based on stroke features [1]	Authors used MLP with a variant of the back propagation algorithm and obtained satisfactory results
2.	2009	A hierarchical approach to recognition of handwritten bangle characters [2]	Authors proposed a hierarchical approach and used CDM classifier to obtain a better analysis.
3.	2009	A new benchmark on the recognition of handwritten Bangla and Farsi Numeral character [3]	Authors proposed a technique of image processing and feature extraction on Bangla database, i.e. Bangla numerals and obtained an accuracy of 99.40%.

4.	2010	Multi-orient Bangla and Devanagari text recognition [4]	Authors used a convex hull and water reservoir principle for Bangla and Devanagari script recognition.
5.	2012	A classifier for Bangla handwritten numeral recognition [5]	Authors used kernel based Bayesian discriminant and obtained better results in terms of accuracy and time.
6.	2013	Recognition of Bangla compound characters using structural decomposition [6]	Authors proposed new topological features and decomposition rules to simplify complex character. The proposed technique produced satisfactory results.
7.	2015	Handwritten Bangla character recognition using a soft computing paradigm embedded in two pass approach [7]	Authors used soft computing paradigm. GA based local region selection technique is used to enhance accuracy.
8.	2016	A multi-objective approach towards cost-effective isolated handwritten Bangla character and digit recognition [8]	Authors used multi-objective region sampling, harmony search algorithm, AFS theory and attained 86.6478% accuracy for handwritten Bangla character.
9.	2017	Handwritten isolated Bangla compound character recognition: A new benchmark using a novel deep learning approach [9]	Authors used deep Convolutional neural network using RMSprop. They obtained error rate of 19% to 9.67% on CMATERdb dataset.
10.	2018	Shape decomposition based handwritten compound character recognition for bangle OCR [10]	Authors proposed shape decomposition for Bangla compound characters that have a complex shape and obtained better accuracy.
11.	2018	Ambiguity reduction through an optimal set of region selection using GA and BFO for handwritten Bangla character recognition [11]	Authors used GA and BFO to find out the regions having important information and obtained satisfactory results.

Overview of Arabic Script

There are 28 basic letters, eight diacritics, and 12 additional special letters. Figure3 represents a sample of Arabic script.

Figure3: Handwritten Arabic Script

The writing procedure is from right to left. Most of the letters vary the shape, and it depends on their position in a word. Identification of Arabic involves various

attributes like handling ligatures, non-presence of diacritics, and a variety of writing styles and also includes bad writing manners. Table2 represents a comparative analysis of various techniques developed by researchers in the past.

Table2. Comparative analysis of handwritten character recognition techniques for the Arabic language

S.No.	Year	Title	Technique and Results
1.	1990	Real-time Arabic handwritten character recognition [12]	Authors used a division of sets into subsets based on several strokes in character and obtained a 99.6% recognition rate.
2.	2014	Arabic word descriptor for handwritten word indexing and lexicon reduction [13]	Authors used Arabic word descriptor for shape indexing and lexicon reduction using IFN/ENIT and ibn Sina database.
3.	2016	A novel fuzzy approach for handwritten Arabic character recognition [14]	Authors used Fuzzy ARTMAP neural networks on IFN/ENIT database and reported a high recognition rate.
4.	2016	Puzzle based system for improving Arabic handwriting recognition [15]	Authors designed handwritten text as a puzzle. Concepts of feedbacks to avoid cuts and overlap of characters is used. Authors attained satisfactory performance.
5.	2017	Impact of features and classifiers combinations on the performance of Arabic recognition systems [16]	Authors identified the impact of several features and classifier combinations on OCR performance and developed a robust system to attain satisfactory performance.
6.	2017	Investigation on deep learning for off-line handwritten Arabic character recognition using Theano research platform [17]	Authors used deep Convolutional neural network under Theano framework for Arabic handwritten character recognition and found 97.32% accuracy.
7.	2017	Automatic recognition of common Arabic handwritten words based on OCR and N-GRAMS [18]	Authors used synthesis system to produce Arabic handwritten database. N-gram and Levenstein distance is used for error detection and correction.
8.	2017	Recognition of cursive Arabic handwritten text using embedded training based on HMMs [19]	Authors used Hidden Markov Models on IFN/ENIT benchmark database and found improved recognition.
9.	2017	Investigation on deep learning for off-line handwritten Arabic character [20]	Authors used deep Convolutional neural network on HACR dataset and found good results.
10.	2017	Efficient multiple classifier systems for Arabic handwritten word Recognition [21]	Authors used statistical and counter features with Chebyshev Moments. Various classifiers like MLP, SVM, ELM are used. Authors found competitive results.
11.	2018	An artificial immune system for offline isolated handwritten Arabic character recognition [22]	Authors used the artificial immune system on IFN/ENIT benchmark and obtained 93.25% accuracy.

Overview of Chinese Script

There are around 50,000 characters in Chinese script, but 99.65% only 3775 characters are commonly used. The pattern of writing in this language is just like English from top to bottom and left to right.

Figure4. Chinese handwriting

Figure4 represents a sample of Chinese handwriting. Quantity of characters is high in Chinese, and each character contains 500 components also called radicals. They are written in predefined position and order. Various online algorithms can trace stroke order successfully that process becomes complex in case of offline identification. Identification of a large number of character is not easy, and research is going on to identify all characters with high accuracy. Table3 represents a comparative analysis of various techniques developed in past literature.

Table3. Comparative analysis of handwritten character recognition for the Chinese language

S.No.	Year	Title	Technique and Results
1.	2000	A novel algorithm for handwritten Chinese character recognition [23]	Authors used a novel block-based ICM algorithm and found it better than 2-D HMM method.
2.	2013	Self-generation voting based method for handwritten Chinese character recognition [24]	Authors used methods like Boosting & Bagging and proposed a self-generation voting method for improving the detection rate.
3.	2014	Adaptive local receptive field Convolutional neural networks for handwritten Chinese character recognition [25]	Authors improvised the training process of CNN and used the same for handwritten Chinese character recognition. They observed improved performance.
4.	2016	Drop Sample: A new training method to enhance deep Convolutional neural networks for large scale unconstrained handwritten Chinese character recognition [26]	Authors proposed a training method using CNN. They found a new state of the art results on three handwritten Chinese character dataset.
5.	2017	Building fast and compact Convolutional neural networks for off-line handwritten Chinese character recognition [27]	Authors proposed small CNN model with Adaptive Drop-weight (ADW) and global supervised low-rank expansions (GSLRE) and found improved results.
6.	2017	Offline handwritten Chinese character recognition based on new training methodology [28]	Authors proposed a data generation method to enhance the size of the training database. Authors obtained 97.53% accuracy on ICDAR2013 competition database.
7.	2017	Online and offline handwritten Chinese character recognition: A comprehensive study and new benchmark [29]	Authors used a combination of Convent and domain oriented knowledge of direct Map on ICDAR-2013 competition database and found good results.
8.	2018	In air handwritten Chinese character recognition with locality sensitive sparse representation toward optimized prototype classifier [30]	Authors proposed a novel classifier LSROPC on IAHCC-UCAS2016 dataset and suggested to apply proposed algorithms in other domains.
9.	2018	Drawing and recognizing Chinese character using recurrent neural network	Authors used Recurrent neural network on ICDAR-2013 competition

		[31]	database and obtained excellent results.
10.	2018	Building efficient CNN architecture for offline handwritten Chinese character recognition [32]	Authors used global weighted pooling technique on ICDAR-2013 dataset and found 97.1% accuracy.
11.	2018	Compact MQDF classifiers using sparse coding for handwritten Chinese character recognition [33]	Authors proposed a modified quadratic discriminant function (MQDF) for handwritten Chinese character recognition and offered a comparison with other techniques for good results.

Overview of Devanagari Script

In India, Devanagari is a very popular script. Figure5 represents handwritten Devanagari script.

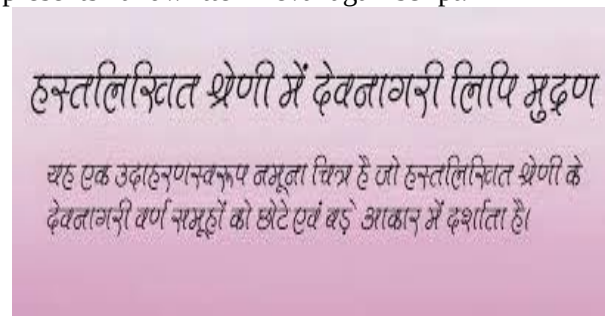

Figure5: Handwritten Devanagari Script

It contains 14 vowels and 37 consonants, generally known as central characters. It is written from left to right and does not have the idea of uppercase and lowercase like the English language. Table4 represents a comparative analysis of various techniques developed in past literature.

Table 4. Comparative analysis of handwritten character recognition techniques of Devanagari language

S.No.	Year	Title	Technique and Results
1.	2006	Recognition of off-line handwritten Devanagari characters using Quadratic classifier [34]	Authors proposed a technique based on quadratic classifier using 64-dimensional features and obtained 80.36% accuracy on Devanagari characters.
2.	2007	Off-line handwritten character recognition of Devanagari script [35]	Authors used a Gaussian filter to get 392-dimensional feature vector. The quadratic classifier is used on 36172 handwritten data and obtained 94.24% accuracy.
3.	2013	Identification of Devanagari and Roman scripts from Multi-script handwritten documents [36]	Authors proposed an original feature based technique using Multilayer perceptron (MLP) with 39 distinct features and obtained 99.54% accuracy.
4.	2015	A fuzzy-based classification scheme for unconstrained handwritten Devanagari character recognition [37]	Authors used a multi-stage classification system, including fuzzy inference and structural parameter. Proposed model produced 96.95% accuracy.
5.	2015	Deep learning based large scale handwritten Devanagari character recognition [38]	Authors used 92 thousand images of 46 different classes of Devanagari script. Deep Convolutional neural network is used as a classification algorithm and obtained 98.47% accuracy.
6.	2016	Performance optimization and comparative analysis of neural networks for handwritten Devanagari character recognition [39]	Authors used optimization at the pre-classification stage, feature extraction, and recognition state and found satisfactory results.
7.	2016	Handwritten Devanagari script database development for offline Hindi character with Mantra (Modifiers) [40]	Authors collected database containing 23,000 images from different locations and performed analysis for contributing to Devanagari

			database design.
8.	2016	Performance analysis of handwritten Devanagari and MODI character recognition system [41]	Authors used the neural network, BPN, KNN & SVM techniques and obtained good accuracy.
9.	2016	Accuracy enhancement of Devanagari character recognition by grey level normalization [42]	Authors used gradient local Auto-correlation feature extraction technique on Devanagari database and obtained 95.94% accuracy.
10.	2018	Combined classifier approach for off-line handwritten Devanagari character recognition using multiple features [43]	Authors extracted features based on the gradient of the image. Combination of SVM and quadratic classifier is used and obtained 95.81% accuracy.
11.	2018	Handwritten Devanagari character recognition using layer-wise training of deep Convolutional neural networks and adaptive gradient methods. [44]	Authors used Deep Convolutional neural network on ISIDCHAR and V2DMDCHAR database and obtained comparable results.

V. DATASETS

Proper handwritten character recognition system requires proper database which contains different handwritings. In this, we have considered four languages: Arabic, Devanagari, Chinese and Bangla. In research articles, authors have taken various datasets from online sources as well as self-prepared datasets. IFN/ENIT [45] contains 946 Tunisian villages/ towns names & postal codes generated by 411 people. ICDAR 2009 [46] and ICDAR [47] contains 20,575. Arabic words from 165 different writers. Arabic language technology centre [48] generated the big dataset, which contains 1,000 writers, 5,000 pages, 175,000 words, and approx 1 million characters. Arabic database "OHASD" [49] contains 154 paragraphs 194000 characters from 48 writers.

CMATERdb1.22 databases are used for scripts Bangla and Roman. It contains the mixed text of 150 pages. CMATERdb1.5.1 database is used for Devanagari and Roman script. It contains mixed script of 150 pages. CMATERdb2.1.3 is used for Bangla and contains 18931 words. CMATERdb2.2.3 is used for Devanagari and contains 15528 words. CMATERdb2.3.1 is used for Roman and includes 103331 words. ETL1-ETL9 contains 1.2 million handwritten characters, which include Japanese, Chinese, Latin, and numeric characters. ETL9 contains 2956 Chinese, 71 Hiragana samples collected from 4000 people.

Hanja1 database contains 783 classes, and Hanja2 database contains 1309 samples, taken from the real-time scenario. JEITA-HP [50] contains two databases, database A consist of 480 writers and database B consist of 100 writers. The complete database contains 3214-character class of 2965 Kanji, ten numerals, 82 hiragana, 157 characters consisting of English, Katakana, and symbols. HCI2000 consist of 3755 Chinese characters, written by 1000 people. ITRI [51] contains 5401 Chinese character classes, and each class has 1000 samples. 4MSL contains 4060 Chinese characters.
The main conclusions of the study may be presented in a short Conclusion Section. In this section, the author(s) should also briefly discuss the limitations of the research and Future Scope for improvement.

VI. CHALLENGES IN AUTOMATIC HANDWRITTEN DIGIT RECOGNITION

1. Challenges in handwritten character recognition

Solutions of handwritten character recognition have various limitations.

a.) **Error Rate: -** As shown in the literature [8-12], various algorithms have been designed to solve the problem of handwritten character recognition, but accurate detection is still a challenging issue. Figure6 also depicts the same scenario of Bangla character [52].

b.) **Detection Speed: -** Advance algorithms and deep networks take time in training so to process multiple images, detection time automatically increases.

c.) **Scalable Detectors: -** Development of scalable detection algorithms that can detect the expanding data properly is a burning issue of handwritten character recognition.

Poor Quality, Poor Inking, and Obsolete Fonts: - As written in the heading, these factors determine the rate of detection accuracy. Proper dataset and its preparation is also a crucial issue.

VII. EXPERIMENTAL ANALYSIS

We experimented on various state of the art and other standard methods for Handwritten Digit Recognition. The performance of the methods, namely the **AutoEncoders and DenseNet** models, were recorded on various changing parameters. The best performing activation functions were applied to the network, including Google's new SWISH activation function and ELISH activation function.

Table5: Observation For MNIST Datase.

Activation Function	**Accuracy Autoencoder**
Relu	*0.9953599962234497*
Swish	*0.9956799955368042*
E-swish	*0.9956899953842163*
Elish	*0.9955199964523316*
Selu	*0.9951099985122681*
Activation Function	***Accuracy DenseNet***
Relu	*0.982619*
Swish	*0980000*
E-swish	*0.982143*
Elish	*0.982247*
Selu	*0.969524*

As can be seen from the table that the best performing function on average is the E-Swish Activation Function. The results also describe the accuracy of the techniques in recognizing the Handwritten Characters.
conclusions of the study may be presented in a short Conclusion Section. In this section, the author(s) should also briefly discuss the limitations of the research and Future Scope for improvement.

VIII. CONCLUSION

Handwritten character recognition is a complex problem because of a variety of character in different languages. The complex architecture of characters is another major reason that makes the handwritten character recognition task stuff. Research in this direction focuses on segmentation procedures, feature extraction procedure, and classification algorithms.

Various machine learning techniques have been used for solving the same problem. Now with the advancements in hardware and the efficient algorithm has given birth to deep learning, and it is widely used for solving handwritten character recognition. In this paper, we presented a survey on handwritten character recognition. Initially, we presented a procedure of handwritten character recognition. Four languages, Devanagari, Bangla, Chinese, and Arabic, are taken for analysis. We presented a study in tabular form that reflects the various techniques.

Used & accuracy attained in the handwritten character recognition task. Challenges in the concerned domain are also discussed. The wide use of handwritten character recognition for commercial products like mobile phones, PC, etc. attracts the attention of the research community towards this problem. As stated above that deep learning is catching attention the modified version of deep learning algorithms like Discriminative Restricted Boltzmann Machines (DRBM) [53], Conditional restricted Boltzmann machines (CRBM) [54], CBIR (Content-based image retrieval) [55], CDBNs (Convolutional deep belief network) [56], Separable deep encoder [57], Recursive Convolutional network (RCN) [58], Convolutional restricted Boltzmann machine (CRBM) [59], Dense convolutional neural network [60] etc. have been developed in past literature. Analysis and exploration of these algorithms, along with advance feature extraction algorithms [61-65] will be used in the future. I hope that this intuition will be helpful for those who are working in this direction.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

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