Bangla Handwritten Digit Recognition Using Convolutional Neural Network

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This Report Presented in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Computer Science and Engineering

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APPROVAL

This Project/internship titled **"Bangla Handwritten Digit Recognition Using Convolutional Neural Network"**, submitted by Dip Datta, ID No: 191-15-2382 to the Department of Computer Science and Engineering, Daffodil International University has been accepted as satisfactory for the partial fulfilment of the requirements for the degree of B.Sc. in Computer Science and Engineering and approved as to its style and contents. The presentation has been held on *04/02/2023*.

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We hereby declare that, this project has been done by us under the supervision of **Mushfiqur Rahman, Senior Lecturer, Department of CSE** Daffodil International University. We also declare that neither this project nor any part of this project has been submitted elsewhere for award of any degree or diploma.

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ABSTRACT

Handwritten digit recognition is the process of automatically identifying and interpreting handwritten digits, such as those found on a bank check or a handwritten phone number. In Bangladesh, this technology could be used in a variety of ways, including automating the process of reading and interpreting documents, reducing the need for manual data entry, and improving the accuracy and efficiency of data processing tasks. It could also be used to help automate certain business processes, such as invoicing and billing, or to streamline the process of filling out forms. Overall, the use of handwritten digit recognition technology could potentially have a significant impact on productivity and efficiency in Bangladesh. Handwritten digit recognition is a machine learning task that involves identifying and detecting written digits from digital data. In order to improve efficiency and transition to paperless offices, a system for recognizing Bengali handwritten digits is necessary. However, recognizing these digits can be difficult due to variations in shape, size, and writing style. In this report, we propose a neural network approach using TensorFlow's CNN algorithm (Keras Sequential Model API) and the BHAND dataset to accurately and efficiently recognize Bengali handwritten digits. Our model, which consists of six layers, achieved a recognition accuracy of 99.1%.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction

1.1 Introduction

Handwritten digital recognition development research is rapidly evolving and redesigning automation fields such as automatic check reading, automatic number plate reading, digital postal service, optical image recognition (OCR), etc. Due to the different aspects of its use, computer vision researchers really feel the need to work on and improve on it - actually quality and performance. But handwriting identification is more challenging than typed letters. Because different people write differently and that creates a high level of diversity in the writing style. Also, there are some similarities between the shapes of the different characters. Overwriting situations make it even more challenging to properly classify handwritten numbers.

To a human, an image is a sophisticated visual representation that can be easily interpreted and understood. But to a computer, an image is simply a collection of pixel values – a series of numerical combinations ranging from 0 to 255, depending on the color format (e.g., RGB, black and white, grayscale). By analyzing the pixel values, we can extract useful information from the image. The human eye has light-sensitive cells that can divide the image into sections and interpret features like shape, size, and color, which are then sent to the visual cortex for analysis and mapping to our memory for identification. Similarly, machine learning algorithms can be trained to recognize and classify images by analyzing their features. There are numerous applications that can utilize this capability. Machine learning also works like that and there are many applications that can use this Bangla Digit Recognition System. Such as Bangla Handwritten Letters Base OCR (Optical Character Recognition), Picture to Text to Speech, Bangla ID Card Reading, Number Plate Reading, Vehicle Tracking, Post Office Automation etc. And we are using the database from BHaND. Which is similar to MNIST's English handwritten digit database. So, the work will be easier. This dataset is used to train the model which contains 70000 handwritten Bangla digits. From which 50000 digits are used for training and validation. Also, the dataset is being compressed by GZIP compression algorithm for faster transmission.

1.2 Motivation

The aim of this research is to create an improved system for recognizing Bengali handwritten digits. The goals are to achieve an Automation method Data Input and analyze them to find the best accuracy for recognizing Bangla Handwritten Digit. We used to manually enter data from a document with many input fields when we needed to digitize it. It is, however, extremely time consuming. If we can find a way to do it automatically, the problem will be solved. As a result of this, we want to work together to find a solution for our mother tongue, Bangla. We occasionally want to extract and save data in digitized form so that it can be used in the future.

1.3 Rationale of The Study

Bangla handwritten digit recognition is a useful starting point for the Bengali language for developing an Optical Character Recognition (OCR) system. OCR systems have a variety of applications, including sorting postal mail, processing bank checks, entering form data, and more. However, one of the main challenges is developing an algorithm that can accurately recognize handwritten digits submitted by any sort of digital devices. The goal of this study is to create an effective and reliable system for recognizing Bengali handwritten digits. The number recognition system has many potential uses in both government and non-government organizations. For example, it could be used to scan IDs at passport or National Identity Card (NID) offices, reducing the risk of errors caused by manual data entry and saving time. It could also be used to obtain vehicle information through number plate recognition. To address these challenges, we propose a neural network approach using TensorFlow's CNN algorithm and a compressed dataset called BHaND for efficient transmission. Our goal is to achieve high accuracy and an automated method for recognizing Bangla handwritten digits.

1.4 Research Questions

- How is Keras related to TensorFlow?
- What algorithm is used for the model?
- What are the layers used for training the model?
- What dataset was used to train and evaluate the machine learning models?

- How the Data preprocessing works?
- What is the ability of Bangla handwritten digit recognition?

1.5 Expected Output

The primary objective of this research is to achieve a high level of accuracy in prediction using the Keras sequential model algorithm and the BHaND dataset. To do this, we preprocessed the dataset and trained our model using TensorFlow's CNN algorithm, which consists of six layers. Our model is able to deliver accurate results quickly, completing the training process in just seven epochs. An epoch is a measure of the number of times the machine learning algorithm processes the entire training dataset.

1.6 Project Management and Finance

This is a research project in the field of machine learning. The utilities that we had to use were collecting the dataset and an efficient algorithm for our model for implementation, which was free of cost because the dataset was open-source and we had to modify our model to get our expected results. The resource of development tool for our implementation was already available in the TensorFlow library that runs on Google Colab. So, we didn’t have to use any additional resource.

1.7 Report Layout

This section summarizes the steps used in our report.

- Chapter 1: Introduction
- Chapter 2: Background
- Chapter 3: Research Methodology
- Chapter 4: Experimental Results and Discussion
- Chapter 5: Impact on Society, Environment and Sustainability
- Chapter 6: Summary, Conclusion, Recommendation and Implication for Future Research
- References
- Appendices

CHAPTER 2

Background

2.1 Preliminaries

Bangla handwritten digit recognition is a system that converts handwritten images of written digits into digital form. This process can be automated using an Optical Character Recognition (OCR) system, which is faster and less prone to error than manual digitization. In this chapter, we will review relevant previous research and discuss similarities and differences between this work and other studies. The digitalization of government documents, including personal data, is a common task that often involves a large number of Bengali handwritten digits. Our recognition system can extract these digits from documents, saving time and reducing the risk of errors compared to manual extraction.

2.1 Related Works

There are a few studies relying on deep learning to identify Bangla handwritten digits. On that term, Deep learning may also greatly benefit character and numeric discoveries, such as Bengali numeral and character recognition.

Khalil Ahammad, Chowdhury Shahriar Muzammel, and others proposed a convolutional neural network (CNN) architecture for identifying handwritten digits captured by a camera. The CNN architecture was able to identify most of the input digits in real time with a test accuracy rate of 98.37% on the BanglaLekha-Isolated dataset, which contains 10 Bengali digits. The research was conducted using a computer with limited computing capabilities and minimal power consumption.[1]

Afsana Hossain, Md. Sabbir Hasan, and others proposed two approaches for recognizing Bengali handwritten digits using convolutional neural networks (CNNs): one using CNN and the other using transfer learning with ResNet50 and MobileNet. According to the research, the transfer learning approach resulted in better accuracy. The traditional CNN approach achieved an accuracy of 91%, MobileNet 88%, and ResNet50 achieved the best accuracy of 97% all using the CMATERdb dataset. [2]

Yuwen Gu and Shengfeng Chen compared the performance of five machine learning classifier models: Neural Network, (KNN), Random Forest, Decision Tree, and Bagging with gradient boost. They found that the KNN classifier outperformed the Neural

Network in terms of computational efficiency while still maintaining a similar level of performance. In terms of accuracy, KNN and Neural Network both achieved high scores of 96.7% and 96.8%, respectively. However, KNN was able to process data almost 10 times faster than the Neural Network.[3]

Md. Fahim Sikder proposed an architecture for recognizing Bangla handwritten digits which outperforms popular Alexnet and Inception v3 architecture using similar database BHAND dataset. Where in Alexnet the validation accuracy was 97.74% and inception v3 had a validation accuracy of 98.13% and his own model that has been implemented the Semi-Supervised Generative Adversarial Network (SGAN) using the same dataset generates an accuracy of 99.44%. [4]

Kazi Mejbaul Islam, Chaity Saha, and others proposed a method in their paper where they used a convolutional neural network (CNN) model to recognize numerals with high degree of accuracy beyond 96%, even in most challenging noisy conditions by using the NumtaDB dataset. They compared their proposed model with Resnet-18 and Lenet-5 using the same dataset and found that their model performed better.[5]

Kolla Bhanu Prokash and others proposed a simple neural network approach for handwritten digit recognition using the MNIST dataset, which contains 70,000 digits with 250 distinct writing styles. They found that their proposed method, described in their paper, achieved an accuracy rate of 98.51% for predicting real-world handwritten digits with a loss of less than 0.1%.[6]

S M Azizul Hakim and others created a 9-layer sequential convolutional neural network model for identifying 60 Bangla handwritten characters, including 10 digits and 50 basic characters. Using the BanglaLekha-Isolated dataset for training and validation, they found that their model achieved a very high accuracy rate of 99.44% on the BanglaLekha-Isolated dataset and 95.16% accuracy on a different test set.[7]

Pawan Kumar Singh and others proposed a feature extraction technique called SBI that was applied to handwritten images of numerals written in four main language scripts used in India: Arabic, Bangla, Devanagari, and Latin. Using this method and a support vector machine (SVM) classifier, Singh and his colleagues were able to achieve classification accuracies of 98.18%, 96.22%, 96.52%, and 95.53% for digits written in these four scripts, respectively. When all the scripts were combined in together, the accuracy was 90.98%. [8]

Md. Shahadat Hossain and others proposed a deep neural network model called the Fine Regulated Deep Neural Network (FRDNN) for recognizing handwritten numeric characters. They tested both this model and a traditional deep neural network (TDNN) model using the BanglaLekha-Isolated database and found that the FRDNN model had a classification accuracy of 96.99%, while the TDNN model had an accuracy of 96.25%.[9]

Savita Ahlawat et al. proposed a CNN architecture in order to achieve accuracy even better than that of ensemble architectures where they achieved a recognition accuracy of 99.87% for a MNIST dataset.[10]

Muntarin Islam and others proposed a new convolutional neural network (CNN) model for recognizing handwritten digits, which was based on pre-trained models including, EfficientNetB0,Inception-v3, and Resnet-50. They tested their model on the NumtaDB dataset, which included with 10 classes and 17,000 instances, and found that it had a high accuracy rate of 97%. This model outperformed the performance of other models previously developed for this task.[11]

Md. Ferdous Wahid and others conducted a study to evaluate the performance of four classifiers (Gradient Boosted Decision Trees (GBDT), Random Forest (RF), Support Vector Machine (SVM), and K-Nearest Neighbor (KNN)) for recognizing Bangla handwritten digits using three feature extraction techniques (Gabor filter, Local Binary Pattern (LBP), and Histogram of Oriented Gradients (HOG)). They applied these classifiers to four publicly available Bangla handwriting digit datasets: BDRW, Ekush, CMARTDB, and NumtaDB. The results showed that the SVM+HOG method had the highest recognition accuracy on the BDRW, Ekush, CMARTdb, and NumtaDB datasets, achieving rates of 89.68%, 95.68%, 98.08%, and 93.32%, respectively.[12]

Md Zahangir Alom and others developed a system for recognizing handwritten Bangla digits using deep learning approaches, specifically Convolutional Neural Networks (CNN) and Deep Belief Networks (DBN) with the use of dropout and different filters. They tested their system on the CMATERDB 3.1.1 dataset and achieved a recognition rate of 98.78%.[13]

M R Mamun and others proposed a classification system for Bangla handwritten digits using an exception ensemble network. The system was evaluated on a hidden test set and achieved a high accuracy of 96.69% and 97.14% in F1 score This suggests that the system is effective at correctly identifying handwritten Bangla digits.[14]

Md. Jahid Hasan and his colleagues proposed a combination of a deep convolutional neural network and a support vector machine (CNN-SVM) for the recognition of Bangla handwritten digits. They developed a 14-layer deep CNN architecture to automatically extract features from Bangla handwritten digit images, and tested their proposed model on two different datasets BanglaLekha-Isolated:and NumtaDB. The accuracy achieved was on the BanglaLekha-Isolated and NumtaDB dataset and 99.59% and 99.53% respectively.[15]

Ovi Paul aimed to find the benchmark for pre-processed images that would achieve high accuracy on any machine learning model using the NumtaDB dataset. The specific model used in this research saw an approximately 60% increase in accuracy.[16]

Animesh Singh and their team proposed an architecture that combines multi-scale global and local geometric features of pattern images to create a more precise description of the pattern images. The research concludes that using both global and local features together result in a more robust and accurate description of the original image. The proposed methodology achieved significantly better results in terms of recognition accuracy. [17]

Jannatul Ferdous and their team proposed a dataset that aims to recognize 120 Bangla compound characters made up of 2552 isolated handwritten characters written by unique writers, which were collected within Bangladesh. They claim that this is currently the most extensive dataset for Bangla compound characters. [18]

Partha Chakraborty and their team proposed various preprocessing techniques for image processing, with a deep convolutional neural network (CNN) serving as the classification algorithm. The research achieved an accuracy rate of 93% for the NumtaDB dataset and 92% for a separate dataset using the proposed method.[19]

T.R. Das and their team proposed an extended convolutional neural network (CNN) model to recognize Bangla handwritten characters. The CNN model was tested on the BanglaLekha-Isolated dataset and achieved recognition accuracies of 99.50% for Bangla digits, 93.18% for vowels, 90.00% for consonants, and 92.25% for combined classes.[20]

Md. Hadiuzzaman Bappy and their team proposed using custom CNN architectures to build a model for the recognition of digits using the NumtaDB, CMATERdb, and ISI datasets with a high degree of accuracy. The average accuracy of the CNN model for recognizing Bangla numerals was 98%.[21]

Hasibul Huda and their team proposed using two popular datasets, BanglaLekha-Isolated and NumtaDB, to train a convolutional neural network model for the recognition of both digits and characters. They used Keras with a TensorFlow backend in their research and achieved an average accuracy of 96.42% on the BanglaLekha augmented dataset and an accuracy of 98.92% on the NumtaDB dataset.[22]

Md. Ali Akbar and their team proposed a Convolutional Neural Network (CNN) model for the detection of English and Bangla handwritten digits. The 19-layer CNN model was trained using the MNIST and NumtaDB datasets and achieved an accuracy of 98.48% for the recognition of English handwritten digits and 86.76% accuracy for the recognition of Bangla handwritten digits.[23]

A. M. S. Chowdhury and M. S. Rahman developed a new dataset called 'BHaND' that consists of 70,000 handwritten samples from 1750 individuals (982 male and the rest female). They found that the minimum validation error in this dataset was 1.22%, which is the best result compared to other methods in the literature.[24]

2.3 Comparative Analysis and Summary

In this study, we have developed a new dataset of images of handwritten Bengali numerals. Our goal was to create a dataset that is similar to MNIST, a well-known dataset of English handwritten digits. Like MNIST, our dataset includes 70,000 images of Bengali digits, each of which is 32x32 pixels in size (compared to MNIST's 28x28 pixels). Otherwise, the two datasets are largely the same, with 60,000 training examples and 10,000 test examples in MNIST, and 50,000 training examples, 10,000 validation examples, and 10,000 test examples in our Bengali dataset. The digits in both datasets have been normalized and centered in fixed-size images. We have also included the option to group the samples in our dataset into a single file using Python's cPickle serializer and compress them using GZIP for faster transmission.

Table 2.3 shows a comparative analysis of previous research works.

Table 2.3: Comparative analysis of previous research works

SL No	**Author Name**	**Used Algorithm**	**Dataset**	**Accuracy**
1.	Khalil Ahammad et al. [1]	CNN	BanglaLekha-Isolated	98.37%
2.	Afsana Hossain et al. [2]	CNN and Transfer Learning (ResNet50 and MobileNet)	CMATERdb	91%, 88%, and 97%
3.	Chen S. et al. [3]	KNN and Neural Network	MNIST	96.7% and 96.8%
4.	M. F. Sikder et al. [4]	Alexnet, InceptionV3, SGAN	BHAND	97.74%, 98.13%, 99.44%
5.	K. M. Islam et al. [5]	CNN	NumtaDB	96%
6.	Y. S. Bharadwaj et al. [6]	Simple Neural Network	MNIST	98.51%
7.	S. M. A. Hakim et al. [7]	9-layer sequential CNN	BanglaLekha-Isolated	99.44%
8.	P. K. Singh et al. [8]	SBI and SVM	Handwritten Images from 4 Indian Scripts (Arabic, Bangla, Devanagari, Latin)	98.18%, 96.22%, 96.52%, 95.53%, 90.98%

9.	M. S. Hossain et al [9]	FRDNN and TDNN	BanglaLekha-Isolated	96.99% and 96.25%
10.	Ahlawat S. et al. [10]	CNN	MNIST	99.87%
11.	Muntarin Islam [11]	CNN (EfficientNetB0, Inception-v3, and Resnet-50)	NumtaDB	97%
12.	M. F. Wahid et al. [12]	GBDT, RF, SVM, and KNN with Gabor filter, LBP, and HOG	BDRW, Ekush, CMARTDB, and NumtaDB	89.68%, 95.68%, 98.08%, 93.32%
13.	M. Z. Alom et al. [13]	CNN and DBN with dropout and different filters	CMATERDB 3.1.1	98.78%
14.	M. R. Mamun et al. [14]	Exception ensemble network	Hidden test set	96.69% - 97.14% F1 score
15.	M. J. Hasan et al. [15]	CNN-SVM	BanglaLekha-Isolated and NumtaDB	99.59% - 99.53%
16.	O. Paul et al. [16]	SVM	NumtaDB	Approximately 60% increase in accuracy
17.	A. Singh et al. [17]	Multi-scale global and local geometric features	CMATERdb 3.1.1, CMATERdb 3.1.2, CMATERdb 3.1.3, ISIBanglaDigit	98.15 %, 96.65 %, 93.48 %, 99.36 %
18.	J. Ferdous et al. [18]	CNN	MatriVasha	94.49%
19.	P. Chakraborty et al. [19]	Preprocessing techniques with CNN	NumtaDB and separate dataset	93% - 92%

20.	T. R. Das et al. [20]	Extended CNN model	BanglaLekha-Isolated	99.50% (digits), 93.18% (vowels), 90.00% (consonants), 92.25% (combined classes)
21.	M. H. Bappy et al. [21]	Custom CNN architectures	NumtaDB, CMATERdb, and ISI	98%
22.	H. Huda et al. [22]	CNN with Keras and TensorFlow	BanglaLekha-Isolated and NumtaDB	96.42% (BanglaLekha augmented dataset), 98.92% (NumtaDB)
23.	M. A. Akbar et al. [23]	19-layer CNN	MNIST and NumtaDB	98.48% (English digits), 86.76% (Bangla digits)
24.	Chowdhury, A.M et al. [24]	Two-layer convolution neural network architecture	BHAND	98.78% (validation error 1.22%)
25.	This Study	TensorFlow's CNN algorithm: Keras Sequential Model	BHAND	99.12%

2.4 Scope of the Problem

Although the handwritten images of single Bangla digits can be predicted through the recognition system but for connected digits or compound digits the model has not been modified that way. That is a drawback of this system which can be focused in future. But it predicts that handwritten digits those with segmentation. We can also focus on recognizing handwritten digits with real time which will helps to recognizing the digits at current time with more clear understanding. The scope of this work will be achieving the maximum accuracy and an automation method for recognizing Bangla handwritten digits.

2.5 Challenges

The main challenges of the system were image testing of handwritten Bangla digits. For testing an image for getting the predicted output, more than 100 of images were uploaded or stored. In order to input an image, the default pixel size was set in the system was 180x180 pixels which was already the default size of all the test images. But uploading an image without the default pixel won't give the output of the prediction value. For that the image had to be 180x180 pixels in height and width. For that we need to resize the image and set its pixel on 180x180. Also, if the handwritten image number is on compound form or has more than single number the system can't generate the right prediction value. But we can resize that image with segmentation of the image value into each part to get the right prediction value. This problem will be focused for future work.

CHAPTER 3

Research Methodology

3.1. Introduction

In this study, the primary aim was to obtain as accurate a prediction value as possible by using the Keras sequential model algorithm with the BHaND dataset. To do this, we first preprocessed the dataset and then fit our model with TensorFlow's CNN algorithm, which included six layers to achieve a more accurate output from the proposed model. The model was able to run much faster than previous models, as it was able to give an

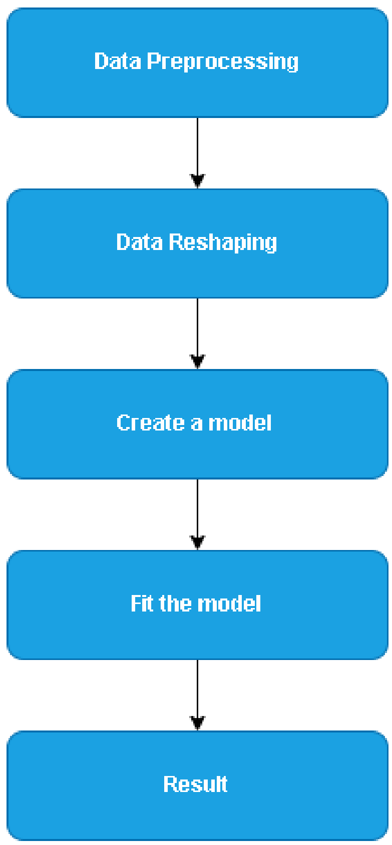

Figure 3.1: A Complete Workflow

accuracy result in just seven epochs. This process involved shaping the data, creating a model for recognition, and fitting the model to get the prediction result.

Digit recognition, like all other methods of recognition, is merely a procedure. There are a few stages available for explicitly recognizing the digit recognition framework. This chapter contains subsections that briefly describe the entire methodology. A good methodology is required for future research and work in this field. The work flow is provided in figure 3.1 as the blueprint for the entire project.

3.2 Research Subject and Instrumentation

In this research project, we focus on using convolutional neural networks to recognize Bangla handwritten digits. This topic has gained significant attention in the fields of machine learning and deep learning recently. In order to effectively implement and train our deep learning model, we require a high-performance machine with a GPU that supports the TensorFlow toolkit.

The following hardware and software were used in our project:

- An Intel Core i5 8th generation processor with 24GB of RAM
- Google Colab with a K80 GPU, and a 1TB HDD.

Additionally, we utilized a number of development tools including:

- Windows 10
- Python 3.8
- Pandas,
- NumPy
- OpenCV
- Keras,
- Matplotlib
- Sklearn.

3.3. Data Collection Procedure

This section divides into two segments. Where we discuss about the dataset and how the data preprocessing works.

- Dataset Description
- Data preprocessing

3.3.1 Dataset Description

The BHaND dataset, which stands for "Bengali Handwritten Numerals Dataset," is used to train the model and is available on GitHub. It includes 70,000 samples that have been divided into three sets: a training set with 50,000 samples, a validation set with 10,000 samples, and a test set with 10,000 samples. The images in the dataset are grayscale and have a size of 32x32 pixels. Each image is labeled with the digit (0-9 in Bengali) that it represents. The samples have been normalized to the intensity range [0,1] and the intensity has been inverted to make black pixels 1 and white pixels 0. The images have also been reshaped into a single dimension with 1024 features (32x32). The first dimension of each row in each set is a 1024-dimensional vector, and the second dimension is an integer number (0-9). The samples have been grouped together in a single pickle file using Python's serialization tool Pickle and then compressed using the GZIP compression algorithm for faster transmission.

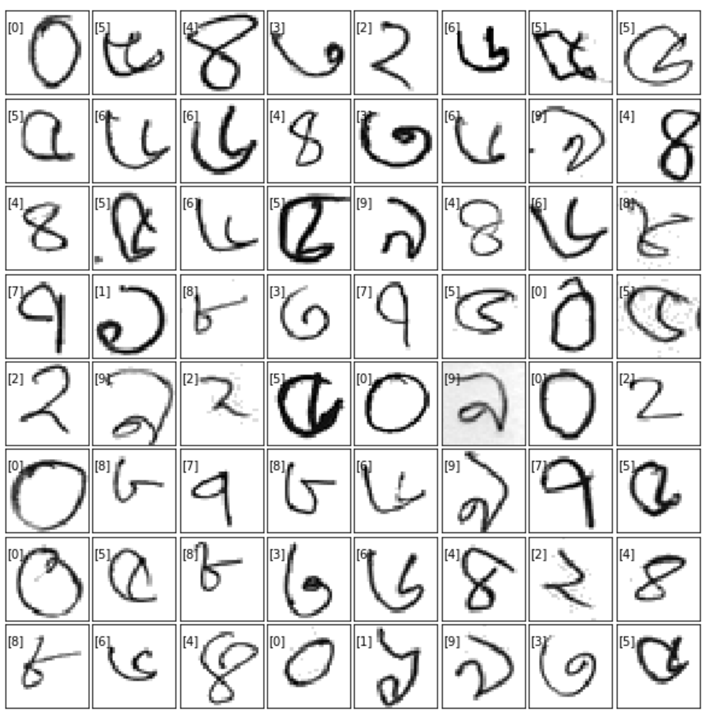

Figure 3.3.1(a): Dataset Visualization of BHaND dataset.

	0	1	2	3	4	5	6	7	8	9	...	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5 rows × 1024 columns

Figure 3.3.1(b): Data Frame

3.3.2 Data Preprocessing

First, we have to invert the image so that black pixels are close to 1 and the white pixels are close to 0. Then we have to normalize the image by converting values that are less than 0.5 to 0. Then we can crop the extra background to get better results. Now we shape the data to our required square shape 32x32. Now, we have to compress the data to a GZIP file to use it easily in our project.

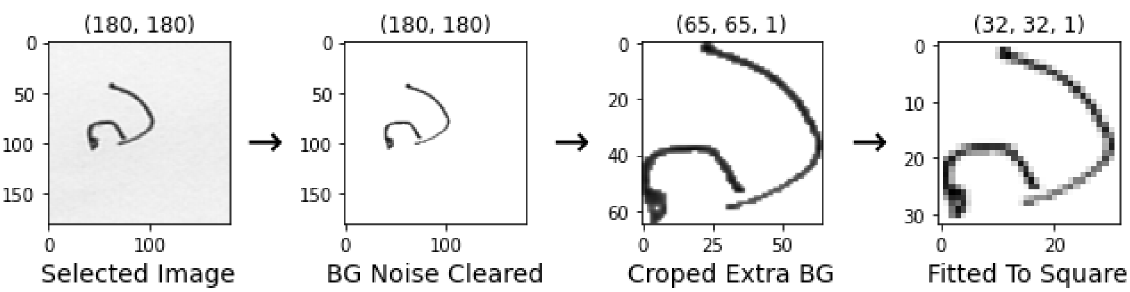

Figure 3.3.2: Image Normalizing

Now we load that GZIP compressed file in our project and we decompress the file. After decompressing we load the pickle file to three two-dimensional Tuple sets (trainSet, validSet, testSet). Then we separate that tuple to (X_train, y_train) Arrays. Here, X_train is our png data and y_train is our label of that data. Then we convert those two Arrays to Pandas DataFrame. We do similar operations for validSet and testSet.

Now, we have to reshape our data by transforming X_train sets from a 50000x1024 data frame to a 50000x32x32x1 4D tensor for Keras modeling. Here, we have 50000 images in the train set which are in 32x32 pixels and the 4th dimension is for color profile. Our color profile means those are gray-scale images.

3.4 Statistical Analysis

The dataset for this model contains 70,000 samples The samples are divided into three sets: training (50,000), validation (10,000), and test (10,000).

- Training set - for learning purposes.
- Validation set - for picking the model which minimize the loss on this set
- Test set - for testing the performance of the model picked using metrics such as accuracy score.

From the number of samples, we can represent a statistical analysis with a pie chart [25]:

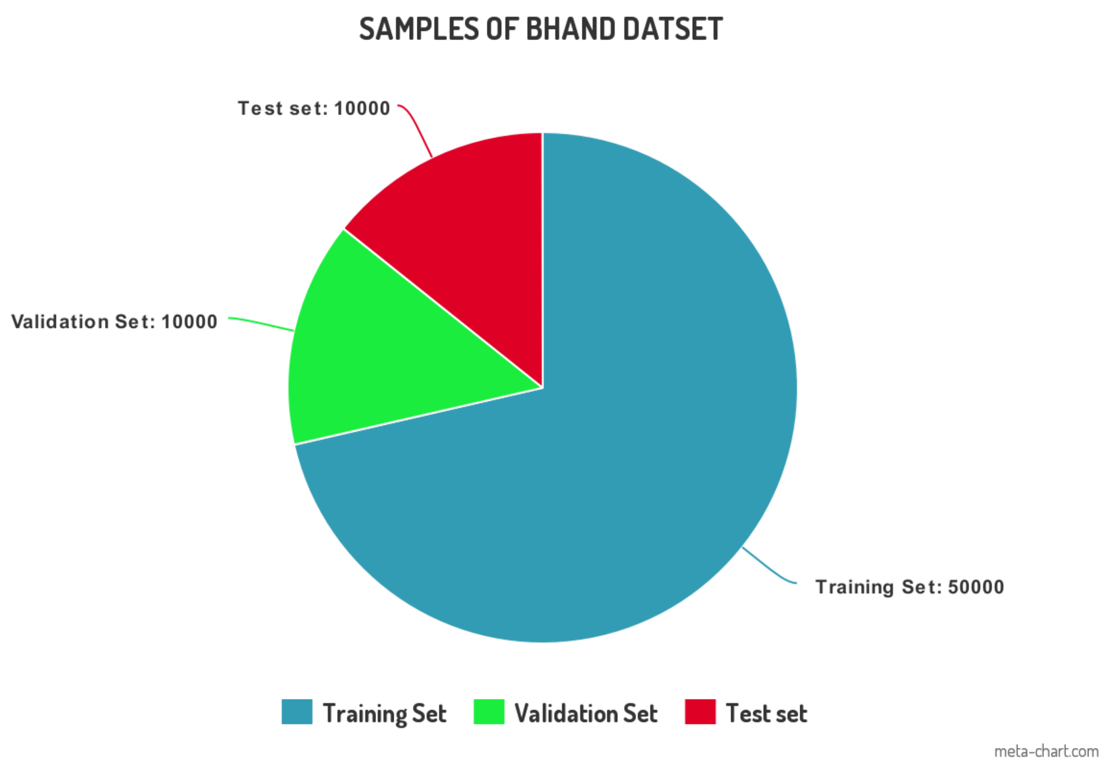

Figure 3.4: Pie chart of Statistical analysis.

3.5 Proposed Methodology

3.5.1 Model Training

In our model, we used Sequential Modeling, which is a method of creating deep learning models by creating an instance of the Sequential class and adding layers to it. Our model consists of 6 layers, including an input layer for inputting images and subsequent layers including conv2D, MaxPool2D, Flatten, Dense, Dropout, and another Dense layer.

3.5.2 Proposed Layer Description

In this model, we used a combination of different types of layers to build a neural network. These layers play a vital role in the model's ability to learn and make predictions. Here is a brief overview of the 5 layers that were used:

- Conv2D: A convolutional layer that applies a 2D convolution operation to the input data.
- MaxPool2D: A pooling layer that down-samples the input data along its spatial dimensions.
- Flatten: A layer that converts the multi-dimensional input tensors into a single dimension.
- Dense: A fully-connected layer in which each neuron receives input from all neurons in the previous layer.
- Dropout: A layer that prevents overfitting by randomly setting input units to 0 during training. Each of these layers has a specific function and plays a unique role in the overall operation of the model.

In summary, each of the above layers plays an important role in creating a machine learning model by performing specific functions such as feature extraction, down-sampling, flattening, prediction, and regularization. The figure 3.5 represents the sequential model layers consists of 6 layers in total excluding the input layer.

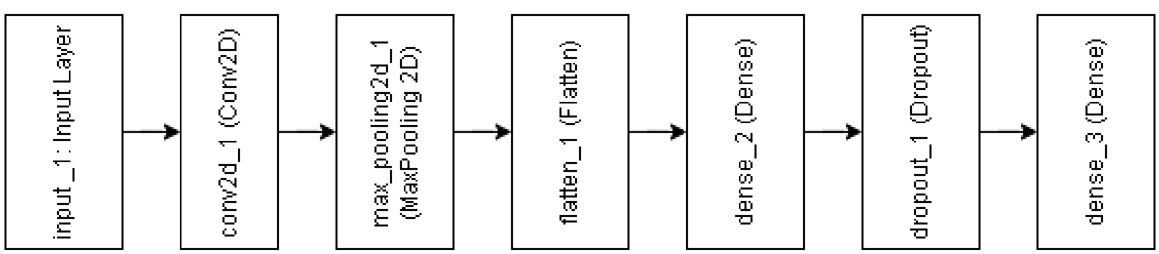

Figure 3.5: Layered Diagram of Proposed Model

Here is our Model Summary:

Table 3.5: Summary of the proposed model

Layer (type)	**Output Shape**	**Param #**
conv2d_1 (Conv2D)	(None, 30, 30, 64)	640
max_pooling2d_1 (MaxPooling 2D)	(None, 15, 15, 64)	0
flatten_1 (Flatten)	(None, 14400)	0
dense_2 (Dense)	(None, 128)	1843328
dropout_1 (Dropout)	(None, 128)	0
dense_3 (Dense)	(None, 10)	1290

Here,
Total parameters: 1,845,258

Trainable parameter: 1,845,258

Non-trainable params: 0

3.6 Implementation Requirements

In order to effectively recognize handwritten digits, it is important to have a system that can understand the structure of these digits. Convolutional neural networks (CNNs) are particularly well-suited for this task, as they are able to perceive the structure of handwritten digits in a way that helps with the automated extraction of distinguishing features. As a result, CNNs are the best choice for solving handwriting recognition challenges. To build a system for recognizing Bangla handwritten digits, it is necessary to use a CNN architecture. This is because the CNN architecture is specifically designed to work with this type of problem, and is therefore essential for the development of a successful Bangla handwritten digit recognition system.

3.6.1 Convolutional Neural Network (CNN)

A convolutional neural network (CNN) is a type of deep learning network that is able to learn directly from data. This type of network is particularly effective at detecting patterns in images, which can be used to recognize objects, categories, and classes. A CNN is composed of three types of layers: pooling layers, and convolutional layers fully connected layers. When these layers are stacked together, they form the architecture of a CNN. Additionally, there are two other important parameters that are often used in CNNs: the dropout layer and the activation function. The dropout layer helps to prevent overfitting by randomly setting input units to 0 during training, while the activation function is used to introduce non-linearity into the network.

Features of CNN:

- A convolution tool that separates and identifies the image's various features for analysis, a process known as Feature Extraction.
- The feature extraction network is made up of many pairs of convolutional or pooling layers.
- A fully connected layer that uses the convolution process output to predict the image class based on the features extracted in previous stages.

The goal of this CNN feature extraction model is to reduce the number of features in a dataset. It generates new features that summarize the existing features in an initial set of features. As shown in the CNN architecture diagram, there are numerous CNN layers. (Figure 3.6.1)

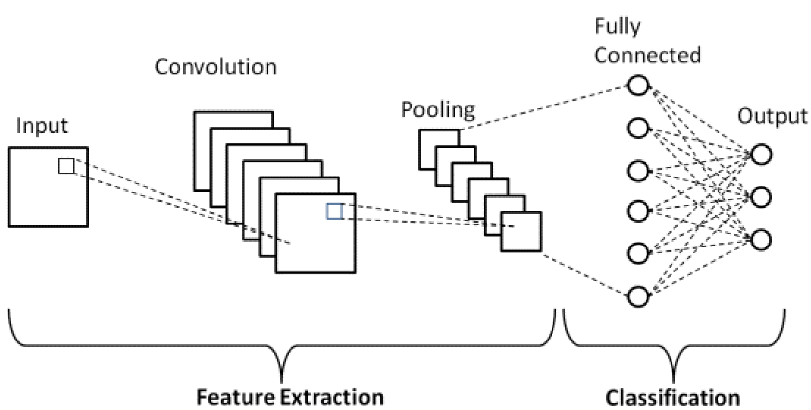

Figure 3.6.1: Basic architecture of CNN

CHAPTER 4

Experimental Results and Discussion

4.1 Experimental Setup

The results are based on their accuracy, confusion matrix and test images for expected test outcomes. In order to get these results, we need to compile the model for fitting the model. When compiling the model with dedicated layers we callback for the accuracy and set the condition as long as the model accuracy has reaches 99.1% accuracy.

We run for 100 epochs for fitting the model where we reached on 99.1% accuracy just on 7 epochs. Further describing with proper analysis in next sections.

4.2 Experimental Results & Analysis

In our model, we were able to achieve an accuracy of 99.1% within a few minutes of training, after completing 7 epochs of model fitting. Model fitting refers to the process of evaluating how well a machine learning model is able to generalize to new, similar data. In this case, we were able to see the accuracy and loss of the model after it was trained and compiled. This high level of accuracy suggests that the model was able to effectively learn from the training data and apply that knowledge to new, similar data.

```
========================= Compiling  model =========================


============================ Model- Fit ============================
Epoch 1/100
1250/1250 [==============================] - 13s 4ms/step - loss: 0.3244 - acc: 0.9001 - val_loss: 0.1306 - val_acc: 0.9586
Epoch 2/100
1250/1250 [==============================] - 4s 3ms/step - loss: 0.1089 - acc: 0.9681 - val_loss: 0.0955 - val_acc: 0.9705
Epoch 3/100
1250/1250 [==============================] - 5s 4ms/step - loss: 0.0672 - acc: 0.9796 - val_loss: 0.1027 - val_acc: 0.9699
Epoch 4/100
1250/1250 [==============================] - 4s 3ms/step - loss: 0.0469 - acc: 0.9854 - val_loss: 0.0962 - val_acc: 0.9725
Epoch 5/100
1250/1250 [==============================] - 4s 3ms/step - loss: 0.0364 - acc: 0.9881 - val_loss: 0.1143 - val_acc: 0.9699
Epoch 6/100
1250/1250 [==============================] - 4s 3ms/step - loss: 0.0330 - acc: 0.9886 - val_loss: 0.1022 - val_acc: 0.9755
Epoch 7/100
1243/1250 [============================>.] - ETA: 0s - loss: 0.0265 - acc: 0.9912

Model has reached >99% accuracy :)

1250/1250 [==============================] - 4s 3ms/step - loss: 0.0264 - acc: 0.9912 - val_loss: 0.1114 - val_acc: 0.9730
```

Figure 4.2: Model accuracy and loss

4.2.1 Model Evaluation and Confusion Matrix

We can also visualize our accuracy and loss from the model evaluation by showing the Confusion Matrix. Here is our Confusion Matrix based on the true label a predicted label.

```
========================= Model Evaluation =========================
625/625 [==============================] - 2s 3ms/step - loss: 0.1199 - acc: 0.9725

=================== Tensorflow Confusion Matrix ====================
625/625 [==============================] - 1s 2ms/step
```

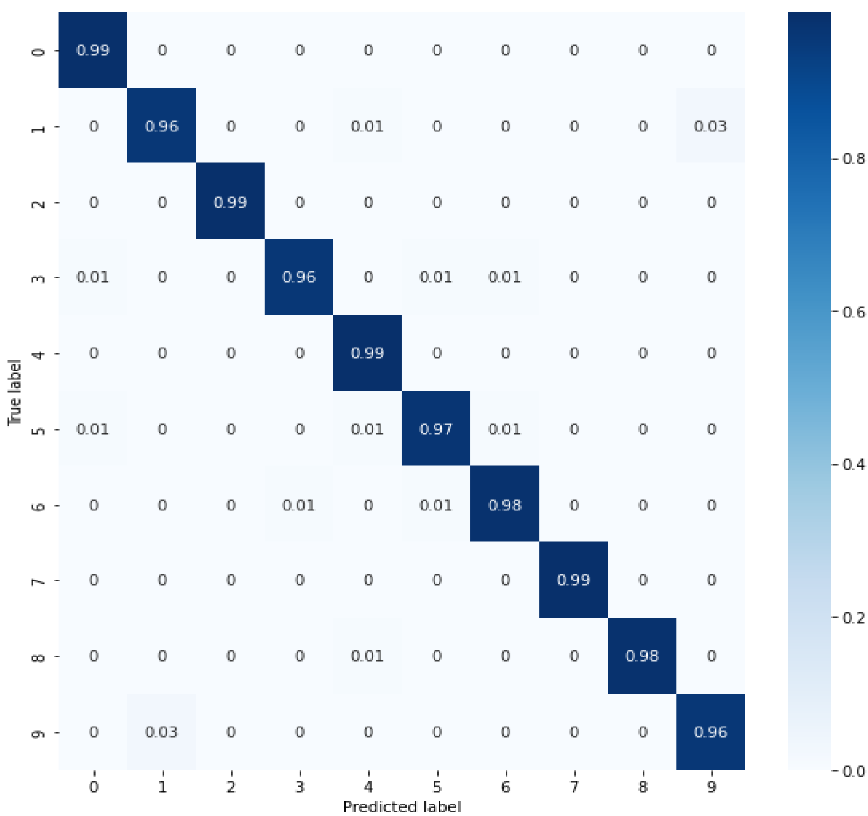

Figure 4.2.1: Model Evaluation and Confusion Matrix

4.2.2 True label and Predicted label

The below figure shows the predicted label and its true label at a range of 1 to 24. Which took less than a second to execute (56ms) and all the true label results are similar with the predicted labels.

```
1/1 [==============================] - 0s 56ms/step
True Label     : [7. 0. 7. 1. 7. 4. 5. 7. 2. 1. 6. 5. 5. 2. 3. 2. 1. 3. 7. 3. 4. 4. 7. 8.]
Pridcted Label : [7 0 7 1 7 4 5 7 2 1 6 5 5 2 3 2 1 3 7 3 4 4 7 8]
```

Figure 4.2.2: True label and Predicted label results

4.2.3 Model Prediction Results

The image was taken from the drive which was already mounted and stored for model predicting test images. For testing an image for getting the predicted output, more than 100 of images were uploaded or stored. In order to input an image, the default pixel size was set in the system was 180x180 pixels which was already the default size of all the test images. Showing the input samples of test images from 0-9 down below:

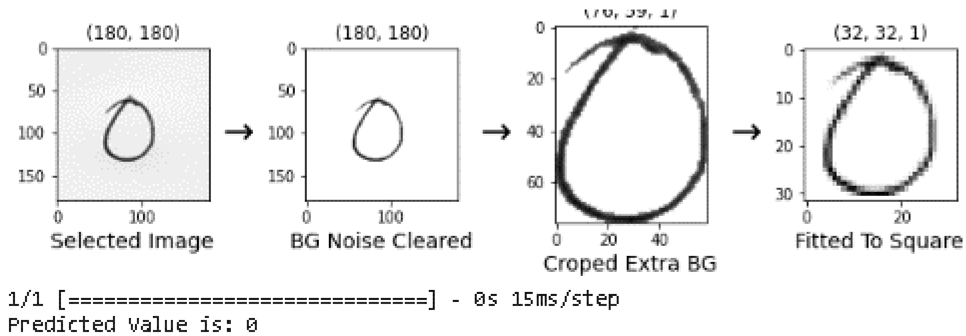

Figure 4.2.3 (i): Prediction test of 0

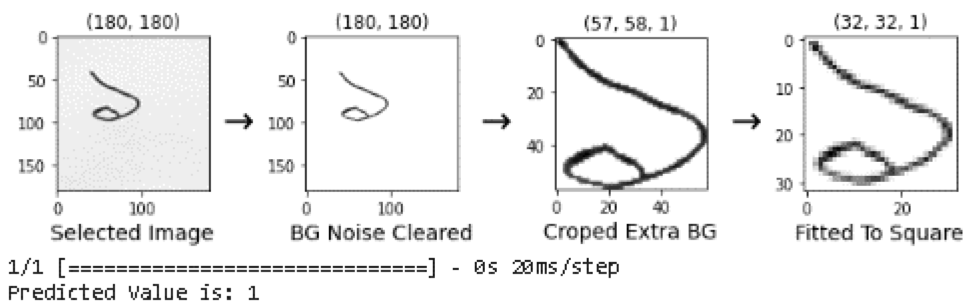

Figure 4.2.3 (ii): Prediction test of 1

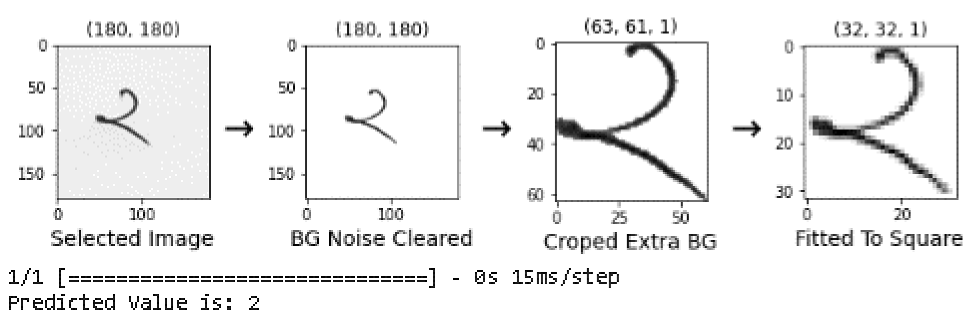

Figure 4.2.3 (iii): Prediction test of 2

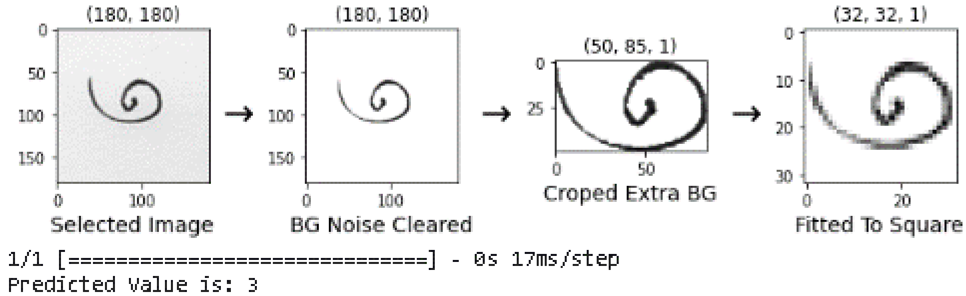

Figure 4.2.3 (iv): Prediction test of 3

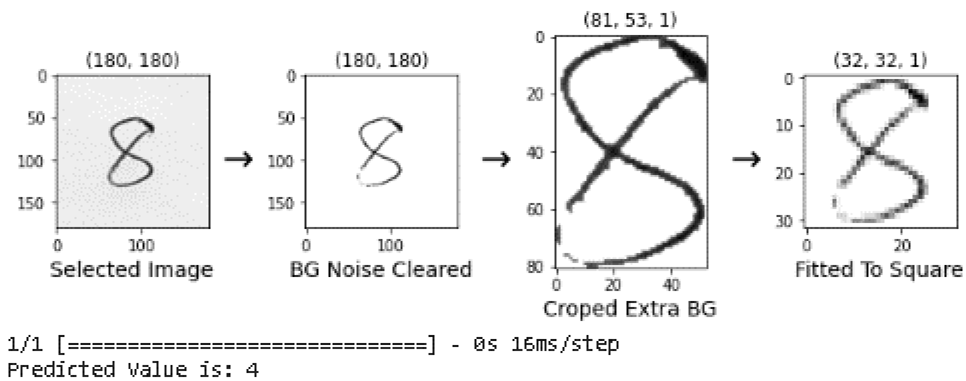

Figure 4.2.3 (v): Prediction test of 4

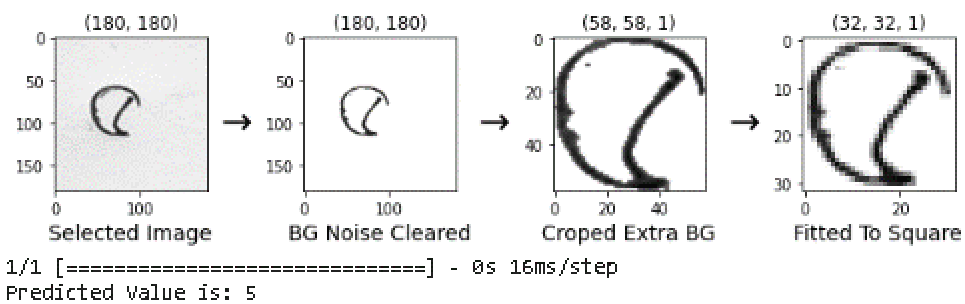

Figure 4.2.3 (vi): Prediction test of 5

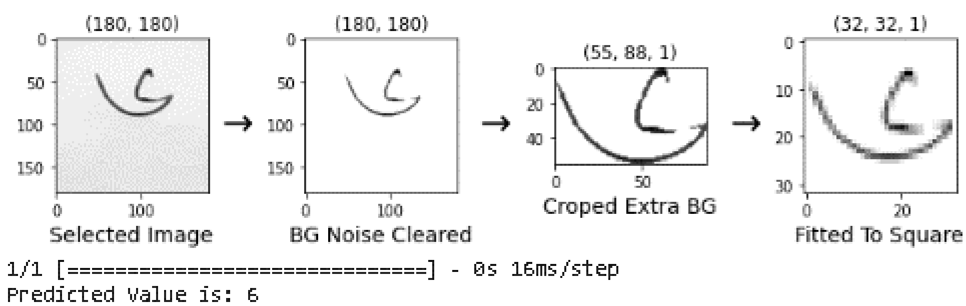

Figure 4.2.3 (vii): Prediction test of 6

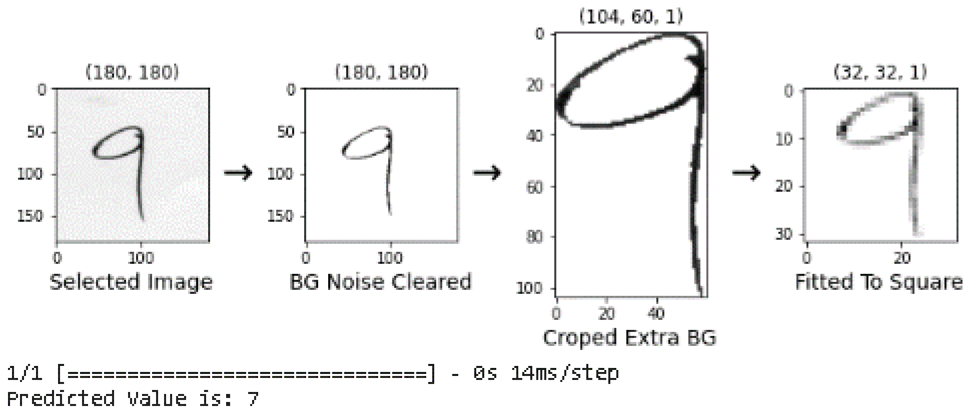

Figure 4.2.3 (viii): Prediction test of 7

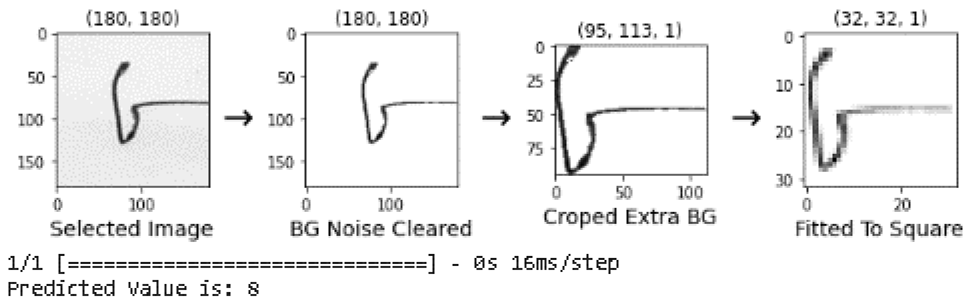

Figure 4.2.3 (ix): Prediction test of 8

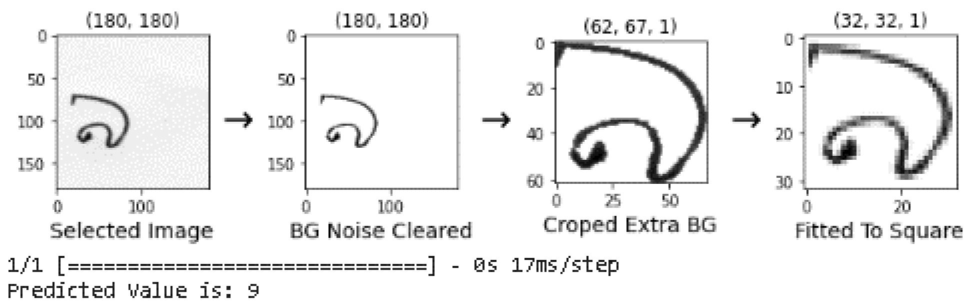

Figure 4.2.3 (x): Prediction test of 9

4.3 Discussion

From Model fitting and Model evaluation we can check the accuracy and TensorFlow confusion matrix where we have achieved an accuracy of 99.1%. We can also see the test images that we have predicted from 0-9 digits with accurate predicted output from the test images. So far, the model has performed so well with 'BHaND' dataset both for accuracy and prediction output.

CHAPTER 5

Impact on Society, Environment and Sustainability

5.1 Impact on Society

The research on "Bangla Handwritten Digit Recognition Using Convolutional Neural Network" has an impressive impact in today's society. In Bangladesh, a lot of cities and districts has many organizations that are using and storing with government or non-government documents that are being processed manually. Specially many documents are filled with Bangla handwritten numerals that takes time to process the data manually from the documents. Every day, a large number of government or non-government documents must be digitalized in order to store office data and people's biodata. Where a mass number of Bangla handwritten digits are used. With the help of Machine learning our recognition system will extract those digits from those documents much quicker with accurate output and saves us a lot of time and less error than manually extracting by people.

5.2 Impact on Environment

With less error and good accuracy, a system can work much better where humans can't. Machine learning approaches will make daily aspects of computer-related work much easier in the near future. Our Bangla handwritten recognition system, on the other hand, will allow people to work much more easily and quickly in computer working environments where people can use our feature extraction for automation and digitizing documents with accurate prediction results and efficient accuracy with less error. The Bangla handwritten digit recognition system will be helpful for digitizing documents and reducing the need for paper, which will have a positive environmental impact.

5.3 Ethical Aspects

Ethical aspect refers to the ethical considerations or principles that are relevant to a particular issue or situation. As we consider the ethical aspects of using a Bangla handwritten digit recognition system in Bangladesh, it's important to keep the following points in mind: We should strive to ensure that the system is fair and unbiased, and that it is accessible to all users in the country. We should be mindful of the potential consequences of using the system, and make sure that it is being used in a responsible and respectful manner. We should be transparent about how the system works and how data is being used, in order to ensure that individuals understand the potential implications of using the system and can make informed decisions about whether to use it. We should respect the cultural and legal norms around privacy in Bangladesh when using the system, and make sure that it is being used in a way that respects the privacy of the individuals whose data might be contained in the images. We should ensure that the system is secure and that data is protected from unauthorized access or misuse.

5.4 Sustainability Plan

As I work on “Bangla handwritten digit recognition system using a convolutional neural network” (CNN), I am mindful of the need to ensure the long-term sustainability of the system. To this end, I will focus on a number of key areas in my work. One such area is the use of open-source tools and libraries. By using open-source tools and libraries, I can reduce the cost of developing and maintaining the system, and make it easier for others to contribute to and improve the system. This can help to ensure the long-term sustainability of the system by enabling a community of developers to collaborate and support the system over time. Another important area is resource consumption. By optimizing the system for efficiency and minimizing the use of resources such as energy and computing power, I can reduce the environmental impact of the system and make it more sustainable. This is particularly important given the global challenge of climate change and the need to reduce our reliance on non-renewable resources. In addition to these considerations, I will also focus on using data responsibly and ethically, engaging with stakeholders such as users, developers, and regulators, and monitoring and assessing the system to identify any potential issues and address them in a timely manner. By making conscious choices and taking specific actions, I can make sure that the impact of my work is beneficial to society, the environment, and the well-being of people and communities.

CHAPTER 6

Summary, Conclusion, Recommendation and Implication for Future Research

6.1 Summary of the Study

The goal of the project was to build a machine learning model that could accurately recognize handwritten digits in the Bangla script. To achieve this goal, we evaluated the performance of Keras Sequential Model with lesser epochs and less computation time. Here are the basic steps we followed for our system:

- Data preprocessing
- Reshape the data of the BHaND dataset.
- Used Keras Sequential model API to create and fit the model, and achieved an accuracy of 99.1%.
- The model was then tested on a set of test images to evaluate its performance. The test images for the model were saved to a drive for further analysis.

This project was successful in creating a machine learning model that can accurately identify handwritten Bangla digits. The use of the BHaND dataset and the Keras Sequential model API were essential to this achievement.

6.2 Conclusions

To summarize, this project successfully created a machine learning model that can identify handwritten Bangla digits with a high degree of accuracy. The goal of the project was achieved through the use of two main parts as BHaND dataset, and a TensorFlow CNN algorithm Keras Sequential model API. However, the system faced challenges in testing images that were not the default pixel size or had more than one handwritten digit. These challenges could be addressed in future work by improving the image preprocessing and segmentation techniques used in the system. Overall, this project has demonstrated the potential of machine learning techniques in recognizing handwritten digits in the Bangla script, and could potentially be used in a variety of applications such as handwritten digit recognition in documents or automated data entry.

6.3 Recommendations

- Improve image preprocessing techniques and explore other machine learning techniques to improve the model's performance.
- Address challenges related to compound digits and non-default pixel sizes through techniques such as image segmentation or additional preprocessing steps.
- Expand the dataset and evaluate the system's performance in real-world scenarios to identify additional challenges and limitations.
- These efforts could involve collecting and testing additional images or using the system in a real-world application to see how it performs under different conditions.

6.4 Implication for Further Study

The development of a machine learning model that can accurately recognize handwritten Bangla digits has a number of potential implications for further study, in terms of the broader use of machine learning in language processing and recognition tasks. Here are some potential implications for further study based on the project:

Improved digit recognition in documents and data entry: The ability to accurately recognize handwritten Bangla digits could have a number of practical applications in Bangladesh, such as in the recognition of handwritten digits in documents or in automated data entry. This could improve the efficiency and accuracy of these processes, and reduce the need for manual data entry.

Reduced reliance on paper documents: The development of a machine learning model that can recognize handwritten Bangla digits could also help to reduce the reliance on paper documents in Bangladesh. This could have environmental benefits by reducing the amount of paper used, as well as practical benefits such as improving the accessibility and security of digital documents. Improved access to information: The ability to accurately recognize handwritten Bangla digits could also improve access to information in Bangladesh, particularly for those who may have difficulty reading printed materials or using digital technologies. This could include individuals with visual impairments or those who are not literate in the written language.

Further research on machine learning techniques: The success of this project could also encourage further research on machine learning techniques for recognizing handwritten digits in the Bangla script and other languages, and potentially lead to the development of similar systems for other scripts or languages. This could have broader implications for the use of machine learning in language processing and recognition tasks.

References:

[1] Khalil Ahammad, Chowdhury Shahriar Muzammel, Fozilatunnesa Masuma, and Chayti Saha, "Real time bangla digit recognition through hand gestures on air using ...," 02-Feb-2022. [Online]. Available: https://www.researchgate.net/publication/358622019_Real_time_Bangla_Digit_Recognition_through_Hand_Gestures_on_Air_Using_Deep_Learning_and_OpenCV. [Accessed: 26-Dec-2022].

[2] Afsana Hossain, Md. Sabbir Hasan, Mujtaba Asif, and Amit Kumar Das, "Performance analysis on Bangla handwritten digit recognition using CNN ...," Jan-2021. [Online]. Available: https://www.researchgate.net/publication/354212966_Performance_Analysis_On_Bangla_Handwritten_Digit_Recognition_Using_CNN_And_Transfer_Learning. [Accessed: 26-Dec-2022].

[3] Chen, S., Almamlook, R., Gu, Y., & Wells, L, "Offline handwritten digits recognition using machine learning," Sep-2018. [Online]. Available: https://www.researchgate.net/profile/Rabia-Al-Mamlook/publication/328342141_Offline_Handwritten_Digits_Recognition_Using_Machine_learning/links/5d1ba47c458515c11c0ca16d/Offline-Handwritten-Digits-Recognition-Using-Machine-learning.pdf. [Accessed: 02-Jan-2023].

[4] M. F. Sikder, "Bangla handwritten digit recognition and generation," *arXiv.org*, 14-Mar-2021. [Online]. Available: https://arxiv.org/abs/2103.07905. [Accessed: 26-Dec-2022].

[5] K. M. Islam, R. Noor, C. Saha, and J. Rahimi, "A Deep Convolutional Neural Network for Bangla Handwritten Numeral Recognition," in 2018 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE), 2018, pp. (45-50). doi: 10.1109/WIECON-ECE.2018.8783151.

[6] Y. S. Bharadwaj and B.P. Kolla, "[PDF] effective handwritten digit recognition using deep convolution neural network: Semantic scholar," *International Journal of Advanced Trends in Computer Science and Engineering*, Apr-2020. [Online]. Available: https://www.semanticscholar.org/paper/Effective-Handwritten-Digit-Recognition-using-Deep-Bharadwaj/35190e26a1714702873ecfb11a8afcc11c456f90. [Accessed: 02-Jan-2023].

[7] S. M. A. Hakim and Asaduzzaman, "Handwritten bangla numeral and basic character recognition using deep convolutional neural network: Semantic scholar," *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, 01-Jan-1970. [Online]. Available: https://www.semanticscholar.org/paper/Handwritten-Bangla-Numeral-and-Basic-Character-Deep-Hakim-Asaduzzaman/f7c7535d5faf82dfeeae684b90fdcb98097dc7c9. [Accessed: 03-Jan-2023].

[8] P. K. Singh, I. Chatterjee, R. Sarkar, E. B. Smith, and M. Nasipuri, “A new feature extraction approach for script invariant handwritten ...,” 01-Apr-2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1111/exsy.12699. [Accessed: 26-Dec-2022].

[9] M. S. Hossain, M. A. Hossain, A. F. M. Z. Abadin, and M. M. Ahmed, “Handwritten Bangla Numerical Digit Recognition Using Fine Regulated Deep Neural Network,” 01-Jul-2022. [Online]. Available: https://www.researchgate.net/publication/357203011_Handwritten_Bangla_Numerical_Digit_Recognition_Using_Fine_Regulated_Deep_Neural_Network. [Accessed: 26-Dec-2022].

[10] Ahlawat S;Choudhary A;Nayyar A;Singh S;Yoon B; A. Choudhary, A. Nayyar, S. Singh, and B. Yoon, “Improved handwritten digit recognition using convolutional neural networks (CNN),” *Sensors (Basel, Switzerland)*, 12-Jun-2020. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/32545702/. [Accessed: 26-Dec-2022].

[11] M. Islam, S. A. Shuvo, M. S. Nipun, R. B. Sulaiman, J. Nayeem, Z. Haque, M. M. Shaikh, and M. S. U. Sourav, “Efficient approach of using CNN based pretrained model in Bangla handwritten digit recognition,” *arXiv.org*, 19-Sep-2022. [Online]. Available: https://arxiv.org/abs/2209.13005. [Accessed: 26-Dec-2022]

[12] M. F. Wahid, M. F. Shahriar, and M. S. I. Sobuj, “A classical approach to handcrafted feature extraction techniques for Bangla handwritten digit recognition,” *arXiv.org*, 25-Jan-2022. [Online]. Available: https://arxiv.org/abs/2201.10102v1. [Accessed: 26-Dec-2022].

[13] M. Z. Alom, P. Sidike, T. M. Taha, and V. K. Asari, “Handwritten Bangla digit recognition using Deep Learning,” *arXiv.org*, 07-May-2017. [Online]. Available: https://arxiv.org/abs/1705.02680. [Accessed: 26-Dec-2022].

[14] M. R. Mamun, Z. Al Nazi, and M. S. U. Yusuf, “Bangla handwritten digit recognition approach with an ensemble of deep ...,” 21-Sep-2018. [Online]. Available: https://ieeexplore.ieee.org/document/8554674/. [Accessed: 02-Jan-2023].

[15] M. J. Hasan, M. F. Wahid, and M. S. Alom, “A new state of Art Deep Learning Approach for bangla ... - IEEE xplore,” 03-Jul-2020. [Online]. Available: https://ieeexplore.ieee.org/document/9225367. [Accessed: 02-Jan-2023].

[16] O. Paul, “Image pre-processing on numtadb for Bengali handwritten digit recognition,” 18-Aug-2020. [Online]. Available: https://arxiv.org/pdf/2008.07853. [Accessed: 26-Dec-2022].

[17] A. Singh, R. Sarkhel, N. Das, M. Kundu, and M. Nasipuri, “A skip-connected multi-columnnetwork for isolated handwritten Bangla character and digit recognition,” *arXiv.org*, 27-Apr-2020. [Online]. Available: https://arxiv.org/abs/2004.12769

[18] J. Ferdous, S. Karmaker, A. K. M. S. A. Rabby, and S. A. Hossain, “Matrivasha: A multipurpose comprehensive database for Bangla handwritten compound characters,” *arXiv.org*, 06-May-2020. [Online]. Available: https://arxiv.org/abs/2005.02155. [Accessed: 26-Dec-2022].

[19] P. Chakraborty, S. S. Jahanapi, and T. Choudhury, “Bangla handwritten digit recognition,” *SpringerLink*, 29-Sep-2021. [Online]. Available: https://link.springer.com/chapter/10.1007/978-981-16-4284-5_14. [Accessed: 26-Dec-2022].

[20] T. R. Das, S. Hasan, M. R. Jani, F. Tabassum, and M. I. Islam, “Bangla handwritten character recognition using extended convolutional neural network,” *Journal of Computer and Communications*,26-Feb-2021. [Online]. -Available: https://www.scirp.org/journal/paperinformation.aspx?paperid=108201. [Accessed: 26-Dec-2022].

[21] M. H. Bappy, M. S. Haq, and K. H. Talukder, “Bangla handwritten numeral recognition using deep convolutional neural network,” *Khulna University Studies*, 03-Jul-2022. [Online]. Available: https://ku.ac.bd/journal/kustudies/article/view/911. [Accessed: 26-Dec-2022].

[22] H. Huda, M. A. I. Fahad, M. Islam, and A. K. Das, “Bangla handwritten character and digit recognition using deep ...,” 28-Feb-2022. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9721634/. [Accessed: 26-Dec-2022].

[23] M. A. Akbar and M. S. Islam, “Deep convolutional neural network for handwritten Bangla ... - IEEE xplore,” 21-Dec-2021. [Online]. Available: https://ieeexplore.ieee.org/document/9641127. [Accessed: 26-Dec-2022].

[24] Chowdhury, A.M. and Rahman, M.S. (2016) “Towards optimal convolutional neural network parameters for Bengali handwritten numerals recognition,” *2016 19th International Conference on Computer and Information Technology (ICCIT)* [Preprint]. Available at: https://doi.org/10.1109/iccitechn.2016.7860237.

[25] “Graphing/charting and General Data Visualization app,” *Meta*. [Online]. Available: https://www.meta-chart.com/. [Accessed: 31-Dec-2022]

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