CHAPTER 1

INTRODUCTION

1.1 Overview

Handwritten digit recognition is the ability of a computer system to recognize the handwritten inputs like digits, characters etc. from a wide variety of sources like emails, papers, images, letters etc. This has been a topic of research for decades. Great strides have been achieved in pattern recognition in recent years. This rapid progress has resulted from a combination of a number of developments including the proliferation of powerful, inexpensive computers, the invention of new algorithms that take advantage of these computers, and the availability of large databases of characters that can be used for training and testing. Handwritten digit recognition is an active topic in Optical Character Recognition (OCR) applications and pattern classification/learning research. In OCR applications, digit recognition is dealt with in postal mail sorting, bank check processing, form data entry etc.

1.2 Handwritten Digit Recognition

With the rapid development of electronic information, computer input has become more andmore common, but handwriting is still an irreplaceable way for people to transfer information. As a link combining handwritten characters and computer input, handwriting recognition has received more and more attention for its practicability. Handwriting recognition technology is the basis of handwriting interpolation and handwriting identification. In the past decade, machine learning and pattern recognition have extended many highly intelligent handwriting recognition classifications, including artificial neural networks (ANN), support vector machine (SVM), modifiedquadratic discriminant function (MQDF) and hidden Markov model.The performance (accuracy and speed) of digit recognition is crucial to the overall performance.

1.3 Machine Learning

Machine learning is a branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy. Machine learning is actively being used today, perhaps in many more places than one would expect.

Machine learning (ML) is a type of artificial intelligence (AI) that allows software applications to become more accurate at predicting outcomes without being explicitly programmed to do so. Machine learning algorithms use historical data as input to predict new output values.

1.3.1 Applications of Machine Learning:

- Image Recognition Image recognition is one of the most common applications of machine learning. It is used to identify objects, persons, places, digital images, etc.
- Virtual Personal Assistant We have various virtual personal assistants such as Google assistant, Alexa, Cortana, Siri. As the name suggests, they help us in finding the information using our voice instruction. These assistants can help us in various ways just by our voice instructions such as Play music, call someone, open an email, Scheduling an appointment, etc.
- Medical Diagnosis In medical science, machine learning is used for disease diagnoses. With this, medical technology is growing very fast and able to build 3D models that can predict the exact position of lesions in the brain. It helps in finding brain tumors and other brain-related diseases easily

1.3.2 Importance of Machine Learning:

Machine learning is important because it gives enterprises a view of trends in customer behaviour and business operational patterns, as well as supports the development of new products. Many of today's leading companies, such as Facebook, Google and Uber, make machine learning a central part of their operations. Machine learning has become a significant competitive differentiator for many companies.

1.3.3 Types of Machine Learning:

Classical machine learning is often categorized by how an algorithm learns to become more accurate in its predictions. There are four basic approaches: supervised learning, unsupervised learning, semi-supervised learning and reinforcement learning. The type of algorithm data scientists chooses to use depends on what type of data they want to predict.

- Supervised learning: In this type of machine learning, data scientists supply algorithms with labeled training data and define the variables they want the algorithm to assess for correlations. Both the input and the output of the algorithm is specified.

- Unsupervised learning: This type of machine learning involves algorithms that train on unlabelled data. The algorithm scans through data sets looking for any meaningful connection. The data that algorithms train on as well as the predictions or recommendations they output are predetermined.
- Semi-supervised learning: This approach to machine learning involves a mix of the two preceding types. Data scientists may feed an algorithm mostly labelled training data, but the model is free to explore the data on its own and develop its own understanding of the data set.
- Reinforcement learning: Data scientists typically use reinforcement learning, to teach a machine to complete a multi-step process for which there are clearly defined rules. Data scientists program an algorithm to complete a task and give it positive or negative cues as it works out how to complete a task. But for the most part, the algorithm decides on its own what steps to take along the way.

1.3.4 Advantages and Disadvantages of Machine Learning:

Machine learning has seen use cases ranging from predicting customer behaviour to forming the operating system for self-driving cars. When it comes to advantages, machine learning can help enterprises understand their customers at a deeper level. By collecting customer data and correlating it with behaviours over time, machine learning algorithms can learn associations and help teams tailor product development and marketing initiatives to customer demand. Some companies use machine learning as a primary driver in their business models. Uber, for example, uses algorithms to match drivers with riders. Google uses machine learning to surface the ride advertisements in searches. But machine learning comes with disadvantages. First and

foremost, it can be expensive. Machine learning projects are typically driven by data scientists, who command high salaries. These projects also require software infrastructure that can be expensive. There is also the problem of machine learning bias. Algorithms trained on data sets that exclude certain populations or contain errors can lead to inaccurate models of the world that, at best, fail and, at worst, are discriminatory. When an enterprise bases core business processes on biased models it can run into regulatory and reputational harm.

1.4 Deep Learning

Deep learning is a subfield of machine learning, which is, in turn, a subfield of artificial intelligence (AI). For a graphical depiction of this relationship. The central goal of AI is to provide a set of algorithms and techniques that can be used to solve problems that humans perform intuitively and near automatically, but are otherwise very challenging for computers. A great example of such a class of AI problems is interpreting and understanding the contents of an image – this task is something that a human can do with little-to-no effort, but it has proven to be extremely difficult for machines to accomplish. While AI embodies a large, diverse set of work related to automatic machine reasoning (inference, planning, heuristics, etc.), the machine learning subfield tends to be specifically interested in pattern recognition and learning from data.

Artificial Neural Networks (ANNs) are a class of machine learning algorithms in the Fig 1.4.1 that learn from data and specialize in pattern recognition, inspired by the structure and function of the brain. As we'll find out, deep learning belongs to the family of ANN algorithms, and in most cases, the two terms can be used interchangeably. In fact, you may be surprised to learn that the deep learning field has been around for over 60 years, going by different names and incarnations based on research trends, available hardware and datasets, and popular options of prominent researchers at the time.

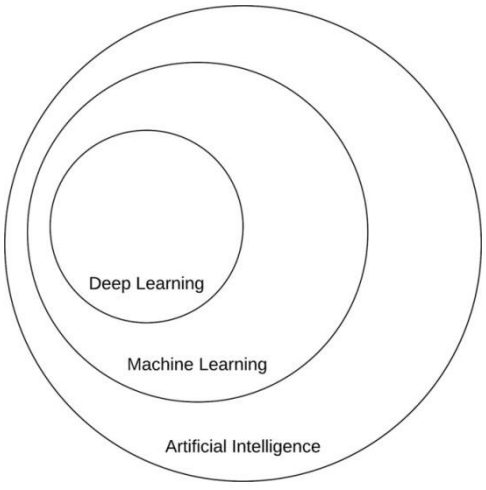

Fig 1.4.1: A Venn diagram describing deep learning as a subfield of machine learning which a subfield of artificial intelligence is in turn.

1.5 Convolutional Neural Network

A Convolutional Neural Network (ConvNet/CNN) is a Deep Learning algorithm which can take in an input image, assign importance (learnable weights and biases) to various aspects/objects in the image and be able to differentiate one from the other. The pre-processing required in a ConvNet is much lower as compared to other classification algorithms. While in primitive methods filters are hand-engineered, with enough training, ConvNets can learn these filters/characteristics. The architecture of a ConvNet is analogous to that of the connectivity pattern of Neurons in the Human Brain and was inspired by the organization of the Visual Cortex. Individual neurons respond to stimuli only in a restricted region of the visual field known as the Receptive Field. A collection of such fields overlaps to cover the entire visual area.

In the **Fig 1.5.1** each layer of CNN applies a different set of filters, typically hundreds or thousands of them, and combines the results, feeding the output into the next layer in the network. During training, a CNN automatically learns the values for these filters.

In the context of image classification, CNN may learn to:

- Detect edges from raw pixel data in the first layer.
- Use these edges to detect shapes (i.e., “blobs”) in the second layer.
- Use these shapes to detect higher-level features such as facial structures, parts of a car, etc.in the highest layers of the network.

The last layer in a CNN uses these higher-level features to make predictions regarding the contents of the image.

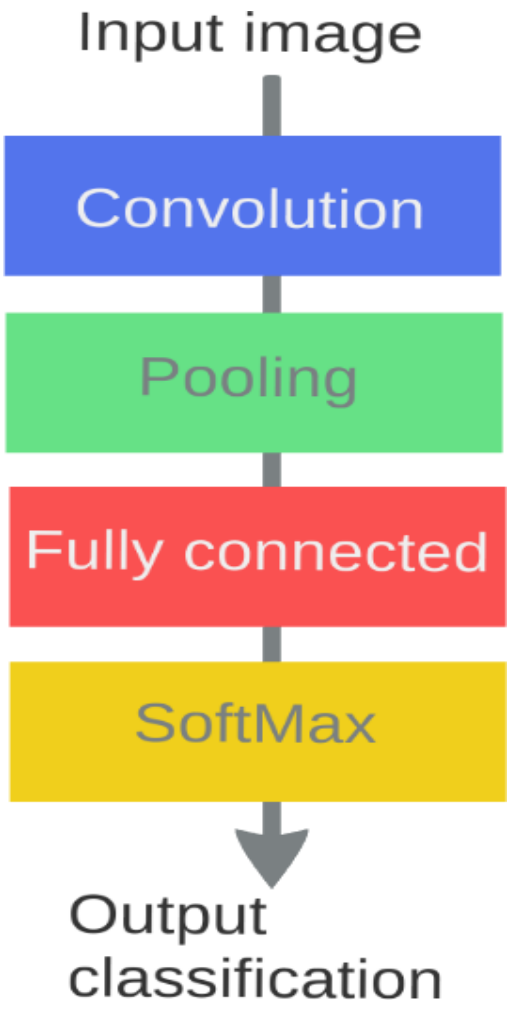

Fig 1.5.1: CNN Layers

Layer 1: CONVOLUTIONAL

The role of the convnet is to reduce the images into a form which is easier to process, without losing featureswhich are critical for getting a good prediction. Example regarding this is shown in **Fig 1.5.2**.

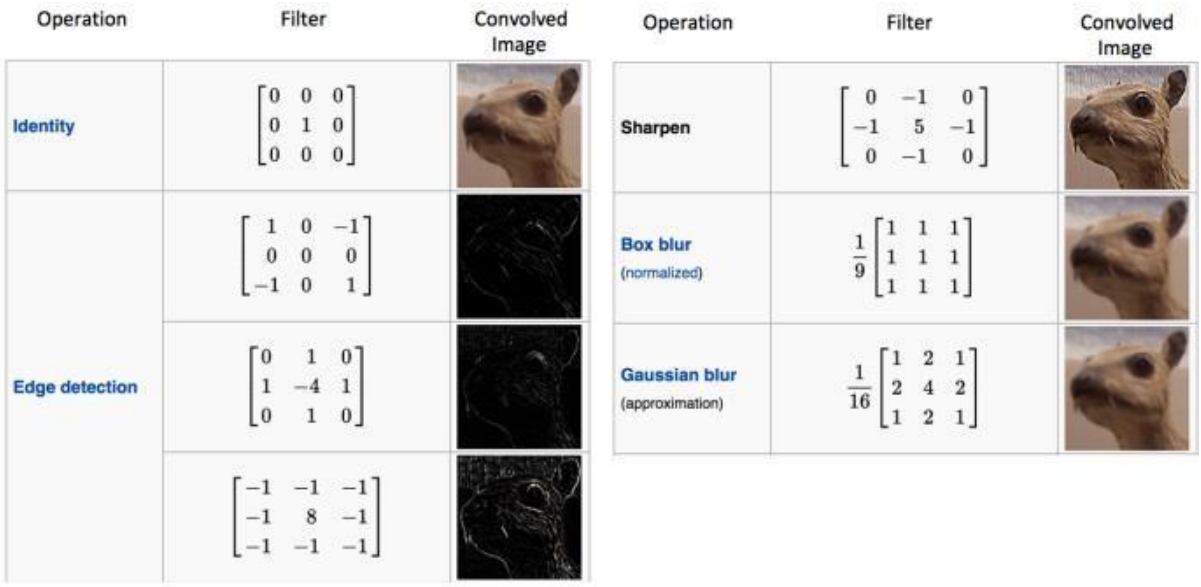

Fig 1.5.2: Example for Convolutional Layer

Layer 2: POOLING LAYER

The pooling layer is responsible for reducing the spatial size of the convolved feature. This is to decrease the computational power required to process the data through dimensionality reduction.

Layer 3 & 4: FULLY CONNECTED OUTPUT LAYER And SOFTMAX

Neurons in FC layers are fully connected to all activations in the previous layer, as is the standard for feedforward neural networks. FC layers are always placed at the end of the network (i.e., we don't apply a CONV layer, then an FC layer, followed by another CONV) layer. It's common to use one or two FC layers prior to applying the softmax classifier, as the following (simplified) architecture demonstrates:

INPUT => CONV => RELU => POOL => CONV => RELU => POOL => FC => FC

Here we apply two fully connected layers before our (implied) softmax classifier which will compute our final output probabilities for each class.

Gives the final probabilities for each label. We have an activation function such as softmax or sigmoid to classify the outputs as cat, dog, car, truck etc. This is shown in the Fig 1.5.3.

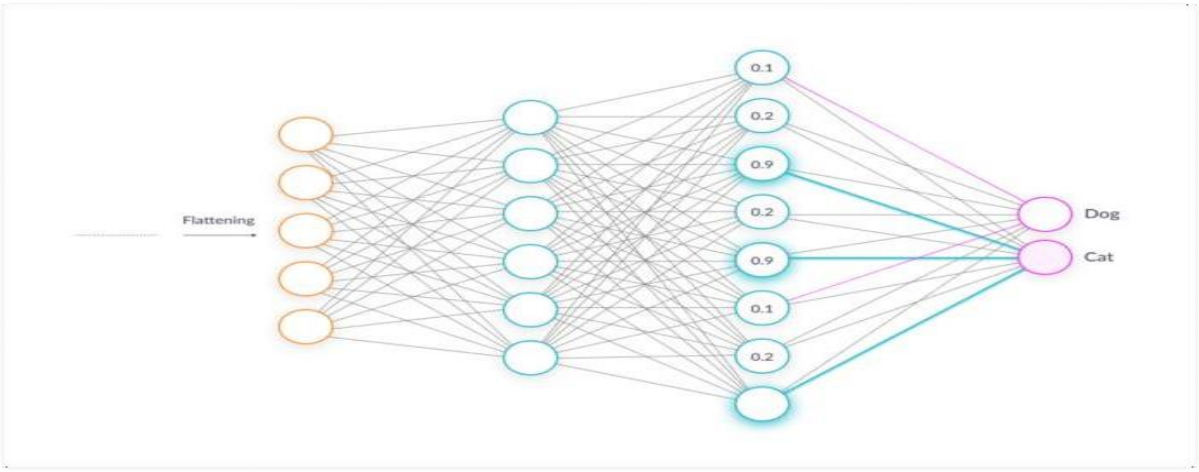

Fig 1.5.3: Fully Connected Output Layer

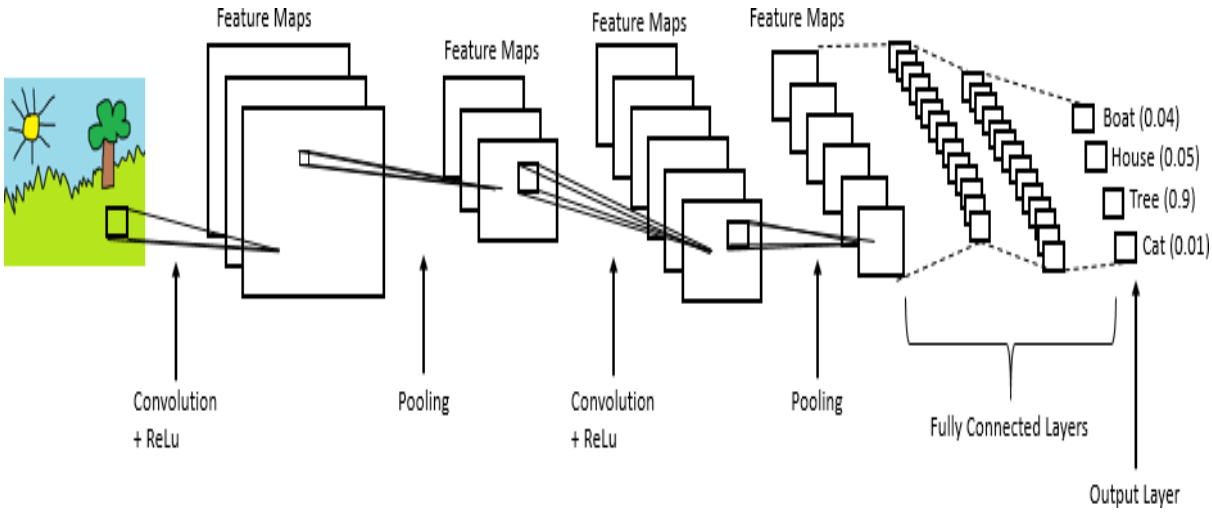

Fig 1.5.4: Complete CNN Architecture

1.6 Principal Component Analysis

Principal component analysis, or PCA, is a statistical procedure that allows you to summarize the information content in large data tables by means of a smaller set of "summary indices" that can be more easily visualized and analyzed.

PCA forms the basis of multivariate data analysis based on projection methods. The most important use of PCA is to represent a multivariate data table as smaller set of variables (summary indices) in order to observe trends, jumps, clusters and outliers. This overview may uncover the relationships between observations and variables, and among the variables.

PCA goes back to Cauchy but was first formulated in statistics by Pearson, who described the analysis as finding "lines and planes of close.

1.7 Support Vector Machine

Support Vector Machine or SVM is one of the most popular Supervised Learning algorithms, which is used for Classification as well as Regression problems. However, primarily, it is used for Classification problems in Machine Learning.The goal of the SVM algorithm is to create the best line or decision boundary that can segregate n-dimensional space into classes so that we can easily put the new data point in the correct category in the future. This best decision boundary is called a hyperplane.

SVM chooses the extreme points/vectors that help in creating the hyperplane. These extreme cases are called as support vectors, and hence algorithm is termed as Support Vector Machine. Consider the below Fig in which there are two different categories that are classified using a decision boundary or hyperplane.

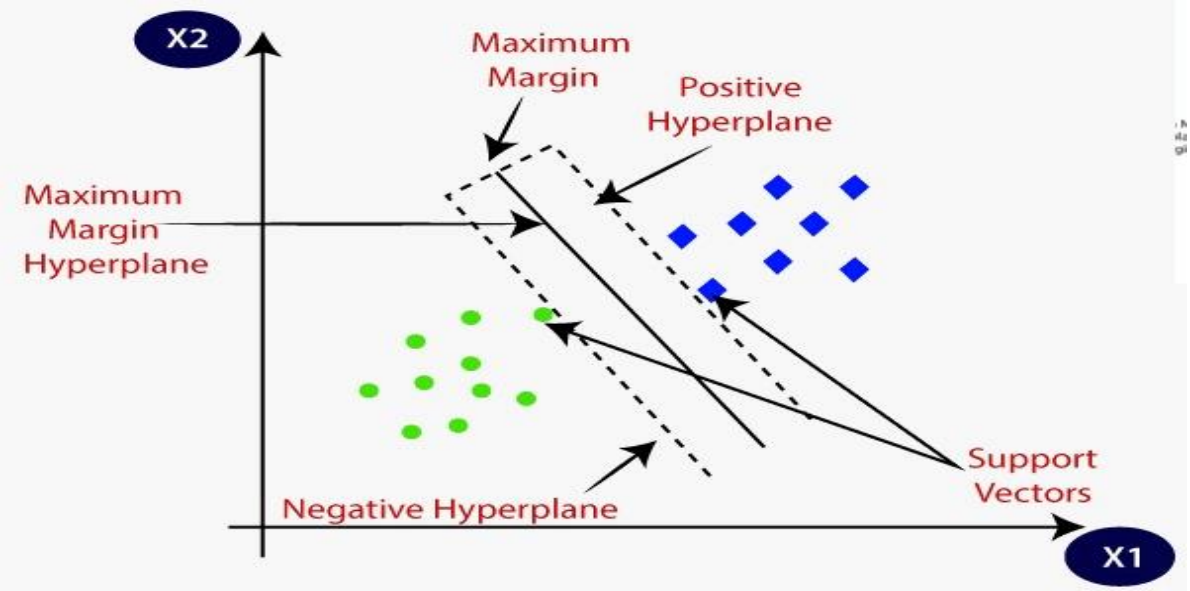

Fig 1.7.1: Support Vector Machine Graph

CHAPTER 2

DETAILED LITERATURE SURVEY

A detailed survey of 16 papers was carried out which are listed below. The main objectives of the paper, the problem statement and the author's approach was studied which helped us to extract the information required for our project and hence come up with our own problem statement and objectives.

1. **[2020] Deep Convolutional Self-Organizing Map Network for Robust Handwritten Digit Recognition,** Saleh Aly , S. Almotairi.

   Deep Convolutional Neural Networks (DCNN) are currently the predominant technique commonly used to learn visual features from images. However, the complex structure of most recent DCNNs impose two major requirements namely, huge labeled dataset and high computational resources. In this paper, we develop a new efficient deep unsupervised network to learn invariant image representation from unlabeled visual data. The proposed Deep Convolutional Self-organizing Maps (DCSOM) network comprises a cascade of convolutional SOM layers trained sequentially to represent multiple levels of features.The N-Dimensional SOM (ND-SOM) grid is trained to extract abstract visual features using its classical competitive learning algorithm. The input image is divided into overlapped local patches where each local patch is represented by the N-coordinates of the winning neuron in the ND-SOM grid.. The output layer of the DCSOM network computes local histograms of each FII bank in the final convolutional SOM layer. Experimental results reveal that the performance of DCSOM outperforms state-of-the-art methods for noisy digits and achieve a comparable performance with other complex deep learning architecture for other image variations.

2. **[2019] Morphological Convolutional Neural Network Architecture for Digit Recognition,** Dorra Mellouli, Tarek M. Hamdani, Javier J. Sanchez-Medina, Mounir Ben Ayed, and Adel M. Alimi

   With the advent of the era of big data in the world and the commercial value of face recognition technology, the prospects for face recognition technology are very bright and have great market demand. This article aims to design a face recognition attendance system based on real-time video processing. This article mainly sets four directions to

consider the problems: the accuracy rate of the face recognition system in the actual check-in, the stability of the face recognition attendance system with real-time video processing, the truancy rate of the face recognition attendance system with real-time video processing and the interface settings of the face recognition attendance system using real-time video processing. By analyzing the situation of these problems, the concept of attendance system based on face recognition technology is proposed, and the research on face recognition attendance system based on real-time video processing is carried out. Experimental data shows that the accuracy rate of the video face recognition system is up to 82%. Compared with the traditional check-in method, the face recognition attendance system can be reduced by about 60%.

3. **[2019] Real-Time Surveillance Through Face Recognition Using HOG and Feedforward Neural Networks,** Muhammad Awais, Muhammad Javed Iqbal, Iftikhar Ahmad, Madini O. Alassafi, Rayed Alghamdi, Mohammad Basheri, and Muhammad Waqas**.**

   Reading handwritten information like examination answer sheets is still a difficult task for many of us, because each one of us is having a different interpretation style.As the world moving towards digitization, converting handwritten information into a readable digital format reduces difficulty.This approach will be beneficial for the readers as it gives a better understanding of the information.With the help of machine learning and deep learning algorithms , the handwritten patterns can be recognized and classify them accordingly to a digital format with human level accuracy.This research paper deals with real time handwritten digits only.To classify handwritten digits MNIST dataset is used for training the model.OpenCV python library is used for detecting the patterns in the real time handwritten digits. These detected patterns are predicted to human level accuracy with help of convolutional neural network model.Convolutional Neural network has hidden layers called has convolutional layers,these layers detect the patterns or extract the features from the images.The objective of this project is to recognize the real time handwritten digits from a scanned image have been achieved.

4. **[2020] Handwritten Digit Recognition Based on Convolutional Neural Network, Chao Zhang, Zhiyao Zhou, Lan Lin**.

In order to meet the needs of paperless offices and greatly improve work efficiency, it is necessary to research and implement a handwritten digit recognition system. Handwritten digit recognition plays an important role in large-scale data statistics and the financial business, such as industry annual inspection, population census, tax statements and checks, etc. This paper proposes a new type of handwritten digit recognition system based on convolutional neural network (CNN). In order to improve the recognition performance, the network was trained with a large number of standardized pictures to automatically learn the spatial characteristics of handwritten digits. For model test, the system uses the camera to capture the pictures composed of the images generated by the test data set of MNIST and the samples written by different people, then continuously processes the captured graphics and refreshes the output every 0.5 seconds. With the trained deep learning model, we got a recognition accuracy of 97.3% in test process. Good performance in this experiment shows that our system can automatically recognize the handwritten digital content appearing in the target area and output the content label in real time.

5. **[2018] Farsi Handwriting Digit Recognition based on Convolutional Neural Networks**, Atefeh Dehghanian, Vahid Ghods.

In this paper, a convolutional neural network (CNN) is exploited for Farsi handwritten digit recognition. For training and evaluating the CNN, the “HODA” dataset was used which consists of 80000 images of Farsi handwritten digits. In the proposed method, we focused on the efficient and unique feature of Farsi digits that is using just the half upper part of the digits for recognition purposes. The proposed method, despite a 50% reduction in the data size which fed to the CNN, yielded an acceptable reduction in time consuming for training and evaluating CNN of about 50 % compared when using the full image of the digits (full data), and just a 1.5% increase in recognition error

6. **[2020] Handwritten Digit String Recognition using Deep Autoencoder based Segmentation and ResNet based Recognition Approach, Anuran Chakraborty, Rajonya**.

De ,Samir Malakar ,Friedhelm Schwenker and Ram Sarkar.Recognition of isolated handwritten digits is a well studied research problem and several models show high recognition accuracy on different standard datasets. But the same is not true while we

consider recognition of handwritten digit strings although it has many real-life applications like bank cheque processing, postal code recognition, and numeric field understanding from filled-in form images. The problem becomes more difficult when digits in the string are not neatly written which is commonly seen in freestyle handwriting. The performance of any such model primarily suffers due to the presence of touching digits in the string. To handle these issues, in the present work, we first use a deep autoencoder based segmentation technique for isolating the digits from a handwritten digit string, and then we pass the isolated digits to a Residual Network (ResNet) based recognition model to obtain the machine-encoded digit string. The proposed model has been evaluated on the Computer Vision Lab (CVL) Handwritten Digit Strings (HDS) database, used in HDSRC 2013 competition on handwritten digit string recognition, and a competent result with respect to state-of-the-art techniques has been achieved.

7. **[2021] Multi-Digit Recognition using Image Processing and Neural Network, Anway Shirgaonkar, Neeraj Sahasrabudhe, Prathamesh Sandikar, Tapan Sawant, Shahid Sayyad, Prof. Archana Chaudhari.**

Digitization has become one of the most important aspects in today's era. One such application is in the local markets where many vendors still use handwritten bills to provide for the customer. To solve this real time issue the work proposes a new method for digitizing handwritten bills. In the proposed method, image processing and neural networks are used to convert handwritten bills into digital format using image processing and neural networks. The proposed method is very convenient and easy for the vendor as all he has to do is to click a photograph of the handwritten bill.

8. **[2019] Recognition of Handwritten Digit using Convolutional Neural Network (CNN), Md. Anwar Hossain, Md. Mohon Ali**

Humans can see and visually sense the world around them by using their eyes and brains. Computer vision works on enabling computers to see and process images in the same way that human vision does. Several algorithms developed in the area of computer vision to recognize images. The goal of our work will be to create a model that will be able to identify and determine the handwritten digit from its image with better accuracy. We aim to complete this by using the concepts of Convolutional Neural Network and MNIST

dataset. We will also show how MatConvNet can be used to implement our model with CPU training as well as less training time. Though the goal is to create a model which can recognize the digits, we can extend it for letters and then a person's handwriting. Through this work, we aim to learn and practically apply the concepts of Convolutional Neural Networks

9. **[2020] Cloud-Based Efficient Scheme for Handwritten Digit Recognition, Saqid Ali, Qurat ul Ali, Allah Ditta**.

Handwritten digit recognition has been acknowledged and achieved more prominent attention in pattern recognition research community due to enormous application and vagueness in application methods, while cloud computing delivers appropriate, on demand access of network to a joint tarn of configurable computing resource. The research aimed to make the trail towards digitalization clearer by providing high accuracy and faster cloud based computational for handwritten digit recognition. This paper uses cloud based neural network (CNN) as a classifier, suitable parameters of dataset MNIST for testing and training purpose as a framework called DL4J for cloud based handwritten digit recognition. This method decreases the cost and computational time significantly and algorithm becomes more efficient.

10. **[2018] Neurocomputing, Min-Rong Chen, Bi-Peng Chen, Guo-Qiang Zeng, Kang-Di Lu, Ping Chu**.

As a widely studied challenging issue in the field of handwriting recognition, handwritten digit recognition algorithms such as vector machines and neural network. Nevertheless, most research works have focused on the recurrent networks of Hopfield type while only few studies concerning fractional order back propagation (FOBP). This paper presents an adaptive fractional order BP neural network abbreviate as PEO-FOBP for handwritten digit recognition problems by combining a competitive evolutionary algorithm called population external optimization and a fractional order gradient descent learning machine. The traditional integer-order BP neural network in terms of training and testing accuracies.

11. **[2020] FPGA Implementation of CNN for Handwritten Digit Recognition, Rui Xiao, Junsheg Shi, Chao Zhang**.

    Convolutional neural network (CNN) has been used very successful in the field of handwritten digit recognition CNN has performed well in application areas such as image classification, recognition, detection, and segmentation and have attracted more attention. CNN is difficult to deploy on the embedded platform because of its large computation, complex structure and frequent memory access. In this paper a manual hardware level design, CNN configurable IP core method is proposed to construct the FPGA basic unit of CNN structure. Reconfigurable convolution, pooling and fully connected module in the CNN structure are designed. By setting the parameters of reconfigurable modules and connecting these modules end to end, CNNs of different structure sizes can be quickly deployed. The system was finally implemented on the intel cyclone 10 FPGA hardware platform. Under the 150MHz clock, CNN only needs 0.0176ms to recognize a handwritten digit picture, and the accuracy rate is 97.57%.

12. **[2020] Handwritten Digit Recognition System Based on Convolution Neural Network, Jinze Li, Gongbo Sun, Leiye Yi, Qian Cao, Fusen Liang, Yu Sun.**.

    The Image recognition is widely used in the field of computer version today. As a kind of image recognition, digit recognition is widely used. With the rapid development of electronic information, computer input has become more and more common, but handwriting is still an irreplaceable way for people to transform information. This paper mainly introduces a offline recognition system for handwritten digits based on convolution neural networks. The system uses the MINST dataset as a training sample and pre-processes the picture with the OpenCV toolkit. Then it uses LeNet-5 in the convolution neural network to extract the handwritten digit image features, repeatedly convolution pooling, and pull the result into one dimensional vector. The application with the SoftMax regression model can greatly reduce labor costs and improve work efficiency, which is of great significance in many fields..

13. **[2020] DIGITNET: A Deep Handwritten Digit Detection and Recognition Method Using a New Historical Handwritten Digit Dataset, Huseyin Kusetogullari, Amir Yavariabdi , Johan Hall , Niklas Lavesson.**.

The Handwritten document image analysis, one of the most important and well-known problems is to detect and recognize digit strings in the handwritten document images. This paper introduces a novel deep learning architecture, named DIGITNET, and a large-scale digit dataset, named DIDA, to detect and recognize handwritten digits in historical document images written in the nineteen century. Moreover, DIDA is used to train the DIGITNET network, which consists of two deep learning architectures, called DIGITNET-dect and DIGITNET-rec, respectively, to isolate digits and recognize digit strings in historical handwritten documents. In DIGITNET-dect architecture, to extract features from digits, three residual units where each residual unit has three convolution neural network structures are used and then a detection strategy based on You Look Only Once (YOLO) algorithm is employed to detect handwritten digits at two different scales. In DIGITNET-rec, the detected isolated digits are passed through 3 different designed Convolutional Neural Network (CNN) architectures and then the classification results of three different CNNs are combined using a voting scheme to recognize digit strings. The proposed model is also trained with various existing handwritten digit datasets and then validated over historical handwritten digit strings.

14. **[2019] A Comparison of Three Classification Algorithms for Handwritten Digit Recognition, Maiwan Bahjat Abdulrazzaq, Jwan Najeeb Saeed.**.

The Recognizing the numeral handwriting of a person from another is a hard task because each individual has a unique handwriting way. The selection of the classifiers and the number of features play a vast role in achieving best possible accuracy of classification. This paper presents a comparison of three classification algorithms namely Naive Bayes (NB), Multilayer Perceptron (MLP) and K_Star algorithm based on correlation features selection (CFS) using NIST handwritten dataset. The objective of this comparison is to find out the best classifier among the three ones that can give an acceptable accuracy rate using a minimum number of selected features. The accuracy measurement parameters are used to assess the performance of each classifier individually, which are precision, recall and Fmeasure. The results show that K_Star algorithm gives better recognition rate than NB and MLPas it reached an accuracy of 82.36%.

15. **[2020] Automatic CNN-Based Arabic Numeral Spotting and Handwritten Digit Recognition by Using Deep Transfer Learning in Ottoman Population Registers, Yekta Said Can and M. Erdem Kabaday**.

In Arabic scripts are widely adopted in manuscripts of different countries and cultures, e.g.,Ottoman, Arabic, Urdu, Kurdish and Persian . These scripts can be written in different ways, which complicates the page segmentation, keyword spotting, HTR and OCR processes. It is a cursive script in which combined letters form ligatures . Moreover, the Arabic words can consist of dots and diacritics, which makes it even more difficult to extract information. Recently, researchers also proposed numeral spotting and handwritten digit recognition systems for Arabic scripts on different datasets. These studies achieved accuracies above 90%.Text and non-text areas were differentiated by using the Support Vector Machine (SVM) algorithm. Further trained a CNN-based segmentation scheme for spotting these numerals. Our numeral spotting technique is both training-based and segmentation-based then form a small Arabic digit dataset from the spotted numerals by selecting uni-digit ones and tested the Deep Transfer Learning (DTL) methods from the models trained in large open datasets for digit recognition, compare these results obtained by training and testing a system by using dataset. We obtain promising results for recognizing Arabic digits in these historical documents.

16. **[2020] Comparisons on KNN, SVM, BP and the CNN for Handwritten Digit Recognition, Wenfei Liu, Jingcheng Wei, Qingmin Meng**.

In this proposed paper it takes the MNIST handwritten digit database as samples, discusses algorithms KNN, SVM, BP neural network, CNN and their application in handwritten digit recognition. In the training process, this work rewrites KNN with Python, SVM with scikit-learn library, and BP, CNN with Tensorflow, and finetunes the algorithm parameters to get the best results for each algorithm. Finally, by comparing the recognition rate and recognition duration of the four algorithms, the advantages and disadvantages of the four algorithms in handwriting recognition are analyzed. The Literature proposed a SVM multi-level classification algorithm based on DTP features. BP neural network algorithm is used in the Literature to realize handwritten digit recognition; it also introduces image preprocessing methods such as graying, binarization, and sharpening. In this, we use different programming methods to complete

the comparison of KNN, SVM, BP neural network and CNN algorithms in handwritten digit recognition from different angles, and evaluate its characteristics with the recognition rate and recognition time as indicators.

2.1 Literature Survey Summary Table

The Table 2.1 represents the summary of the Literature Survey review which consists of the paper referred to,the problems that have been encountered in the particular paper, the author's approach in solving the problemand finally the results that were obtained.

SL. NO	Title of the Paper	Problem Addressed	Authors Approach/ Method	Results
1	Deep Convolutional Self-Organizing Map Network for Robust Handwritten Digits. IEEE - 2020	It classifies the handwritten digits using deep convolutional neural network, to learn about invariant image representation from unlabeled visual data.	New unsupervised deep convolutional network based on self-organizing maps(SOM) , the network utilizes multiple convolutional SOM layers to extract hierarchical features from training images.	DCSOM network can eliminate the effect of noise in input image through its competitive learning algorithm and feature image bank representation.
2	Morphological Convolutional Neural Network Architecture for Digit Recognition. IEEE - 2019	This paper proposed for pattern recognition in order to generate enhanced feature maps	This paper proposed an morphological convolutional neural network called Morph-CNN for pattern recognition .	Using Morph-CNN provides effectiveness for digit recognition. It aims for a good recognition rate..
3	Real time Handwritten Digits Recognition Using Convolutional Neural Network IEEE - 2021	Reading handwritten information like examination answer sheets is still a difficult task, so converting the handwritten information to a	This paper proposed the convolutional neural network using deep learning methodology in machine learning	The proposed model gave an accuracy of 99.59% on the test data set.

		readable digital format reduces the difficulty. .		
4	Handwritten Digit Recognition based on Convolutional Neural Network. IEEE - 2020	This proposed in order to meet the needs of paperless offices and in order to improve work efficiency.	This paper proposed the digit recognition system based on convolutional neural network in order improve the performance. .	This method has a very high recognition accuracy for handwritten digit recognition.
5	Farsi Handwriting Digit Recognition based on Convolutional Neural Networks. IEEE - 2018	Data See what happens to accuracy and error when the input dataset is altered.	HODA dataset used Focusing on the efficient and unique feature of Farsi digits that is using just the half upper part of the digits for recognition purpose.	Accuracy rate of 97.38% was achieved. There was 1.5% increase in recognition error
6	Handwritten Digit String Recognition using Deep Autoencoder based Segmentation and ResNet based Recognition Approach. IEEE - 2020	Digits in the string are not neatly written which is commonly seen in freestyle handwriting. They sometimes are touching each other.	First use a deep autoencoder based segmentation technique for isolating the digits from a handwritten digit string, and then we pass the isolated digits to a ResNet based recognition model to obtain the machine-encoded digit string. .	The Proposed approach can produce results comparable with state-of-the-art techniques. Even the overall results are satisfactory considering the complexity of the research problem.
7	Multi-Digit Recognition using Image Processing and Neural Network.	Digitalization of Handwritten bills to help vendors provide for the customer.	Techniques used in pre-processing are resizing, normalization, denoising,	The model was able to correctly recognize 12 digits from the given 13.

	IEEE - 2021		thresholding and segmentation.	Although more state of the art neural networks like CNN or RNN can be developed which can guarantee almost a 100% prediction accuracy.
8	Recognition of Handwritten Digits using Convolution Neural Networks IEEE - 2019	Show how MatConvNet can be used to implement this model with CPU training as well as less training time	It extracts feature map from 2D images and classified. And mapping of image pixels with the neighborhood space rather than having fully connected layer of neurons.	It proves to be far better than other classifiers and abolish the need for typing and gives us a great way to develop advanced technologies.
9	Cloud Based Efficient Scheme for Handwritten Digit Recognition. Springer-2020	To recognizing Handwritten digit recognition using Cloud Computing.	Convolutional Neural Network, Cloud Computing, Deep learning.	The This system recognizes with 99.41% accuracy with less computation time.
10	Neurocomputing. ELSEVIER-2019	To test the performance of different pattern recognition algorithms.	Fractional Order Neural Neural Network, FOBP	Analyzed the effect of hidden nodes and learning rates on training and testing accuracy.
11	FPGA Implementation of CNN for Handwritten Digit Recognition. IEEE - 2020	A manual hardware level design and recognition of digit.	FPGA, Convolution Neural Network, Reconfigurable IP core. .	It needs 0.0176 ms to recognize a handwritten digit pictures and the accuracy rate is 97.57 %. x.

12	Handwritten Digit Recognition System Based on Convolutional Neural Network. IEEE-2020	It address the Bangla Handwritten digit recognition of typical image classification.	OpenCV Toolkit, LeNet-5, Convolution Pooling, SoftMax Regression, one-dimensional vector.	The application this system can greatly reduce financial, accounting and improve work efficiency.
13	A Comparison of Three Classification Algorithms for Handwritten Digit Recognition IEEE-2019	It compares best classifier among the three ones that can give an acceptable accuracy rate using a minimum number of selected features, Its has wide application in computerized bank check numbers reading	This paper presents a comparison of three classification algorithms namely Naive Bayes (NB), Multilayer Perceptron (MLP) and K_Star algorithm based on correlation features selection (CFS) using NIST handwritten dataset.	As a result it determines K_Star algorithm gives better recognition rate than NB and MLPas it reached the accuracy of 82.36%.
14	Automatic CNN-based Arabic numeral spotting and handwritten digit recognition by using Deep Transfer Learning in Ottoman Population Registers IEEE-2020	This paper mainly proposes Arabic handwritten character recognition .Arabic digit recognition scheme that used multi-layer perceptron and K-nearest neighbor classifiers.	It uses CNN model for numeral spotting and Resnet-50 for training. It consists DTL on HODA and AHDBase Datasets.	On basis of handwritten digit recognition systems for Arabic scripts on different datasets have been achieved accuracy above 90%.
15	A Deep Handwritten Digit Detection and Recognition Method Using a New Historical Handwritten Digit Dataset IEEE-2020	It is a novel deep learning architecture, named DIGITNET, and a large-scale digit dataset, named DIDA, to detect and recognize handwritten digits in historical document images written	The detection strategy based on You Look Only Once (YOLO) algorithm is employed to detect handwritten digits well-known existing handwritten digit datasets are MNIST ,NIST and USPS.	DIDA dataset provides the highest detection rate results verify effectiveness and efficiency of DIGITNET-dect, which outperforms the digit detection methods as well as deep learning.

16	Comparisons on KNN,SVM,BP and the CNN for Handwritten Digit Recognition	This paper mainly proposes Tamil handwritten character recognition constructed by executing a sequence of stroke or shape based representation.	It is character consists of grouping stroke labels obtained for recognition where it uses feature extraction and stroke recognition from previous stage and converting into suitable character code.	Recognition rates of the BP neural network algorithm and the CNN algorithm are slightly higher than the other two algorithms

Table 2.1: Summary of Literature Survey describing the problems addressed, author's approach and the results of the survey.

CHAPTER 3

PROBLEM STATEMENT & OBJECTIVES

3.1 Problem Statement

To reduce the time taken while recognizing the digits manually and to increase its efficiency and accuracy by minimizing errors

3.2 Objectives

The objectives of Proposed system are:

1) Create a system that recognizes handwritten digits [0-9] automatically and classify them to get the best possible model.
2) Among these methods, the deep learning-based network has been demonstrated to be a promising method to solve such recognition problems.
3) Handwritten digit recognition is a task involving feature-extracting and decision-making.
4) Many of the current practical applications of machine learning use linear classifiers on top of hand-engineered features.
5) A deep-learning architecture is a multilayer stack of simple modules, all (or most) of which are subject to learning, and many of which compute non-linear input–output mappings.
6) Each module in the stack transforms its input to increase both the selectivity and the invariance of the representation.

CHAPTER 4

SYSTEM ANALYSIS

4.1 Requirement Specifications

4.1.1 Hardware Requirements

- Processor: Intel Core3 Quad @ 2.4Ghz on Windows® Vista 64-Bit / Windows® 7 64- Bit / Windows® 864-Bit / Windows® 8.1 64-Bit.
- RAM: 4GB of RAM
- Memory: 256GB Hard drive
- Keyboard: MS compatible keyboard
- Mouse: MS compatible mouse

4.1.2 Software Requirements

- **Operating system:** Windows® Vista 64-Bit / Windows® 7 64-Bit / Windows® 8 64- Bit /Windows® 8.1 64-Bit.
- **Libraries:** OpenCV, NumPy, scikit-learn, scikit-image, imutils.
- **IDE:** IDLE Python 3.8.

4.2 Tools Used

➢ Python 3.8

- **Python** is a general-purpose interpreted, interactive, object-oriented, and high-level programming language. It was created by Guido van Rossum during 1985- 1990. Like Perl, Python source code is also available under the GNU General Public License (GPL). This **tutorial** gives enough understanding on **Python programming** language.
- It supports functional and structured programming methods as well as OOP.
- It can be used as a scripting language or can be compiled to byte-code for building large applications.
- It provides very high-level dynamic data types and supports dynamic type checking.
- It supports automatic garbage collection.
- It can be easily integrated with C, C++, COM, ActiveX, CORBA, and Java.

- **Easy-to-learn** − Python has few keywords, simple structure, and a clearly defined syntax. Thisallows the student to pick up the language quickly.
- **Easy-to-read** − Python code is more clearly defined and visible to the eyes.
- **Easy-to-maintain** − Python's source code is fairly easy-to-maintain.
- **A broad standard library** − Python's bulk of the library is very portable and cross-platformcompatible on UNIX, Windows, and Macintosh.
- **Interactive Mode** − Python has support for an interactive mode which allows interactivetesting and debugging of snippets of code.
- **Portable** − Python can run on a wide variety of hardware platforms and has the same interfaceon all platforms.
- **Extendable** − You can add low-level modules to the Python interpreter. These modules enable programmers to add to or customize their tools to be more efficient.
- **Databases** − Python provides interfaces to all major commercial databases.
- **GUI Programming** − Python supports GUI applications that can be created and ported to many system calls, libraries and windows systems, such as Windows MFC, Macintosh, and theX Window system of Unix.
- **Scalable** − Python provides a better structure and support for large programs than shellscripting.

Libraries used in Python:

- **Imutils**
  - A series of convenience functions to make basic image processing functions such as translation, rotation, resizing, skeletonization, and displaying Matplotlib images easier with OpenCV and both Python 2.7 and Python 3.
  - Imutils is a package based on OpenCV, which can call the opencv interface more simply. It can easily realize a series of operations such as image translation, rotation, scaling, skeletonization and so on.
  - To install: pip install imutils.
- **Tkinter**
  - Tkinter is the Python interface to the Tk GUI toolkit shipped with Python.

- Tkinter is the standard GUI library for Python. Python when combined with Tkinter provides a fast and easy way to create GUI applications. Tkinter provides a powerful object-oriented interface to the Tk GUI toolkit.
- Tkinter provides various controls, such as buttons, labels and text boxes used in a GUI application. These controls are commonly called widgets.
- All Tkinter widgets have access to the specific geometry management methods, which have the purpose of organizing widgets throughout the parent widget area.

➢ **Numpy**

- NumPy is a package that defines a multi-dimensional array object and associated fast math functions that operate on it. It also provides simple routines for linear algebra and fft and sophisticated random-number generation.
- NumPy replaces both Numeric and Numarray.
- It is the core library for scientific computing in Python. It provides a high-performance multidimensional array object, and tools for working with these arrays.

CHAPTER 5

DESIGN

5.1 System Design

The proposed system is a block diagram for the implementation of detection of Handwritten Digit as depicted in the figure below. This has been shown in the below **Fig 5.1.1.** It tells us the entire data flow and the techniques used in the project, initially how the raw data is taken and the model is trained with accuracy being displayed in the end.

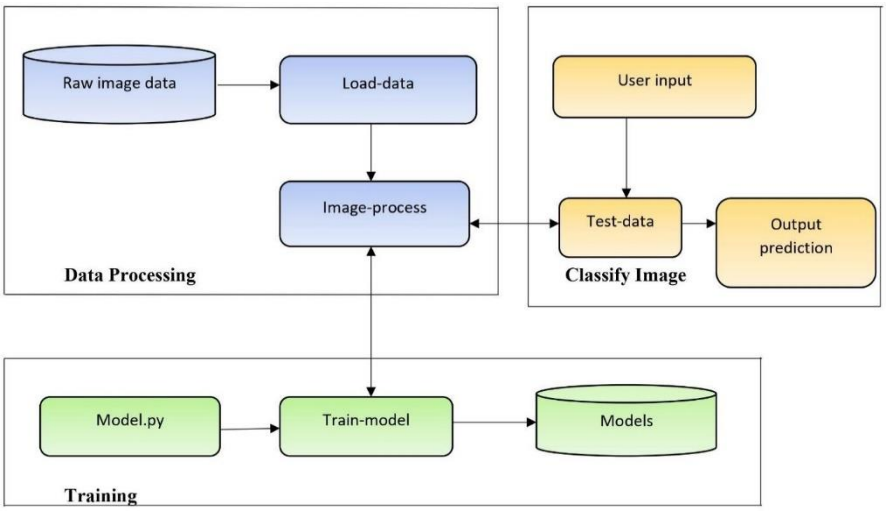

Fig 5.1.1: Block Diagram of System Design

5.2 Data Flow Diagram

The block diagram of the data flow has been shown here from the beginning where data is collected and preprocessed and then the features have been extracted . Then SVM classifier has been used to recognise the digits.

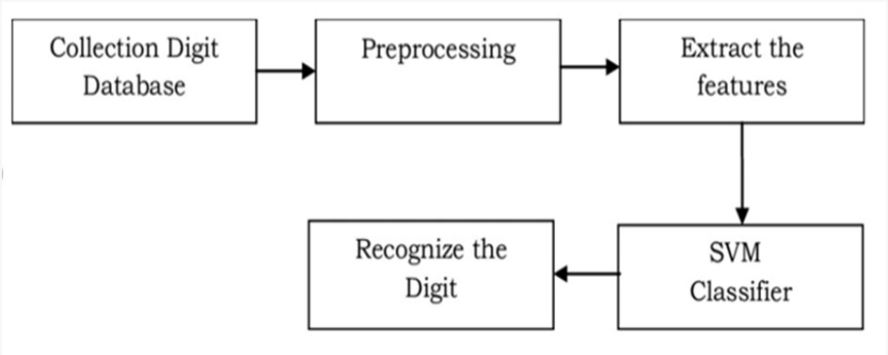

Fig 5.2.1: Flowchart of System Design

CHAPTER 6

IMPLEMENTATION

6.1 Collection of Datasets

The first component of building a deep learning network is to gather our initial dataset. We need the images themselves as well as the labels associated with each image. This is the dataset which we have collected from publicly accessible databases i.e., Kaggle. The images found are in Gray scale format. But we convert the images to Gray Scale. The data set is collected from a source and a complete analysis is carried out. The image is selected to be used for training/testing purposes only if it matches our requirements and is not repeated.

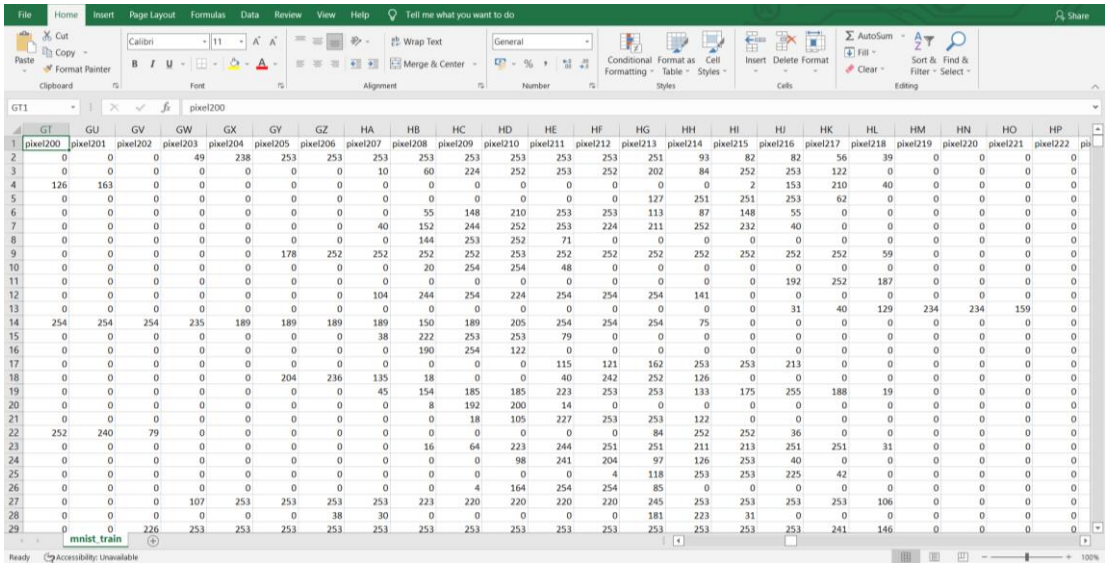

Fig 6.1.1: Dataset of Handwritten Digits

```
def LoadData():
    for dirname, _, filenames in os.walk(r'./Data'):
        for filename in filenames:
            print(os.path.join(dirname, filename))
    test_data = pd.read_csv(r"./Data/mnist_test.csv")
    training_data = pd.read_csv(r"./Data/mnist_train.csv")
    training_data.max().sort_values()
    training_data.isna().sum().sort_values(ascending=False)
    training_data.duplicated().sum()
    count_table = training_data.label.value_counts()
    count_table = count_table.reset_index().sort_values(by='index')
    messagebox.showinfo("Data Load", "Data Loaded Successfully")
    plot_graph(count_table,training_data)
```

Fig 6.1.2: Code for loading the input image from dataset collected to the program

The above code shows to load the input image from the dataset collected into the program using the imutils library. After loading the image, we display it in the screen.

6.2 Feature Extraction

Feature extraction is a part of the dimensionality reduction process, in which, an initial set of the raw data is divided and reduced to more manageable groups. So, when you want to process it will be easier. The most important characteristic of these large data sets is that they have a large number of variables. These variables require a lot of computing resources to process. So, Feature extraction helps to get the best feature from those big data sets by selecting and combining variables into features, thus, effectively reducing the amount of data. These features are easy to process, but still able to describe the actual data set with accuracy and originality.

The technique of extracting the features is useful when you have a large data set and need to reduce the number of resources without losing any important or relevant information. Feature extraction helps to reduce the amount of redundant data from the data set. In the end, the reduction of the data helps to build the model with less machine effort and also increases the speed of learning and generalization steps in the machine learning process. We calculate edged value and threshold value of each image for better understanding of the features that the image possess.

```
def extract_pca(X_train, X_test, y_train, y_test):
    def extract():
        from sklearn.preprocessing import StandardScaler
        from sklearn.pipeline import Pipeline
        from sklearn.decomposition import PCA,IncrementalPCA
        pca = PCA()
        pipe = Pipeline([('scaler', StandardScaler()), ('pca', pca)])
        Xtr = pipe.fit_transform(X_train)
        Xts=pipe.fit_transform(X_test)
        print(X_train[0][0].shape)
        print(X_test[0][0].shape)
        pca=IncrementalPCA(n_components=400)
        x_train=pca.fit_transform(X_train)
        x_test=pca.transform(X_test)
        messagebox.showinfo("PCA Extracted", "PCA extracted Successfully")
        pca_graph(Xtr,Xts,x_train,x_test)
    def pca_graph(Xtr,Xts,x_train,x_test):
        window.destroy()
        plot = plt.scatter(Xtr[:,0], Xtr[:,1], c=y_train)
        plt.legend(handles=plot.legend_elements()[0], labels=list([0,1,2,3,4,5,6,7,8,9]))
        plt.show()

        start_train(x_train,x_test,y_train,y_test)
```

Fig 6.2.1: Code for PCA Extraction

6.3 Methodology

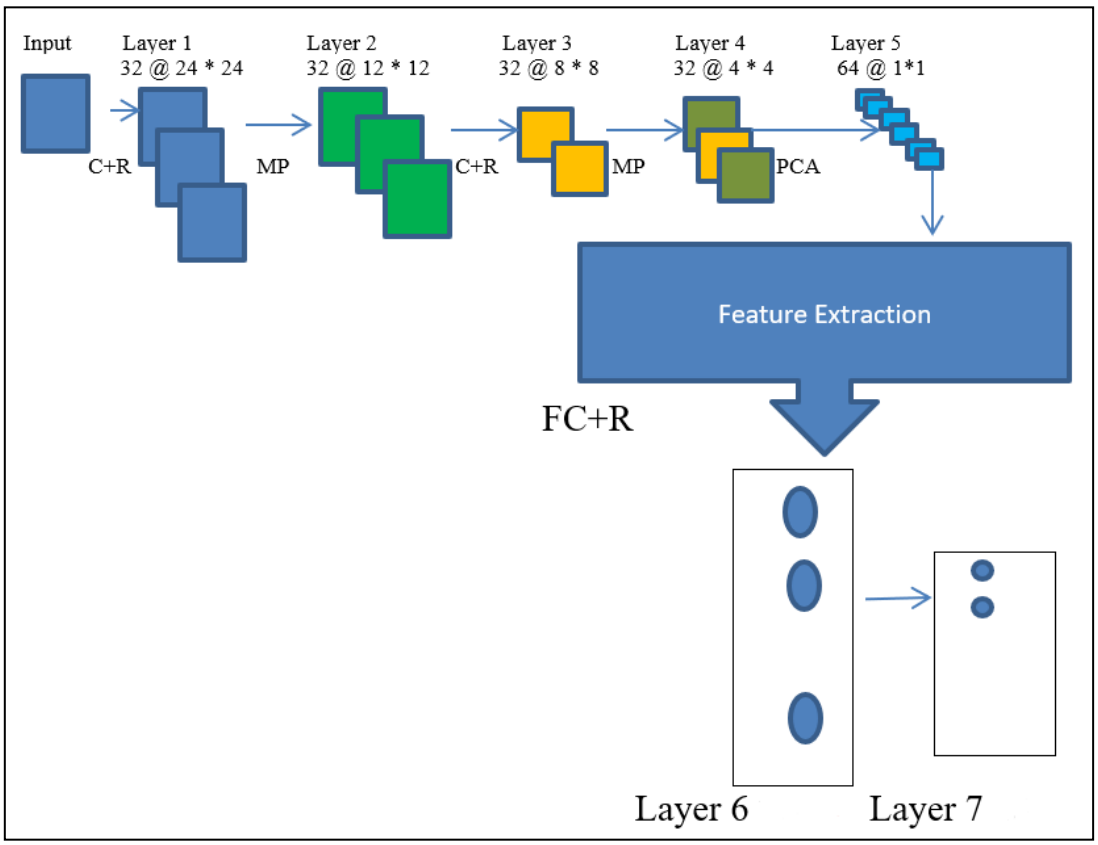

Fig 6.3.1: Proposed Methodology

The above figure 7.1 shows the Proposed methodology of the system. Convolutional neural networks are deep artificial neural networks. IT can be used to classify images (e.g., name what they see), cluster them by similarity (photo search) and perform object recognition within scenes. Convolutional neural networks are deep artificial neural networks. It can be used to classify images (e.g., name what they see), cluster them by similarity (photo search) and perform object recognition within scenes. It can be used to identify faces, individuals, street signs, tumors, platypuses and many other aspects of visual data. The convolutional layer is the core building block of a CNN. The layer's parameters consist of a set of learnable filters (or kernels) which have a small receptive field but extend through the full depth of the input volume. During the forward pass, each filter is convolved across the width and height of the input volume, computing the dot product, and producing a 2-dimensional activation map of that filter. As a result, the network learns when they see some specific type of feature at some spatial position in the input. Then the activation maps are fed into a down sampling

layer, and like convolutions, this method is applied one patch at a time. CNN has also fully connected layer that classifies output with one label per node.

Deep Learning has emerged as a central tool for self-perception problems like understanding images, a voice from humans, robots exploring the world. This project aims to implement the concept of Convolutional Neural Network for digit recognition, with principal component analysis for feature extraction and coupling it with polynomial classifier. Understanding CNN and applying it to the handwritten digit recognition system is the target of the proposed model. Convolutional Neural Network extracts the features maps from the 2D images. Then it can classify the images using the features maps. The convolutional neural network considers the mapping of image pixels with the neighborhood space rather than having a fully connected layer of neurons. The convolutional neural network is a powerful tool in signal and image processing. Even in the fields of computer vision such as handwriting recognition, natural object classification, and segmentation, CNN has been a much better tool compared to all other previously implemented tools.

CHAPTER 7

TESTING AND RESULTS

7.1 Test Cases

Test Case ID	Test Case Description	Expected Output	Actual Output	Remarks
1	Click on Load dataset button.	Dataset should be loaded into the model.	Dataset will be loaded into the model.	Pass
2	Click on Show Graph button.	Graphs should be loaded into the model.	Graphs regarding the dataset is shown.	Pass
3	Click on Extract PCA button.	PCA should be extracted into the model from the dataset.	PCA extraction and heatmap graph is shown.	Pass
4	Click on Test Model button.	Model should be trained.	Model is trained and saved.	Pass
5	Click on Start Training button.	Model should be tested.	Model is tested and accuracy is shown.	Pass
6	Click on Upload Image button.	Image should be taken as input and detected.	Prediction result is shown.	Pass
7	Detection of MNSIT 28*28 pixel image.	The model should recognize the digit.	The model will detect the image.	Pass
8	Detection of MNSIT pixel image.	The model should recognize	The model will detect the	Pass

		the digit.	image.	
9	Detection of colored image.	The model should recognize the digit.	The model will not detect the image.	Fail
10	Detection of handwritten pixel image.	The model should recognize the digit.	The model will detect the image.	Pass

Table 7.1: Test Cases

7.2 Results

From the above project it is evident that the handwritten digit recognition techniques that are widely employed suffer from accuracy. In techniques where better accuracy was obtained the training time of machine learning algorithms used was high. This tradeoff between time and accuracy has given opportunity to solve this problem for optimization using the proposed architecture. The new system developed is validated with a training set of Data from MINST dataset and the necessary calculations is carried out to measure the performance and accuracy of the proposed system. Higher accuracy with lesser training time has been achieved.

CHAPTER 8

SNAPSHOTS

The following snapshot contains the load data page.

Fig 8.1: Load Data page

The following snapshot contains the draw graph page.

Fig 8.2: Draw Graph page

The following snapshot contains the image count graph.

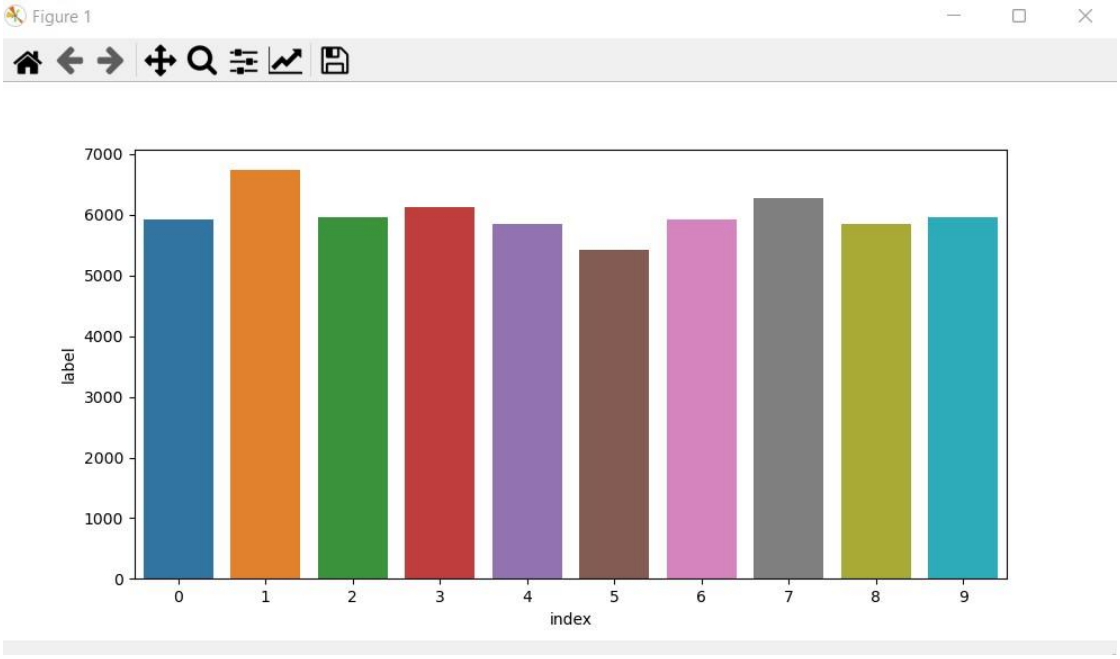

Fig 8.3: Image count graph

The following snapshot contains the heatmap graph.

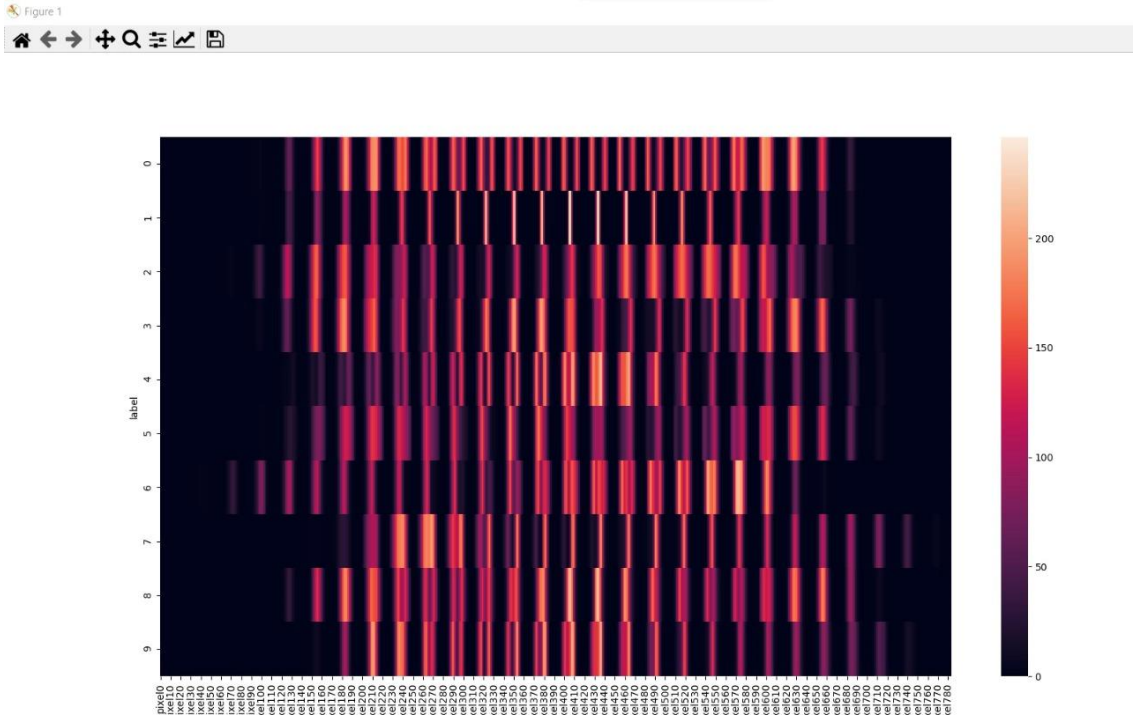

Fig 8.4: Heatmap graph

The following snapshot contains the extract pca page.

Fig 8.5: Extract PCA page

The following snapshot contains the PCA graph.

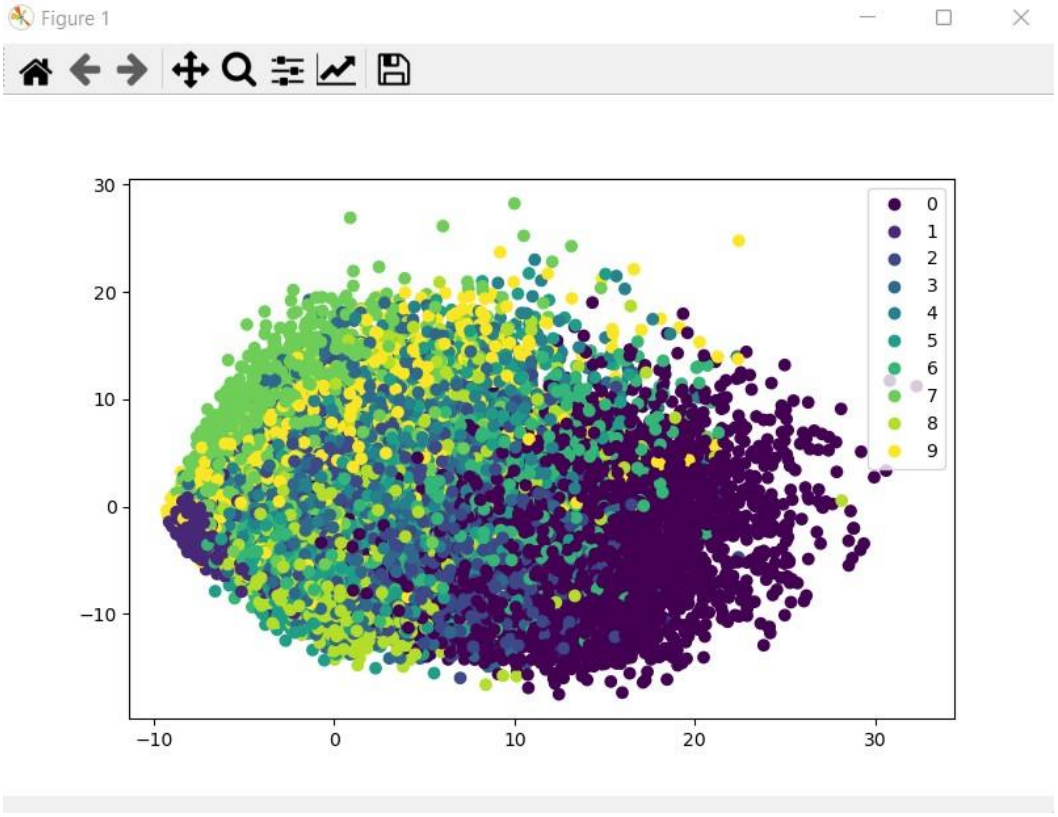

Fig 8.6: PCA graph

The following snapshot contains the test model page.

Fig 8.7: Test Model page

The following snapshot contains the training model page.

Fig 8.8: Training Page

The following snapshot contains the image prediction page.

Fig 8.9: Image prediction Shows

CHAPTER 9

APPLICATIONS

1. This system can be used to recognise the vehicle number from the number plate in real time through security cameras.

2. This system can be used to recognise the bank details like account number, ID proof numbers and bank copies like cheque number, demand drafts, challens.

3. This system can be used to recognise the details necessary in post offices and arranging letters in an order.

4. It can be used in places where data entry jobs requiring numbers are present.

5. It can also be deployed as an example how image recognition can be implemented in all kind of web servers.

CONCLUSIONS AND FUTURE ENHANCEMENTS

Conclusions

The future development of the applications based on algorithms of deep and machine learning is practically boundless. In the future, we can work on a denser or hybrid algorithm than the current set of algorithms with more manifold data to achieve the solutions to many problems. In future, the application of these algorithms lies from the public to high-level authorities, as from the differentiation of the algorithms above and with future development we can attain high-level functioning applications which can be used in the classified or government agencies as well as for the common people, we can use these algorithms in hospitals application for detailed medical diagnosis, treatment and monitoring the patients, we can use it in surveillances system to keep tracks of the suspicious activity under the system, in fingerprint and retinal scanners, database filtering applications, Equipment checking for national forces and many more problems of both major and minor category. The advancement in this field can help us create an environment of safety, awareness and comfort by using these algorithms in day to day application and high-level application (i.e. Corporate level or Government level). Application-based on artificial intelligence and deep learning is the future of the technological world because of their absolute accuracy and advantages over many major problems.

Future Enhancements

In a nutshell, it can be summarized that the future scope of the project circles around maintaining information regarding:

a) A real time payment gateway can be implemented in the future.
b) More advanced software can be used be store the images which provides secure authentication, data protection.
c) The platform can be hosted on online servers to make it accessible worldwide.
d) Integrate multiple load balancers to distribute the load of the system.
e) Implement backup mechanism for taking backup of database on regular basis on different servers.

REFERENCES

[1] Aly, Saleh, and Sultan Almotairi. "Deep convolutional self-organizing map network for robust handwritten digit recognition." *IEEE Access 8 (2020): 107035-107045.*

[2] Mellouli, Dorra, Tarek M. Hamdani, Javier J. Sanchez-Medina, Mounir Ben Ayed, and Adel M. Alimi. "Morphological convolutional neural network architecture for digit recognition." *IEEE transactions on neural networks and learning systems (2019): 2876-2885.*

[3] Upender, Kaveti, and Venkata Siva Kumar Pasupuleti. "Real Time Handwritten Digits Recognition Using Convolutional Neural Network." *In 2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), pp. 69-73. IEEE.*

[4] Zeng, Xiangyan, Yen-Wei Chen, and Caixia Tao. "Feature selection using recursive feature elimination for handwritten digit recognition." *In 2009 Fifth International Conference on Intelligent Information Hiding and Multimedia Signal Processing, pp. 1205-1208. IEEE.*

[5] Arora, Sandhya, Debotosh Bhattacharjee, Mita Nasipuri, Dipak Kumar Basu, and Mahantapas Kundu. "Combining multiple feature extraction techniques for handwritten Devnagari character recognition." *In 2008 IEEE Region 10 and the Third international Conference on Industrial and Information Systems, pp. 1-6. IEEE.Kussul Ernst, Baidyk Tatyana and Kasatkina Lora "Rosenblatt Perceptrons for Handwritten Digit Recognition".*

[6] Kussul, E., T. Baidyk, L. Kasatkina, and V. Lukovich. "Rosenblatt perceptrons for handwritten digit recognition." *In IJCNN'01. International Joint Conference on Neural Networks. Proceedings (Cat. No. 01CH37222), vol. 2, pp. 1516-1520. IEEE, 2001.Md Shopon ,Nabee Mohammed and Md Anowarul Abedin "Bangla Handwritten Digit Recognition Using Autoencoder and Deep Convolutional Neural Network",2016.*

[7] Hossain, Md Anwar, and Md Mohon Ali. "Recognition of handwritten digit using convolutional neural network (CNN)." *Global Journal of Computer Science and Technology (2019).Gaurav Kumar and Pradeep Kumar Bhatia "Analytical Review of Preprocessing Techniques for Offline Handwritten Character Recognition"2013, doi:10.13140/RG.2.1.3896.7842.*

[8] Shopon, Md, Nabeel Mohammed, and Md Anowarul Abedin. "Bangla handwritten digit recognition using autoencoder and deep convolutional neural network." *In 2016 International Workshop on Computational Intelligence (IWCI), pp. 64-68. IEEE .Maiwan Bahajat Abdulrazzaq and Jwan Najeeb Saeed "A Comparison of Three Classification Algorithms for Handwritten Digit Recognition".*

[9] Espana-Boquera, Salvador, Maria Jose Castro-Bleda, Jorge Gorbe-Moya, and Francisco Zamora-Martinez. "Improving offline handwritten text recognition with hybrid HMM/ANN models." *IEEE transactions on pattern analysis and machine intelligence* (2010): 767-779.

[10] Kumar, Gaurav, Pradeep Kumar Bhatia, and Indu Banger. "Analytical review of preprocessing techniques for offline handwritten character recognition." International Journal of Advances in Engineering Sciences (2013): 14-22.

[11] Li, Jinze, Gongbo Sun, Leiye Yi, Qian Cao, Fusen Liang, and Yu Sun. "Handwritten digit recognition system based on convolutional neural network." *In 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA), pp. 739-742. IEEE.*

[12] Abdulrazzaq, Maiwan Bahjat, and Jwan Najeeb Saeed. "A comparison of three classification algorithms for handwritten digit recognition." *In 2019 International Conference on Advanced Science and Engineering (ICOASE), pp. 58-63. IEEE, 2019.*

[13] Can, Yekta Said, and M. Erdem Kabadayı. "Automatic cnn-based Arabic numeral spotting and handwritten digit recognition by using deep transfer learning in Ottoman population registers." *Applied Sciences 10, no. 16 (2020): 5430.*

[14] Kusetogullari, Huseyin, Amir Yavariabdi, Johan Hall, and Niklas Lavesson. "DIGITNET: a deep handwritten digit detection and recognition method using a new historical handwritten digit dataset." *Big Data Research 23 (2021): 100182.*

[15] http://yann.lecun.com/exdb/mnist/

[16] https://docs.python.org/3/library/tkinter.html

[17] https://www.javatpoint.com/machine-learning-support-vector-machine-algorithm

[18] https://www.javatpoint.com/principal-component-analysis

[19] https://towardsdatascience.com/mnist-cnn-python-c61a5bce7a19