

A
Dissertation
On

HANDWRITTEN DIGIT CLASSIFICATION USING DEEP LEARNING

Submitted in partial fulfilment of the requirements

For the award of the degree of

MASTER OF TECHNOLOGY

IN

SOFTWARE ENGINEERING

By

Karan Kumar

(Roll No. 2K13/SWE/06)

Under the guidance of

Dr. (Mrs.) Akshi Kumar

Assistant Professor

Department of Computer Engineering

Delhi Technological University



Department of Computer Engineering

Delhi Technological University, Delhi

2013-2015



Department of Computer Engineering
Delhi Technological University
Delhi-110042

CERTIFICATE

This is to certify that the project report entitled “**HANDWRITTEN DIGIT CLASSIFICATION USING DEEP LEARNING**” is a bona fide record of work carried out by Karan Kumar (2K13/SWE/06) under my guidance and supervision, during the academic session 2013-2015 in partial fulfilment of the requirement for the degree of Master of Technology in Software Engineering from Delhi Technological University, Delhi.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Dr. (Mrs.) Akshi Kumar
Assistant Professor,
Department of Computer Engineering,



DELHI TECHNOLOGICAL UNIVERSITY

ACKNOWLEDGEMENT

With due regards, I hereby take this opportunity to acknowledge a lot of people who have supported me with their words and deeds in completion of my research work as part of this course of Master of Technology in Software Engineering.

To start with I would like to thank the almighty for being with me in each and every step of my life. Next, I thank my parents and family for their encouragement and persistent support.

I would like to express my deepest sense of gratitude and indebtedness to my guide and motivator, **Dr. Akshi Kumar**, Department of Computer Engineering, Delhi Technological University for her valuable guidance and support in all the phases from conceptualization to final completion of the project. I also would like to thank **Mr. A.K. Bhateja**, Scientist G, DRDO, Delhi whose guidance and help has been a vital part in the making of the project.

Finally, I wish to convey my sincere gratitude to all the faculties and PhD. Scholars of Computer Engineering Department, Delhi Technological University who have enlightened me during my project.

I humbly extend my grateful appreciation to my friends whose moral support made this project possible.

Last but not the least; I would like to thank all the people directly and indirectly involved in successfully completion of this project.

Karan Kumar

Roll No. 2K13/SWE/06

ABSTRACT

Abstract Representation of data is identified as a very important concept before applying any classification technique as it helps to make sense of data (images, videos etc.) and learn features. However training a single layer linear or non linear classifier has serious limitations considering the vastness of variability in data. The variability can be expressed in terms of handwriting of a person, pre-processing of images in the problem domain of classifying handwritten digits. Selection of features/latent factors therefore becomes an important aspect of classification since they are able to represent more abstract concepts related to data and each one can be provided a unique significance value. We have compared various approaches and their variations to generate an optima set of features which can be used for the classification problem of handwritten digits. Restricted Boltzmann machines(RBM) which form the baseline for deep learning are used to discover latent factors which then feed forward to higher level RBM's or classifiers. The classifiers studied in the research include Linear Mapping, Radial Basis Function Neural Network, and Backpropagation and up-down algorithm. Results from all variations in RBM parameters and classifiers are observed and discussed. We have compared our results with other related works and it is found that the maximum accuracy achieved is 97.7%

TABLE OF CONTENTS

CERTIFICATE	II
ACKNOWLEDGEMENT	III
ABSTRACT	IV
Table of Contents	V-VII
List of figures	VIII
List of Graphs.....	IX
List of Tables	X
ABBREVIATIONS USED	XI
Chapter 1: INTRODUCTION	1
1.1 Motivation	2
1.2 Related Work.....	2
1.3 Problem Statement.....	3
1.4 Scope of Work	4
1.5 Organization of Thesis	5
Chapter 2: HANDWRITTEN DIGITAL CLASSIFICATION SYSTEM	6
2.1 The MNIST Database	6
2.2 Advantages.....	7
2.3 Applications.....	8
2.4 General system overview.....	8
2.4.1 General Diagram	9

2.4.2	Input	10
2.4.3	Output	10
2.4.4	Pre-processing	11
2.4.5	Feature extraction	11
2.4.6	Classification Process.....	11
2.5	Performance Evaluation of Digital Recognition System.....	12

Chapter 3: RELATED CONCEPTS.....13

3.1	Factor Analysis.....	13
3.2	Restricted Boltzmann Machines.....	15
3.2.1	Markov Random Field.....	15
3.2.2	Maximum Likelihood Estimation.....	16
3.2.3	Markov Chain Monte Carlo Techniques(MCMC).....	17
3.2.4	Gibbs Sampling.....	17
3.2.5	RBM Overview.....	18
3.2.6	Contrastive Divergence (CD).....	19
3.3	Linear Mapping/Transformation.....	21
3.4	Back Propagation	21
3.5	Radial Basis Function Neural Network (RBFNN)	23
3.5.1	RBF Neuron Activation Function.....	25
3.5.2	Number of Neurons in the Hidden Layers.....	27
3.5.3	K-means clustering.....	28
3.5.4	Selecting Beta Values.....	28
3.5.5	Pseudo-Inverse technique for selecting weights in output layer.....	29
3.6	Deep Neural Networks(DNN).....	30
3.6.1	Deep Belief Net.....	31
3.6.2	Stacked Auto encoders (SAE).....	33
3.6.3	Deep Belief network.....	34
3.6.4	Deep Boltzmann Machines (DBM).....	39

Chapter 4: Comparative Analysis of Algorithms	43
4.1 MNIST Database Implementation	43
4.2 Restricted Boltzmann Machines (RBM) + Softmax Units.....	43
4.2.1 Training phase in RBM(CD-1algorithm).....	45
4.2.2 Testing phase in RBM.....	46
4.3 Radial Basis Functions (RBF).....	47
4.3.1 Variations in the algorithm.....	48
4.4 Restricted Boltzmann Machines (RBM)+Radial Basis Functions (RBF).....	48
4.4.1 Variations in the algorithm.....	49
4.5 Deep Belief Networks (DBN)	50
Chapter 5: EXPERIMENTAL RESULTS	53
5.1 Results of RBM with Softmax Units.....	53
5.2 Results of RBM+RBF	56
5.3 Results of RBF.....	57
5.4 Results of DBN	60
Chapter 6: CONCLUSION AND FUTURE WORK	63
6.1 Conclusion.....	63
6.2 Future work.....	64
REFERENCES	65

LIST OF FIGURES

Figure 2.1 Subset of MNIST Database.....	7
Figure 2.2 Examples of 2s in the MNIST database (first 100 examples).....	7
Figure 2.3 General System Overview.....	9
Figure 2.4 General Process Overview.....	10
Figure 3.1 Network Topology of a RBM.....	18
Figure 3.2 n steps of Gibbs sampling.....	20
Figure 3.3 Multilayer feed forward neural network.....	21
Figure 3.4 Basic RBF Network Architecture.....	24
Figure 3.5 RBF Neuron Activation Function plot.....	25
Figure 3.6 RBF Neuron activation for different values of beta.....	26
Figure 3.7 Three neurons in a space with two predictor variables X and Y and Z is activation function value.....	27
Figure 3.8 Training Algorithms for Stacked Auto Associator.....	34
Figure 3.9 Greedy Layer wise Pertaining of Deep Belief Net.....	35
Figure 3.10 Step-1 of Pre-Training Phase.....	36
Figure 3.11 Step-2 of Pre-Training Phase.....	37
Figure 3.12 Step-3 of Pre-Training Phase.....	37
Figure 3.13 Topological differences between DBN and DBM.....	39
Figure 3.14 Pre-training algorithm of DBM.....	41
Figure 3.15 Conversion of a 2-hidden layer Boltzmann machine into a deterministic neural network.....	42
Figure 4.1 Single layered RBM with softmax units.....	44
Figure 4.2 Neural network architecture for two class problem.....	48
Figure 4.3 Network architecture for RBF Classification over RBM.....	49

LIST OF GRAPHS

Graph 5.1 Variation of CORRECTNESS vs. learning rate	53
Graph 5.2 Variation of CORRECTNESS vs. epochs.....	55
Graph 5.3 Variation of size of training data vs. correctness in RBM+RBF.....	56
Graph 5.4 Variation of size of training data vs. correctness in RBF (1000)	59
Graph 5.5 Variation of size of training data vs. correctness in RBF (10000).....	59
Graph 5.6 Variation of hidden neurons with correctness	60

LIST OF TABLES

Table 5.1 Variation of hidden neurons and Correctness	54
Table 5.2 Variation of standard deviation and Correctness	55
Table 5.3 Variation of correctness vs. epochs in the model RBM+RBF	57
Table 5.4 Variation of correctness vs. size of training data	58
Table 5.5 Variation of number of clusters/hidden neurons vs. correctness	60
Table 5.6 Variation of hidden neurons and fine tune algorithms in a DBN.....	62

ABBREVIATIONS USED

RBM	Restricted Boltzmann machine
DRBM	Discriminative Restricted Boltzmann machine
DBM	Deep Boltzmann Machines
DBN	Deep Belief Nets
DNN	Deep Neural Networks
BP	Back Propagation
RBFNN	Radial Basis Function Neural Network
FA	Factor Analysis
RBF	Radial Basis Function
PDA	Personal Digital Assistants
BBRBM	Bernoulli- Bernoulli RBM
GBRBM	Gaussian-Bernoulli RBM
MRF	Markov Random Field
MCMC	Markov chain Monte Carlo
MLP	Multilayer Preceptor model
ML	Machine Learning
HMM	Hidden Markov Models
CRF	Conditional Random Fields
SVMs	Support Vector Machines
CD	Contrastive Divergence
w.r.t.	With respect to
i.e.	That is