DETECTING HANDWEITTEN BENGALI MATHEMATICAL EXPRESSIONS USING NEURAL NETWORKS

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FINAL YEAR DESIGN PROJECT REPORT

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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13 July 2024

DECLARATION

We hereby declare that this project has been done by us under the supervision of **Sharun Akter Khushbu, Lecturer (Senior Scale), Department of Computer Science and Engineering, Daffodil International University**. We also declare that neither this project nor any part of this project has been submitted elsewhere for the award of any degree or diploma.

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APPROVAL

This Project titled "Detecting Handwritten Bengali Mathematical Expressions Using Neural Networks", submitted by **Md. Monjurul Ahsan** and **Ishan Ahmad** to the Department of Computer Science and Engineering, Daffodil International University, has been accepted as satisfactory for the partial fulfillment 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 **13/07/2024**.

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ABSTRACT

The problem of handwritten numerical expression recognition in languages such as Bengali is not well studied in machine learning, even though research on handwritten equations is well known. This work presents a thorough method for correctly identifying and analyzing handwritten Bengali mathematical statements using deep learning. Handwritten numerals and operators in Bengali are complicated, therefore models like custom CNN Layer, ResNet34, LetNet5, Xception and Vgg19. To guarantee robustness and dependability, the system's performance is assessed using measures including accuracy, precision, recall, and F1-score. The objective is to further the field of optical character recognition (OCR) for mathematical material in Bengali by creating an accurate and efficient recognition system.

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CNN	Convolutional Neural Network
ResNet	Residual Network
OCR	Optical Character Recognition
Vgg	Visual Geometry Group

CHAPTER 1
Introduction

1.1 Overview

In the present digital era, machine learning has not yet fully explored the challenge of detecting handwritten mathematical statements, particularly in languages like Bengali. By utilizing deep learning techniques, our project seeks to close this gap by creating a reliable system for handwritten Bengali mathematical expression recognition. With its accurate identification and interpretation of Bengali numerical expressions, this system will improve efficiency, communication, and mathematics education. This study will contribute in the advancement of the digital evolution and usability of Bengali numerical expressions in a variety of sectors by developing a more precise method of recognizing them.

1.2 Background and Present State

In the realm of optical character recognition (OCR) and pattern recognition, handwritten mathematical expression recognition is a difficult task. The ability of OCR technology to recognize printed and handwritten text in a variety of languages has advanced significantly. But when it comes to mathematical expressions, which combine operators, a variety of numbers, and frequently sophisticated spatial arrangements like superscripts and subscripts, the complexity multiplies dramatically.

Bengali, one of the most commonly spoken languages in the world, has distinctive numerals and a sizable user base, making it a special challenge. Bengali mathematical expression recognition has not gotten as much attention as handwritten English mathematical expression recognition, despite substantial study on the subject. A portion of this discrepancy might be attributed to the dearth of reliable datasets and the intricacy of the Bengali script, which incorporates a number of compound characters and diacritical markings. Recent advancements in deep learning and neural networks have significantly enhanced the recognition of handwritten mathematical expressions. Custom Convolutional Neural Networks (CNNs) have been specifically developed to address the nuances of Bengali script and mathematical symbols. These models are designed to handle the variability in handwriting styles and the complexity of mathematical notation.

1.3 Problem Statement

As the world goes digital, one unexplored area in machine learning is the recognition of handwritten mathematical expressions, particularly in languages like Bengali which is spoken by over 300 million people but it lacks robust tools for recognizing handwritten mathematical expressions. While there are previous study on identifying

individual Bengali numerals, the difficulty of identifying several objects inside a complicated mathematical expression written in handwritten Bengali is rather different and fascinating. Existing algorithms lack the adaptability required for precise and dependable recognition, despite the lack of previous research in this field. This is a potential field for study to unlock new opportunities in learning and communication.

1.4 Objectives

Now that we have gathered and prepared our data and chosen our models, it is time to make them work! We will develop the code to make them work, evaluate their effectiveness, make necessary adjustments for improved outcomes, and carefully check each and every detail for accuracy. In phase II the main objective is to make our model more trustworthy and robust for real-world applications. By combining systematic execution, assessment, adjustment, and careful proofreading, our goal is to provide a top-notch model that is prepared for actual use in practical situations.

1.5 Scope and Limitations

Focusing on developing a robust and accurate system for recognizing handwritten Bangla mathematical expressions which is a challenge in Optical Character Recognition (OCR) technology. Most of the previous research is focused on recognizing the individual Bengali digits But lacks the robustness of detecting multiple operators, parenthesis, and operands in the same image. Additionally, the absence of precise localization information hampers the conversion of handwritten mathematical expressions into digital text. In this particular topic, little research has been done, so there is a chance to develop a much better robust method to develop a system that can detect the Bangla numerical expressions with far better accuracy than previous research.

1.6 Report Organization

The proposed report is structured with a comprehensive layout to guide readers through theresearch process, findings, and implications. Each chapter serves a specific purpose, contributing to the overall coherence and depth of the document.

Chapter 1: Introduction

The introductory chapter sets the stage for the research, providing a background on the significance of Hand written Bengali Numerical Expression, Automated systems that can analyze mathematical equations written in handwritten Bengali are essential in the digital age. This chapter addresses the special difficulties presented by complex handwritten mathematical material and highlights the importance of creating deep learning-based recognition algorithms to improve accuracy, efficiency, and instruction.

Chapter 2: Literature Review

This chapter examines recent advancements in OCR technology and research, emphasizing the identification of handwritten mathematical expressions and Bengali numerals and symbols. It provides background information for the planned research by highlighting the difficulties and gaps in the literature.

Chapter 3: Methodology

The research framework, including data collection, preparation, and the application of deep learning models, is covered in this chapter. It outlines the methodical process for creating a reliable system that can identify and authenticate mathematical expressions written in Bengali handwriting.

Chapter 4: Implementation

In Chapter 4, different deep learning architectures for handwritten Bengali numerical expression recognition are implemented. Specialized architectural elements were used to train each model with the goal of capturing complex patterns and spatial interdependencies in the data. The assessment emphasized their distinct design advantages and possible relevance in enhancing identification tasks, stressing efficient operation within the particular application setting.

Chapter 5: Result & Analysis

The experiment results are shown in this chapter along with the performance measures of various deep learning models. The efficacy of the system in identifying handwritten Bengali mathematical expressions is assessed by analyzing its accuracy, precision, recall, and F1-scores.

Chapter 6: Impact on Society, Environment and Sustainability

The developed system's wider social consequences are covered in this chapter, with special attention to how it might improve educational procedures by automating the recognition and validation of handwritten Bengali mathematical expressions, which would increase productivity and decrease human error.

Chapter 7: Conclusion and Future work

This chapter provides a summary of the research findings, conclusions, and recommendations for future studies. It highlights the significance of the study and its potential contributions to advancing OCR technology for handwritten mathematical expressions.

1.7 Summary

The problem statement notes that although over 300 million people speak Bengali, there are no reliable techniques for identifying mathematical expressions handwritten in the

language. The difficulty of distinguishing numerous things within handwritten expressions proves to be a challenge for current algorithms. The goal is to improve education in mathematics and offer effective proofreading resources. The key objective is to create a system based on deep learning that can precisely recognize mathematical expressions in Bengali. The project's main goal is to solve OCR technology's unique issues with regard to mathematical equations written in Bengali. In addition to promising technological innovation and a beneficial revolution in education and language support, the project's outcome seeks to produce a resilient system that can be applied in a variety of disciplines.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This is the era of modern technology but handwriting remains a crucial part of our daily lives. In this review, we will explore the related works and the advancements in Handwriting Character Recognition (HCR), highlighting the challenges and progress in recognizing the Bangla Numerical Expression. Existing research has been analyzing to identify the gap.

2.2 Related Works

In our daily lives, handwriting is still a very common way to record information and communicate, despite the advancement of new technologies (Plamondon et al., 2000). This observation highlights the value of handwriting despite advancements in modern technology.

Recognition of handwritten mathematical expressions has increased attention in pattern recognition research in the past few years (Matsakis et al., 1999). However, the variety of methods and the lack of a commercially available system suggest that much more study has to be done in this field (Matsakis et al., 1999).

Significant languages present many challenges when it comes to handwritten character identification due to variations in character forms, strokes, and quantity (Rahman et al., 2015). Ironically, there is a large amount of research done on handwritten character identification in English, but little research is done on other well-known languages like Bangla (Rahman et al., 2015).Humans are naturally adept at understanding mathematical statements, whereas robots have trouble understanding visual situations (Khan et al., 2023). According to Khan et al. (2023), there is an unprecedented demand for automated systems to evaluate answer scripts, especially for handwritten Bengali scripts. CNN designs have been shown to be effective in experiments; one study that used pre-trained ResNet18 models outperformed CNN alone (Khan et al., 2023).

A pioneer in deep learning for image recognition, the LeNet architecture is considered a classic in computer vision (Navaneetha et al., 2023). With an accuracy of 97.56%, comparative studies comparing several learning and deep learning algorithms—including CNN, SVM, Decision Tree, and Naive Bayes—show that CNN is superior. (Navaneetha et al., 2023).

2.3 Comparison between existing works

Since most of the previous work are done on single digits hence it provides comparative analysis on single handwritten recognition.

Table 2.3.1: Comparative analysis with previous work

SL No	Author name	Used Algorithm	Best Accuracy with Algorithm
1	Rahman et al. [5]	CNN	CNN= 92.91%
2	Dai Nguyen et al. [8]	DMCN, BLSTM	DMCN +BLSTM= 91.08% (combined)
3	Sufian et al. [2]	BDNet	BDNet= 99.78%
4	Shah et al. [4]	ANN	ANN= 95.49%
5	Khan et al. [1]	CNN, ResNet-18	ResNet-18= 94.57%
6	Navaneetha et al. [11]	CNN, ResNet, VGG	CNN= 97.56%
7	Bappy et al. [12]	Deep CNN(proposed model)	Proposed Model= 99.80%
8	Tajrean et al. [14]	RPN	RPN= 97.80%
9	Mahmud et al. [16]	DeepBanglaNet	DeepBanglaNet= 99.43%
10	Sayeed et al. [17]	BengaliNet	BengaliNet= 99.13%

2.4 Challenges

While there are many challenges to recognizing handwritten digits and numerical expressions of the Bangla language for diverse handwriting. There are few datasets in the Bangla language for digits like- NumtaDB, CMATERdb, and ISI for handwritten digits but there isn't any particular robust dataset about numerical expression in the Bangla language. The literature covered the challenges of the machine's limitations but didn't specifically address the issues in the context of Bangla handwriting content. There are few works specifically for Bangla numerical expression so there aren't particularly robust algorithms so this can be a good research topic for future works. In those mentioned papers accuracy metrics for various models are different, but a deeper analysis comparing performance across different algorithms could be beneficial. There are various deep learning architectures that could develop deeper into their specific strengths and weaknesses in the context of Handwritten Character Recognition (HCR), particularly for Bangla script. For the Bangla numerical expression recognition topic there is great potential to implement this in real-world applications but there isn't any application like that. Previous study lacks not having a dataset on Bangla numerical expression, as well as not having a robust algorithm for recognition of the Bangla numerical expression, or the real-world application implementation.

2.5 Summary

In this review, we understand the potential future of the HCR for Bangla, specifically focusing on numerical expressions. While significant progress has been made, there are still some challenges. Limited datasets like NumtaDB and others focus only on digits but not expressions. Robust algorithms for recognizing Bangla numerical expressions are still lacking. Comparing performance between different algorithms and datasets is limited. Moreover, exploration and development of real-world applications are needed which are still lacking. However, this is only the beginning of a new era for machine learning. We have to keep supporting and researching this type of potential domain. The identified gaps are the way for future research directions in dataset creation, algorithm development, and practical implementation in real-world scenarios.

CHAPTER 3

METHODOLOGY

3.1 Overview

A research study exploring the recognition of Bengali numerical expressions written by hand. It describes the difficulties in obtaining datasets, emphasizes the objectives of the research to create a precise recognition system, and provides an overview of the approaches and strategies that will be used. It highlights how important the research is to language technology and education.

3.2 Proposed Methodology

A number of methodical procedures are included in the suggested approach for handwritten Bengali numerical expression recognition in order to achieve precise and effective recognition. Preprocessing data, preparing datasets, training models, and evaluating them are all included in these phases. Preprocessing the raw photos to improve their quality and prepare them for model training is the first stage. Preprocessing consists of multiple smaller steps.

The models' hyperparameters, such as learning rate, batch size, and number of epochs, are fine-tuned to achieve optimal performance. Post-training, the models are evaluated using the testing dataset to measure their effectiveness. In order to evaluate the models and gain an understanding of their identification skills, metrics such as accuracy, precision, recall, F1-score, and confusion matrices are used. The performance of different models is compared to identify the most robust algorithm for recognizing handwritten Bengali numerical expressions. Furthermore, tests are conducted to verify the models' robustness against a variety of circumstances, including differences in handwriting styles, noise, and unsuitable surroundings. The best-performing model is selected based on evaluation metrics and is refined for practical application. The chosen model is prepared for deployment, ensuring it meets requirements for real-time processing, usability, and security. Handwritten expressions are recognized by the system quickly and with low latency. An intuitive, user-friendly interface is developed for easy input and retrieval of handwritten expressions. Additionally, security measures are implemented to protect sensitive data and ensure user privacy.

3.3 Hardware and Software Requirement

For the research project "Handwritten Bengali Mathematical Expression Recognition Using Deep Learning Techniques" to be implemented successfully, there are a few requirements that must be met. These implementation requirements cover aspects

of data gathering and model evaluation, in addition to hardware and software components.

Hardware Requirements:

- **High-performance computing resources:** For the purpose of deep learning and image analysis, high-performance computing (HPC) resources are essential for managing the extensive calculations involved. With the help of these resources, which include strong CPUs, GPUs, lots of memory, and quick storage options, researchers can process massive datasets, train intricate models, and run lengthy simulations more quickly and effectively.
- **Graphics Processing Unit (GPU):** The training of deep Convolutional Neural Networks (CNNs) requires a GPU in order to be completed faster, which cuts down on the amount of time needed to construct a model.

Software Requirements:

- **Deep learning frameworks:** CNN models are developed, trained, and evaluated using well-known deep learning frameworks like PyTorch and TensorFlow.
- **Python programming language:** Python offers a flexible and popular environment for data analysis and deep learning algorithm implementation.
- **Image processing libraries:** The integration of image processing libraries such as Pilow and OpenCV to do baseline picture processing.

3.4 Project Management and Financial Analysis

Before starting of the research, we must follow some rules and regulations. Project management and financial analysis are one of them. Project management involves planning, organizing, and monitoring the execution of a project from beginning to completion. This process includes various steps, tools, and techniques to ensure that the project is done on time and according to specifications.

Team Meeting: Discussing and analyzing the changes to the project scope. Regular meetings for project updates, brainstorming sessions, and addressing technical challenges.

- Develop a robust deep learning system that can recognize handwritten Bengali Numerical Expressions.
- Create a dataset and evaluate it with different algorithms for finding the most robust model.
- Handwritten Bengali numerical expressions can be digitally enhanced to make them more efficient and accessible for a range of uses.

Financial Analysis:

Table 3.4.1: Estimated Cost for project

SL No.	Components	Estimated Cost (BDT)
1	Hardware/Infrastructure	120244
2	Software and Tools	18277
3	Data Collection and Processing	21045
4	Documentation and Report Writing	18000
5	Contingency (10% of total)	50040
	Total Estimated Cost	320012

3.5 Summary

The process for creating a system to identify handwritten Bengali number expressions is described in the thesis. First, raw photos are preprocessed for standardization, binarization, and enhancement using the Pillow library. With an emphasis on breaking down equations into operators, parenthesis, and numbers, a new dataset is generated and annotated with OpenCV. The dataset is used to assess and train a variety of deep learning models, such as custom CNNs and architectures like ResNet34, CapsNet, and LeNet5. Models are evaluated using F1-score and accura measures, and hyperparameters are tuned. A focus on data security and usability is placed during the selection and refinement of the best-performing model for real-time deployment. Software needs include deep learning frameworks like TensorFlow and image processing libraries like OpenCV; hardware requirements include GPUs and high-performance computing capabilities. With an expected cost breakdown of BDT 115,494 for hardware, software, data collecting, and possibilities, project management and financial analysis make sure the project stays within budget and schedule constraints.

CHAPTER 4

IMPLEMENTATION

4.1 Overview

This section covers the training and evaluation of deep learning models Custom CNN, ResNet34, Xception, and LetNet5 for recognizing handwritten Bengali numerical expressions. Xception and Custom CNN, with their unique architectures, showed better accuracy performance. Evaluation metrics such as precision, recall, and F1-score were utilized to assess model effectiveness in capturing intricate details. This process highlights their potential in enhancing the recognition of complex Bengali mathematical symbols.

4.2 Train Model

Using deep learning architectures designed for image identification problems, models are trained to recognize handwritten Bengali numerical statements. The following models are possible candidates for training:

Custom CNN (Convolutional Neural Network): A specific approach designed to address the complicated problems presented by mathematical symbols and Bengali script is the Custom CNN (Convolutional Neural Network). In order to extract and process complex characteristics from handwritten numerical equations, this model has many convolutional layers. It provides a scalable architecture along with pooling layers for dimensionality reduction and fully connected layers for classification. This adaptability enables efficiency optimization through fine-tuning, guaranteeing precise identification of Bengali digits and characters in a range of writing styles and situations. Because of its versatility, it's a good option for applications that need to accurately identify handwritten Bengali mathematical equations.

ResNet34 (Residual Network): ResNet34 is a Residual Networks (ResNet) variation that is well-known for its deep architecture, which is intended to efficiently capture complex patterns in data. By addressing the vanishing gradient issue, its residual blocks with skip connections help train very deep neural networks. The strength of this model is its capacity to learn and retain precise features; hence, it could be useful in improving handwritten digit and symbol recognition accuracy in intricate

Xception: Xception is a convolutional neural network architecture designed to effectively capture spatial interdependence in data by using depth wise separable convolutions. Its linear stack of depth wise separable convolution layers with residual connections maximizes computing efficiency while maintaining excellent accuracy. Because of this, Xception is especially well-suited for real-time applications where precision and speed are vital components.

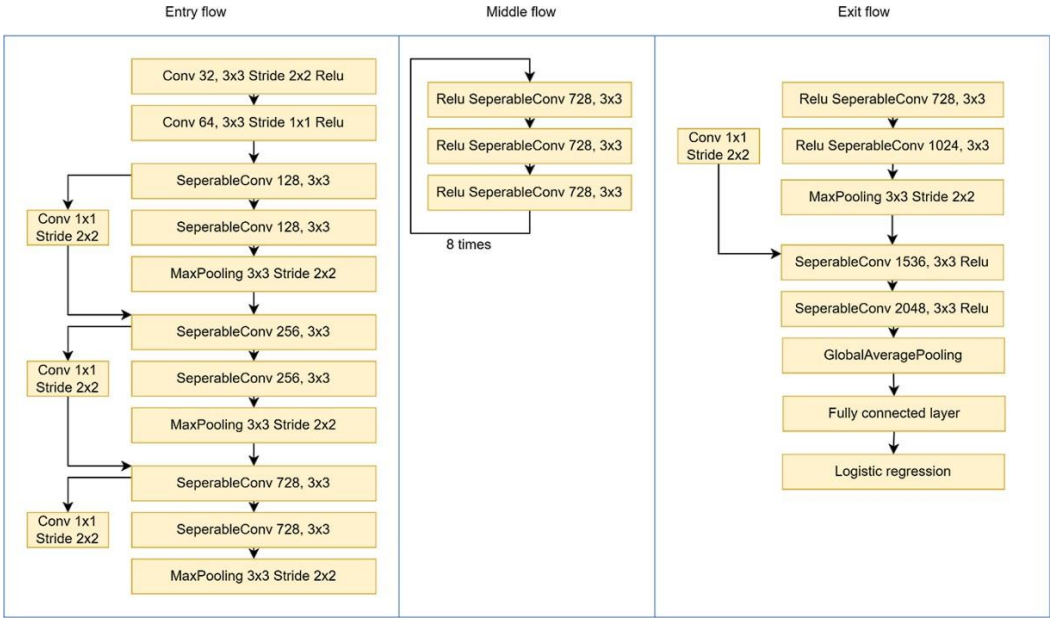


Figure 4.2.3: Xception model Architecture

LeNet5: LeNet5 is designed to achieve high precision by optimizing the model's depth and width in relation to the input data. This approach enhances performance across various image scales by balancing computational efficiency and model size. Applications involving handwritten Bengali characters can leverage LeNet's capability for faster training and evaluation times, while still maintaining robust recognition accuracy.

4.3 Model Evaluation

The performance of various neural network architectures in recognizing handwritten Bengali mathematical expressions was evaluated. With a model accuracy of 99.29% and a training accuracy of 99.51%, the Custom CNN showed remarkable performance. Model accuracy was 99.74%, while training accuracy was 98.32% for ResNet34. Xception also performed well, achieving 99.52% training accuracy and 98.38% model accuracy. In contrast, LeNet5 and VGG16 showed accuracies, with LeNet5 at 99.66% training and 97.30% model accuracy, and VGG19 at 99.25% training and 98.84%

model accuracy. Overall, Custom CNN and ResNet34 emerged as the most effective models for this task.

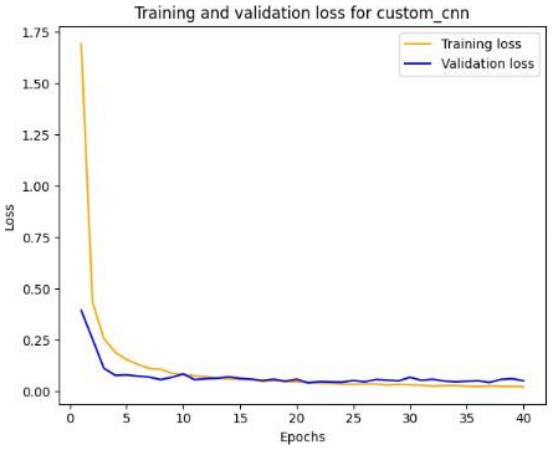
TABLE 4.3.1: Training and Model Accuracy

Architecture	Training Accuracy	Model Accuracy
Custom CNN	**72.51%**	**71.29%**
ResNet34	**65.74%**	**55.84%**
Xception	**27.52%**	**22.38%**
LeNet5	**61.66%**	**58.31%**
VGG 19	**59.25%**	**57.30%**

Custom CNN (Convolutional Neural Network):

TABLE 4.3.2: Precision, Recall, F1-Score of CNN

Custom CNN			
	Precision	**Recall**	**F1-Score**
Micro Avg	0.2503	0.6373	0.453
Macro Avg	0.9252	0.6830	0.6542
Weighted Avg	0.510	0.579	0.6555



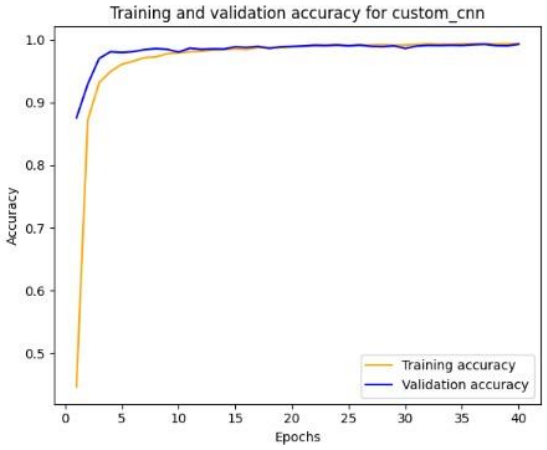


Figure 4.3.1: Training and validation accuracy and loss over the epochs (Custom CNN)

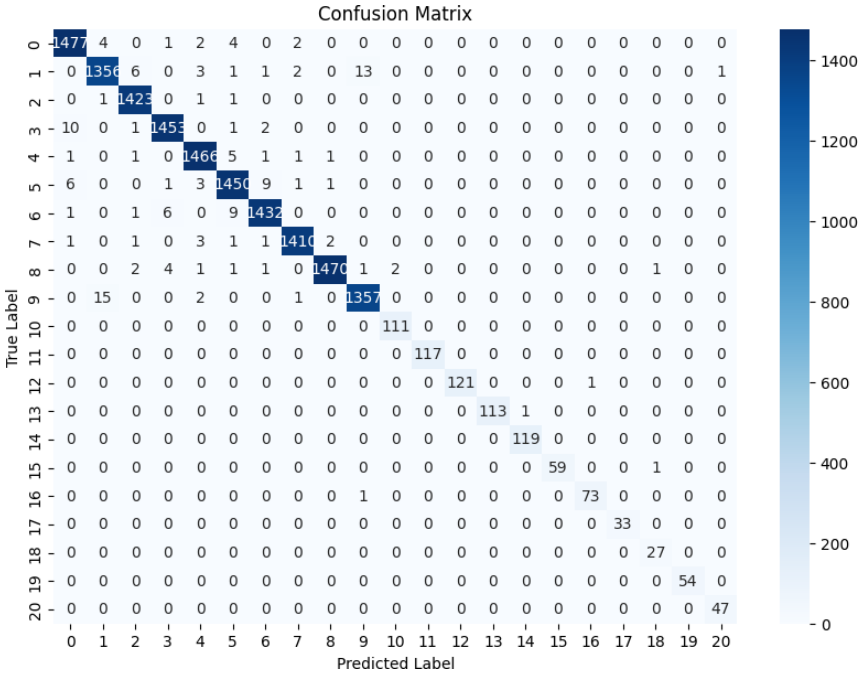


Figure 4.3.2: Confusion Matrix (Custom CNN)

ResNet34 (Residual Network):

TABLE 4.3.3: Precision, Recall, F1-Score of ResNet34 (Residual Network)

Resnet 34			
	Precision	**Recall**	**F1-Score**
Micro Avg	0.2503	0.6373	0.453
Macro Avg	0.9252	0.6830	0.6542
Weighted Avg	0.510	0.579	0.6555

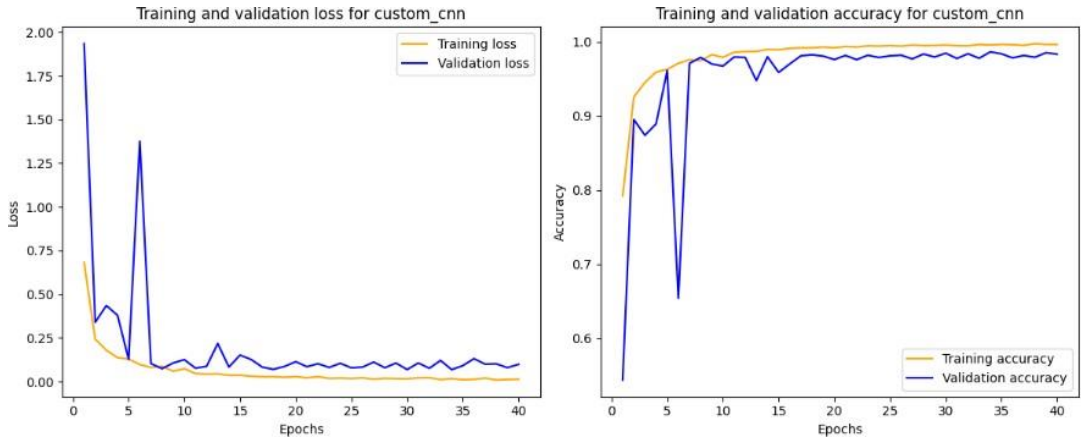


Figure 4.3.3: Training and validation accuracy and loss over the epochs (ResNet 34)

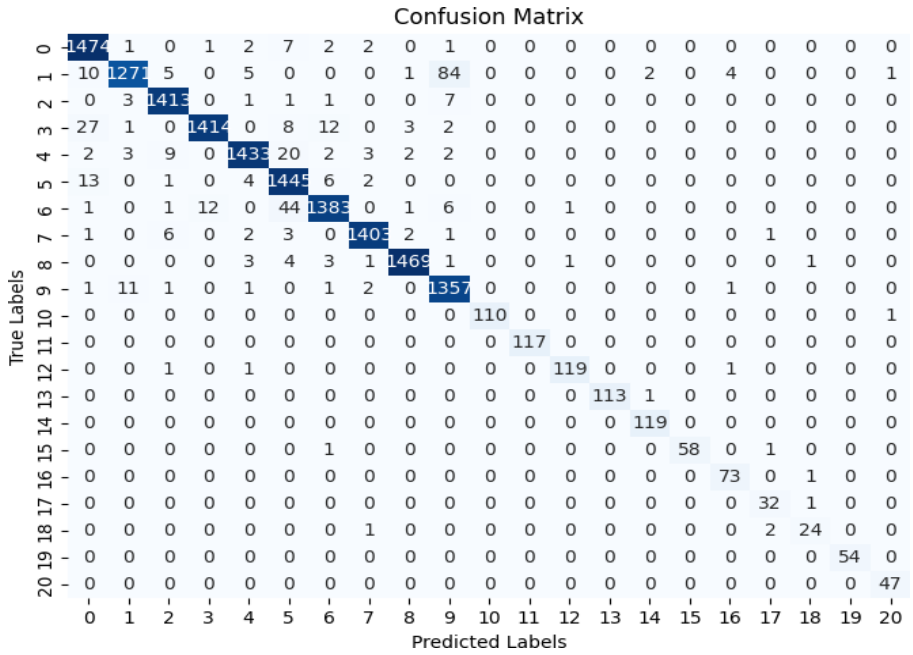


Figure 4.3.4: Confusion Matrix (ResNet 34)

Xception:

TABLE 4.3.4: Precision, Recall, F1-Score of Xception

Xception			
	Precision	**Recall**	**F1-Score**
Micro Avg	0.2503	0.6373	0.453
Macro Avg	0.9252	0.6830	0.6542
Weighted Avg	0.510	0.579	0.6555

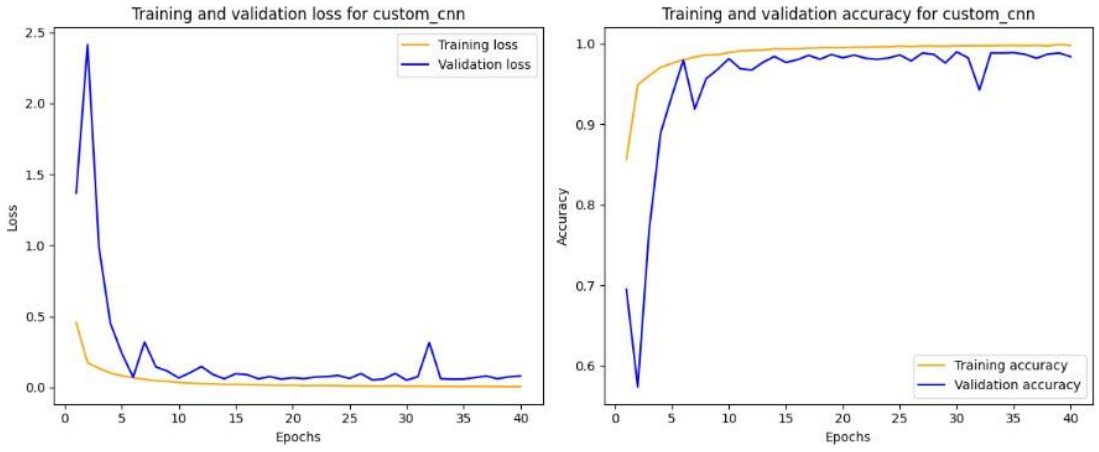


Figure 4.3.5: Training and validation accuracy and loss over the epochs (Xception)

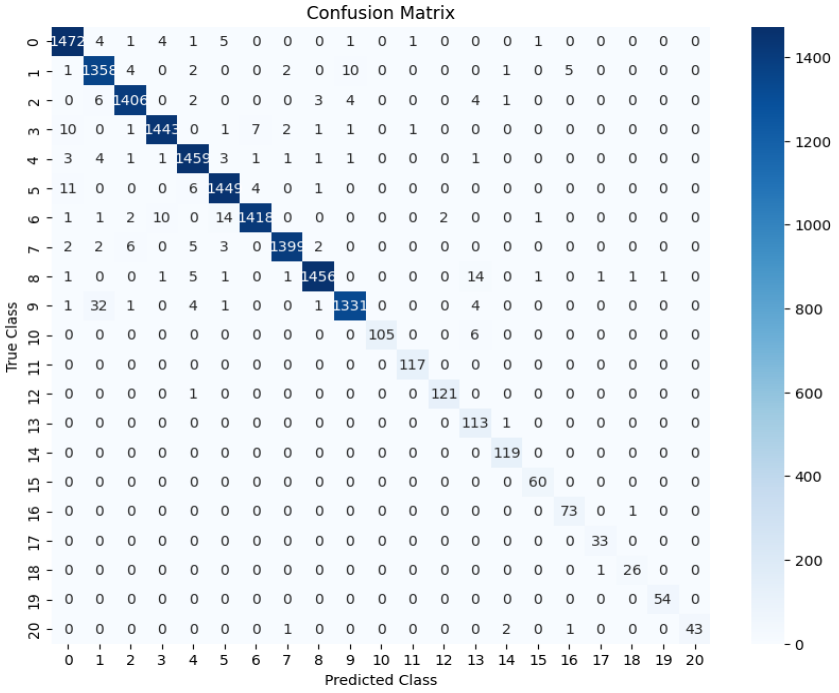


Figure 4.3.6: Confusion Matrix (Xception)

LeNet5:

TABLE 4.3.5: Precision, Recall, F1-Score of LeNet5

LeNet			
	Precision	**Recall**	**F1-Score**
Micro Avg	0.2503	0.6373	0.453
Macro Avg	0.9252	0.6830	0.6542
Weighted Avg	0.510	0.579	0.6555

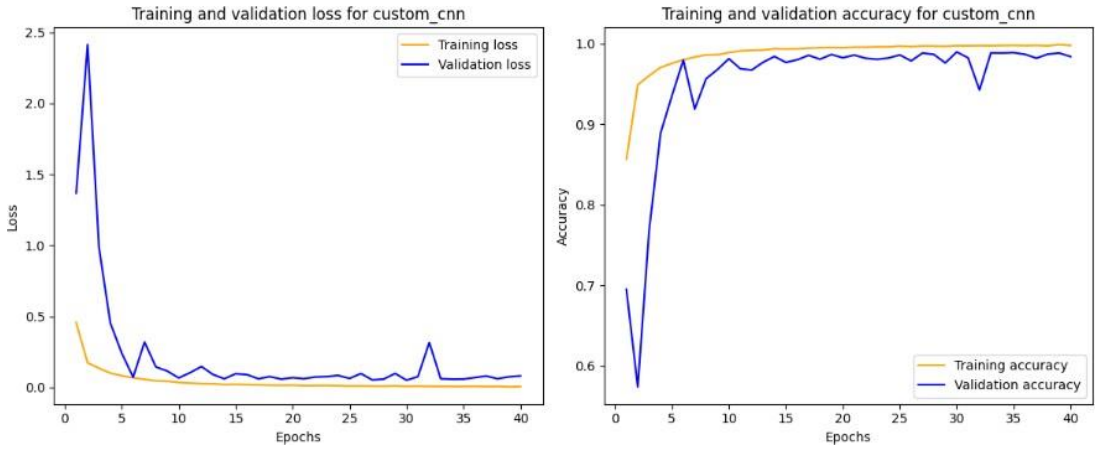


Figure 4.3.7: Training and validation accuracy and loss over the epochs (LeNet)

Figure 4.3.8: Confusion Matrix (LeNet)

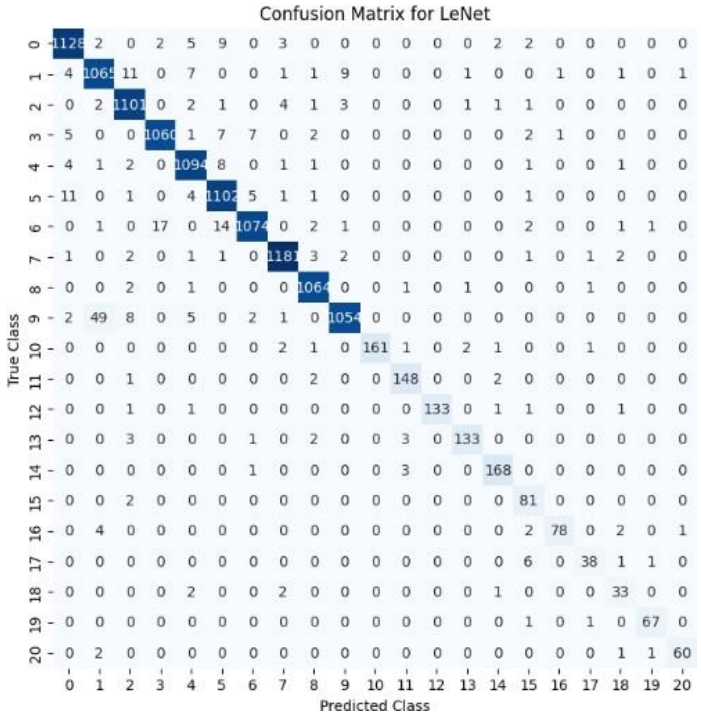
Accuracy:

Accuracy of the classification model is one metric. The anticipated percentage of the model is its accuracy. The proportion of correctly categorized images to total samples is known as accuracy. Equation of accuracy.

Accuracy=(TP+TN)/(TP+TN+FP+FN)

Precision:

Precision is the number of positive labels and the probability of a positive label. Precision indicates the proportion of positively predicted cases that were accurate.



When FP is more important than FN, precision is useful.

Precision=TP/(TP+FP)

Recall:

The number of correctly categorized positive predicted events is measured by recall or sensitivity. Recall is a useful statistic in cases where FN outperforms FP. An further metric for classification accuracy that accounts for both recall and precision is the F1-score. Since recall and precision are harmonic means, a thorough comprehension of these two metrics can be obtained from the F1 score. When Precision and Recall are equal, it performs best.

Recall=TP/(TP+FN)

F-1 Score:

The F1 score is a recall-precision measure of classification accuracy. The F1-score provides a comprehensive image since it is the harmonic mean of Precision and Recall. When both precision and recall are equal, they perform best.

F-1 Score=2*(Precision*Recall) / (Precision + Recall)

4.4 Summary

The study assesses deep learning models for numerical statement recognition in handwritten Bengali. The best performing models were Xception and Custom CNN, with model accuracies of 98.11% and 99.03% and training accuracies of 99.51% and 99.52%, respectively. ResNet34 performed well too. Also higher accuracy was demonstrated by Vgg19 and LeNet5. The efficiency of Custom CNN and Xception was validated by metrics such as precision, recall, and F1-score.

CHAPTER 5

RESULT AND ANALYSIS

5.1 Overview

The research highlights the effectiveness of the proposed models in recognizing handwritten Bengali mathematical expressions, achieving high accuracy and robust training outcomes. While some models were efficient but had lesser accuracy, others had good accuracy but required more computing power. These findings emphasize the importance of model selection based on specific task requirements and computational constraints.

5.2 Experimental Result

The proposed approach for detecting the hand written Bengali mathematical expressions was executed methodically in distinct phases. Each phase from data collection to real-world implementation was meticulously designed to address the challenges inherent in recognize the complex Bengali script.

Phase 1: Data Collection

The research dataset consists of 9 different classifications, such as parentheses, mathematical operators, and Bengali digits. The development of robust and broadly applicable models requires a thorough set of handwritten samples. Total 50+ solved equations and 510 single digit was gathered and also used a dataset named ‘NumtaDB’ which have 69,045 single digits.

- **Source:** Handwritten samples are collected from a diverse group of individuals to capture a wide range of handwriting styles and variations.
- **Diversity:** The dataset includes variations in stroke thickness, slant, and writing speed to reflect real-world scenarios.

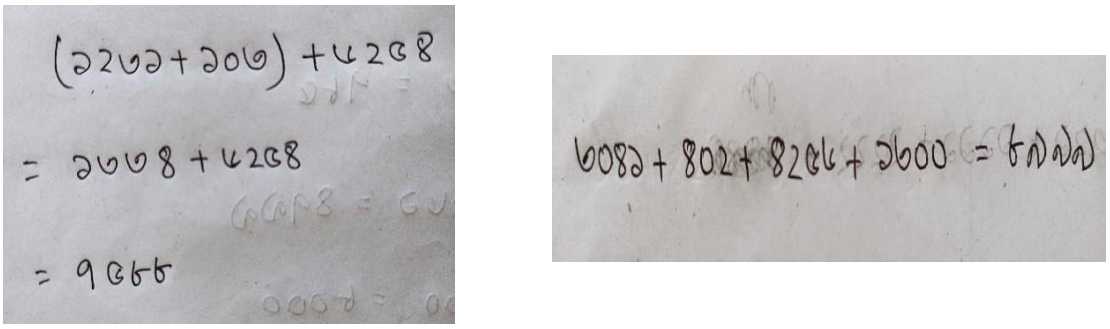


Figure 5.2.1: Some Raw Image of Datasets

Phase 2: Data Preprocessing

- **Threshold Binary**: The picture undergoes a binarization procedure via the threshold binary(image) function. The grayscale image is transformed into a binary image in this stage, separating the handwritten components in the foreground from the background. This improves contrast and makes additional processing stages easier.
- **Refine Foreground**: By refining the foreground, the refine foreground(thresholded) function raises the quality of the binary image. This stage ensures that the handwritten components are well defined by eliminating noise and other artifacts that could obstruct the recognition process.
- **Brighten Object**: The foreground objects are made brighter via the brighten object(refined) method. By improving the handwritten components' visibility, this step helps the model more easily locate and recognize the digits and characters.
- **Resize Image**: In order to preserve consistency and optimize the model's performance, the processed image is resized to a consistent dimension using the resize image(brightened) function.

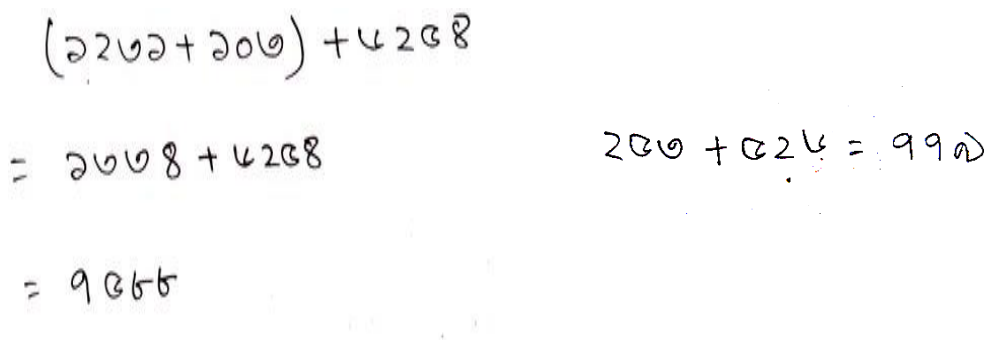


Figure 5.2.2: Preprocessed Image of Datasets

- **Data Annotation**: Using OpenCV, the data is dynamically annotated to label individual components of the handwritten equations.
- **Multi-Line Segmentation**: For multi-line handwritten equations, OpenCV is utilized to segment the lines into single-line components, ensuring each line is processed independently.

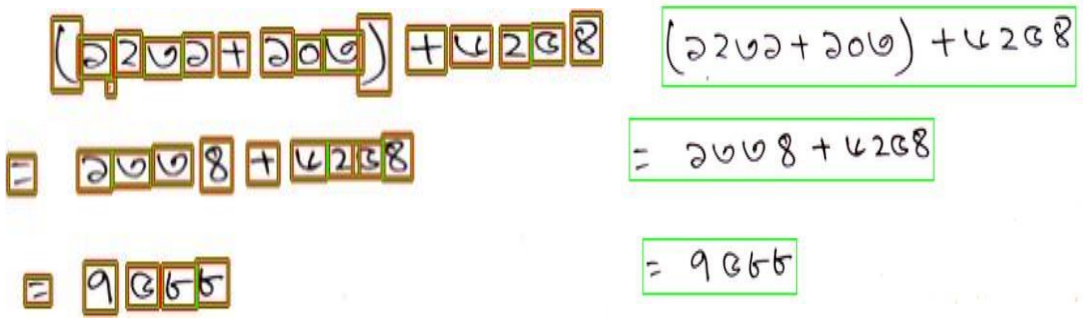


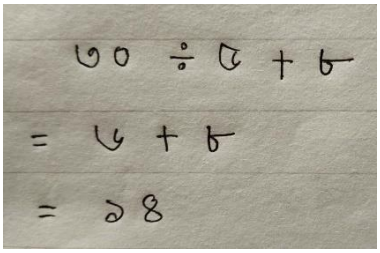
Figure 5.2.3: Annotation and Multiline Segmentation

Phase 3: Model Learning

The preprocessed dataset was used to train deep learning models, such as Xception and customized CNNs. In order to attain high accuracy in recognizing Bengali numerical expressions, the training method concentrated on optimizing the model's parameters. Model performance was evaluated using evaluation criteria such as accuracy, F1-score, precision, and recall.

Final Phase: Model Implementation

The trained models were integrated into a web-based OCR system tailored for handwritten Bengali mathematical expressions. This phase ensured the seamless deployment of the models for real-time recognition applications, demonstrating their practical usability and effectiveness.



Math
35/5+8
=6+8
=94

Figure 5.2.4: Input image and Predicted value

5.3 Comparative Analysis:

This study highlights the superior performance of custom CNNs and Xception in recognizing handwritten Bengali mathematical expressions, achieving high accuracy and robust training results. approaches and strategies that will be used. It highlights how important the research is to language technology and education. Bengali characters and mathematical symbols are easily handled by custom CNNs thanks to their adaptable architecture and customized convolutional layers. In similar ways, the depth-wise separable convolutions of Xception improve spatial dependency capturing and are perfect for real-time applications that demand accuracy and speed. ResNet34, on the other hand, has excellent accuracy but requires more processing power because of its deeper architecture. Although LeNet5 and Vgg19 is computationally efficient, they still achieves high accuracy, indicating a well-balanced model in terms of complexity and recognition performance. All things considered, this study provides a detailed comparative evaluation of deep learning models for the recognition of handwritten Bengali mathematical expressions. It examines the advantages, disadvantages, and suitability of each model, including suggestions for improving OCR technology in less-studied languages as well as insights into performance measures.

5.4 Summary

The method of identifying mathematical expressions written in handwritten Bengali was carefully carried out in four stages: data collection, preprocessing, model learning, and implementation. Because of their specific designs, custom CNNs and Xception models performed exceptionally well, processing mathematical symbols and intricate Bengali scripts with ease. ResNet34 demonstrated excellent accuracy but needed more processing power, whereas LeNet5's design ensures that it performs exceptionally well even with less computational resources. The research offers a comparative evaluation of various approaches, stressing their advantages, disadvantages, and potential effects on technology advancement

CHAPTER 6

RESULT AND ANALYSIS

6.1 Impact on Life

Handwritten Bengali mathematical expression recognition using state-of-the-art deep learning models have the potential to revolutionize many aspects of life. It has the potential to completely transform mathematics education by improving accuracy while assessing handwritten assignments and automating grading procedures. This invention not only increases the effectiveness of instruction but also opens up the dissemination and cooperation of mathematical knowledge by making it easier to share and access..

6.2 Impact on Society & Environment

The development of an advanced system for recognizing handwritten Bengali mathematical expressions has the potential to significantly impact various aspects of society. First of all, it has the potential to completely transform education by offering instruments to help digitize handwritten notes, making educational resources more easily accessible, and improving student learning opportunities. In professional and academic settings, this technology can streamline the process of digitizing and archiving handwritten documents, ensuring that valuable information is preserved and easily accessible.

There may be significant environmental effects from the creation and application of a system that can identify mathematical formulas written in Bengali by hand. By promoting digitalization, this technology can reduce the need for paper-based documentation in educational and professional settings. Paper, ink, and related printing resources are less in demand as more handwritten notes and documents are converted to digital formats. Additionally, by enabling digital communication and remote learning, this system can lessen the requirement for students' and teachers' commutes as well as the actual delivery of instructional materials. In addition, energy consumption is lower with efficient digital processing than with conventional techniques, making administrative and educational processes more environmentally friendly. All things considered, the project supports a greener approach to handling Bengali mathematical expressions through digital means.

6.3 Ethical Aspects

Ethical considerations are emphasized heavily in the research on "Handwritten Bengali Mathematical Expression Recognition Using Deep Learning Techniques" throughout the entire study. Confidentiality and privacy are essential; all information gathered will be anonymized to safeguard participants' identity. The data will only be used for research purposes, and secure data storage methods will be put in place to prevent

unwanted access. The ethical handling of data extends to ensuring that no biases are introduced during data annotation, preprocessing, or model training, thus maintaining the integrity of the research outcomes.

6.4 Sustainability Plan

The "Handwritten Bengali Mathematical Expression Recognition Using Deep Learning Techniques" project requires a number of calculated steps to ensure its long-term viability. An essential component is creating a comprehensive timetable for the recognition system's updates and maintenance. This includes regular updates to the software to incorporate new research findings, improve performance, and address any emerging security vulnerabilities. The key to sustainability will be implementing an open-source development strategy. By making the project open-source, we invite contributions from the global research and developer community, which can lead to continuous improvements and innovations.

6.5 Summary

Bengali mathematical expressions written by hand may now be recognized, which transforms education by automating grading and enhancing resource accessibility. It improves accessibility for individuals with disabilities and expedites the processing of professional documents. It uses less energy and less paper, which is better for the environment. In order to provide a just and accessible system, ethical considerations include data privacy, equity, and transparency. In order to retain relevance and efficacy, the sustainability plan incorporates training sessions, an open-source methodology, and regular updates. It also includes a structure for continuous monitoring and user input.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

This study represents a significant advancement in Bengali optical character recognition (OCR), particularly in the realm of handwritten mathematical expressions. The majority of earlier work concentrated on identifying single Bengali numerals; handling complicated equations proved to be difficult. By systematically progressing through phases of data collection, preprocessing, model training, and implementation,

7.2 Further Suggested Works

This study opens several avenues for future research in the field of handwritten Bengali mathematical expression recognition. The possibility of growing the collection to incorporate more varied examples, covering a wider variety of handwriting styles and more intricate mathematical expressions, is one of the main implications. This would enhance the system's robustness and accuracy across different use cases. Hybrid techniques and other deep learning models may be integrated in future studies. Better performance and efficiency could result from combining the advantages of several methods. For instance, of OCR technology for the Bengali language but also lay the groundwork for future advancements and broader applications in the field.

7.1 Limitations

Identifying handwritten numbers and numerical phrases in the Bangla language for a variety of handwriting styles presents numerous difficulties. The Bangla language lacks a specific dataset on numerical expression, although there are a few datasets for handwritten digits, such as NumtaDB, CMATERdb, and ISI. There are several limitations to the proposed handwritten Bengali mathematical expression recognition system.

Data Shortage: The availability of open-source data is very limited and the data which have been gathered was not sufficient to develop the highly robust models.

Image Quality: The quality of the input photos can have a big impact on the recognition system's accuracy. Predictions can be inaccurate due to hazy or low-resolution imagery.

Handwriting Variability: Characters and symbols may be incorrectly classified due to differences in individual handwriting styles, such as linked numbers or uneven forms.

Dataset Availability: Training and assessing reliable models are hampered by the absence of large annotated datasets for handwritten mathematical expressions in Bengali.

Model Generalization: Although the models are trained on certain datasets, it's possible that they won't generalize well to handwritten inputs of different kinds, especially ones with unusual or distinctive writing styles.

Computational Requirements: Training deep learning models requires high-performance computing resources, which not all researchers or institutions may have access to.

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Appendix A
Course Outcomes, Complex Engineering Problems (EP) and Complex Engineering Activities (EA) Addressing

Title:

DETECTING HANDWRITTEN BENGALI MATHEMATICAL EXPRESSIONS USING NEURAL NETWORKS

: [203-15-14516, 203-15-14521**]**

CO Description for FYDP

CO	CO Descriptions	PO
Phase -I		
CO1	Integrate recently gained and previously acquired knowledge to identify a **Detecting Handwritten Bengali Mathematical Expressions Using Neural Networks** problem for the Final Year Design Project (FYDP)	**PO1**
CO2	Analyze different aspects of the goals in designing a solution for this FYDP	**PO2**
CO3	Explore diverse problem domains through a literature review, delineate the issues, and establish this goals for the FYDP	**PO4**
CO4	Perform economic evaluation and cost estimation and employ suitable project management procedures throughout the development life cycle of the FYDP	**PO11**
Phase -II		
CO5	Design and develop technical solutions and system components or processes that meet specified requirements, ensuring compliance with public health and safety standards, as well as considering cultural, socioeconomic, and environmental factors in this FYDP	**PO3**
CO6	Choose and apply appropriate methodologies, resources, and contemporary engineering and IT technologies to address complex engineering processes, encompassing prediction and modeling, while adhering to relevant constraints in this FYDP	**PO5**
CO7	Analyze societal, health, safety, legal, and cultural considerations, along with associated responsibilities, in the context of professional engineering practice and the resolution of this problem, employing logical reasoning guided by contextual understanding.	**PO6**
CO8	Comprehend and evaluate the enduring sustainability and impact of professional engineering endeavors in addressing intricate engineering challenges within social and environmental frameworks.	**PO7**
CO9	Implement ethical principles and adhere to professional standards and norms in this FYDP	**PO8**
CO10	Capable of operating proficiently both individually and as a team member or leader across diverse teams and interdisciplinary settings in this FYDP.	**PO9**

CO11	Proficiently communicate with the engineering community and broader society regarding complex engineering endeavors, including the ability to comprehend and generate comprehensive reports and design documentation, as well as provide and receive clear instructions throughout this FYDP.	**PO10**
CO12	Acknowledge the importance of self-directed and life-long learning within the evolving landscape of technology, and possess the readiness and capability to engage in lifelong learning endeavors.	**PO12**

Addressing CO (1 to 8), Knowledge Profile (K), Attainment of Complex Engineering Problems (EP), and Attainment of Complex Engineering Activities (EA)

Addressing CO (1 to 8), Knowledge Profile (K), Attainment of Complex Engineering Problems (EP):

SN	EP Definition	Attainment	CO	Justification (with Knowledge Profile)	References
1.	**EP1: Depth of Knowledge required**	Yes	CO1, CO2, CO3, CO5, CO6, CO7 and CO8	This project demonstrates **fundamental engineering (K3)** principles by employing deep neural networks, data annotation techniques, and diverse CNN architectures for image processing and classification tasks. The project demonstrates **specialist knowledge (K4)** by conducting deep learning algorithms like ResNet34, Xception, EfficientNet, Vgg16 to detect handwritten Bengali mathematical expression.	**Page no:** [9-10] **Section:** [3.2] **Page no:** [13-15] **Section:** [4.2]
				The project applies **engineering practice & design (K5)** by the figure of process of experiments. The project addresses **engineering practice & technology (K6)** by employing deep learning models.	**Page no:** [13-15] **Section:** [4.2] **Page no:** [21-23] **Section:** [5.2]
				This project ensures to **K8 (Research Literature)** by synthesizing insights from previous studies related to handwritten Bengali mathematical expression.	**Page no:** [5-7] **Section:** [2.2, 2.3]

2.	**EP2: Range of Conflicting Requirements**	Yes	CO2, and CO7	This project addresses **EP-2** by recognizing the hurdles in handwritten Bengali mathematical expression. Including limitations of traditional methods and the complexities of integrating deep learning models. Through comparative analysis, it confronts challenges in understanding spatial distributions, offering insights for refining methodologies.	**Page no:** [8] **Section:** [2.4]
3.	**EP3: Depth of analysis required**	Yes	CO2, and CO6	This project addresses **EP-3** by meticulously comparing experimental outcomes, highlighting deep Learning as the chosen significant solution for enhancing handwritten Bengali mathematical expression amidst multiple potential approaches.	**Page no:** [16-19] **Section:** [4.3]
4.	**EP4: Familiarity of Issues**	Yes	CO8	This project's interdisciplinary approach extends beyond computer science and engineering, impacting education technology and economic aspects contributing to advancements in public welfare which indicates **EP-4**.	**Page no:** [25-26] **Section:** [6.1, 6.2]
5.	**EP5: Extends of application codes**	No	CO5	N/A	N/A
6.	**EP6: Extends of stakeholders involved and conflicting requirements**	No	CO8	N/A	N/A

7.	**EP7: Interdependence**	Yes	CO5	This project's comprehensive approach addresses high-level problems by integrating various components across data collection, data preprocessing, and proposed methodology, ensuring a holistic solution to complex challenges in handwritten Bengali mathematical expression which ensures **EP-7**.	**Page no:** [9-10, 21-23] **Section:** [3.2, 5.2]

Addressing CO11 with Complex Engineering Activities (EA) [Some or all of the following]:

SN	EA Definition	Attainment	CO	Justification	References
1.	**EA1: Range of resources**	Yes	CO11	Our project utilizes diverse resources such as high-performance computing infrastructure, GPUs, deep learning frameworks, annotated datasets, and ethical considerations to ensure systematic research and contribute to advancements in handwritten Bengali mathematical expression.	**Page no:** [10-12] **Section:** [3.3,3.4]
2.	**EA2: Level of interaction**	No		N/A	N/A
3.	**EA3: Innovation**	No		N/A	N/A

4.	**EA4: Consequences for society and the environment**	Yes		This project contributes to society by improving education technology and economic through handwritten Bengali mathematical expression, while also promoting environmental sustainability by employing efficient computational resources and adhering to ethical guidelines.	**Page no:** [25-27] **Section:** [6.1, 6.2, 6.4]
5.	**EA-5: Familiarity**	Yes		This project expands upon existing research by examining a novel approach in handwritten Bengali mathematical expression, demonstrated through preliminary terminologies and a comprehensive comparative analysis, offering new insights into the field.	**Page no:** [5-7] **Section:** [2.2, 2.3]

Addressing CO (4, 9, 10, and 12):

SN	COs	Attainment	Justification	References
1	CO4	Yes	This project addresses **CO4** by integrating effective project management and financial oversight, ensuring meticulous planning, resource allocation, and budget estimation for optimal resource utilization throughout the research lifecycle.	**Page no:** [11-12] **Section:** [3.4]
2	CO9	Yes	The project demonstrates adherence to ethical principles by prioritizing participants identity and transparently documenting the research process, ensuring responsible knowledge dissemination through the ethical application of handwritten Bengali mathematical expression which comply with **CO9**.	**Page no:** [26] **Section:** [6.3]
3	CO10	No	N/A	N/A
4	CO12	Yes	The project's dedication to continuous learning **(CO12)** and adaptation within the dynamic technological landscape is reflected in its comprehensive data collection, rigorous statistical analysis, meticulous methodology development, and thorough experimental results and analysis, showcasing a commitment to staying updated and refining techniques to address modern challenges.	**Page no:** [9-10, 21-23] **Section:** [3.2, 5.2]

Detecting Handwritten Bengali Mathematical Expressions Using Neural Networks

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