# Offline Recognition of Handwritten Mathematical Expressions Using CNN and Xception

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**Abstract**: In scientific communications, mathematical expressions are typically necessary. They help researchers precisely define and formalize their goal problems because they are not only utilized for numerical computations but also for retrieving scientific material with less uncertainty. Writing down mathematical calculations on paper with a pen takes much less time than manually entering them into a computer. In an attempt to address this problem, we recently proposed deep learning techniques that can recognize trigonometric expression graphics from 2D layouts to 1D strings. In order to enhance the outcomes of this investigation, we use densely linked convolutional neural networks (CNN), which can increase accuracy. In order to compare performance, the Transfer Learning Framework Xception is used.

**Keywords**: Mathematical handwritten recognition, data processing, classification, CNN.

## 1. Introduction

These days, new devices like digital pens, smart writing surfaces, and interactive panels have also gained popularity, mainly in educational institutions and offices, as a result of the expanding technology usage of electronic gadgets like smartphones and tablets. For a certain sort of information, such as diagrams, tables, mathematics, charts, sketches, etc., there is a larger demand for handwritten content recognition.[10]. The development of computer algorithms that can automatically handle mathematical word problems presents a challenge for the AI research community (Bobrow, 1964). The main reason why it is challenging to automatically solve mathematical word problems (MWPs) is that there is a semantic gap between language that humans can understand and logic that computers can comprehend.[12]. The sudden COVID-19 pandemic breakout is another aspect in this; it made users aware of a different scenario and produced new guidelines for handwriting interface software used in distance learning and education. Mathematical expressions are a crucial part of many professions such as engineering, science, commerce, and education. Mathematical expressions differ from textual data in many ways due to the presence of a very large codebook with more than 1,500 symbols that are recognized in the field and the characters' frequent closeness to one another, especially in handwritten expressions. Handwritten notes are frequently used to enter mathematical expressions. Due to the analysing of handwritten texts, convolutional neural network (CNN)-based sequence recognition models have advanced significantly during the past ten years [10]. The advancements in artificial intelligence and machine learning have sparked interest in computer vision. Effective Deep Learning methods have been demonstrated to have a significant impact on picture categorization, object detection, and pattern recognition. Convolutional Neural Networks (CNNs) are widely employed to extract patterns and features from images, and they have shown outstanding results in the field of handwriting recognition. The suggested technique operates on mathematical expressions and converts them into equivalent text (CNN) using

densely coupled convolutional neural networks. This document is structured as follows: section 1 introduces handwritten mathematical expressions using CNN, Section 2 provides a review of the literature on various CNN-based algorithms, Section 3 shows the proposed approach, Section 4 depicts the results

## 2. Literature Survey

[1] C. Lu and K. Mohan. "Recognition of Online Handwritten Mathematical Expressions" cs23 in Project Report Stanford (2015), the proposed approach heavily relies on CNN; the dataset, which contains 75 different mathematical symbols; data enrichment was accomplished through an interpolation scheme; segmentation was accomplished through a straightforward heuristic; and finally, character-level classification using CNN and SVM for comparison, and expression-level classification using Hidden Markov Models (HMMs) with binary and unary potentials. By 3-4%, the CNN-based system outperforms the SVM-based system.

[2] Lyzandra D'souza and Maruska Mascarenhas, "Offline Handwritten Mathematical Expression Recognition using Convolutional Neural Network", 2018 International Conference on Information, Communication, Engineering and Technology (ICICET) Zeal College of Engineering and Research, Narhe, Pune, India, The author has done Segmentation using a recursive projection profiling algorithm and using Classification (CNN). Found very good results of about 88% using Convolutional Neural Network (CNN).

[3] Surendra P. Ramteke, Dhanashri V. Patil , Nilima P. Patil "Neural network approach to mathematical expression recognition system" (2012) International Journal of Engineering Research & Technology (IJERT) Volume 01, Issue 10 (December 2012), A centroid and bounding box are the main components in feature extraction and segmentation. Written data is in jpg format. Neural networks are used and presented a 90% recognition rate. Compared with other existing techniques.

[4] Dai Hai Nguyen, Masaki Nakagawa and Anh Le Duc. "Recognition of Online Handwritten Math Symbols using Deep Neural Networks" IEICE Transaction and Systems - October 16, Bidirectional Long short-term memory (BLSTM) recurrent neural networks for online recognition and offline using Deep Maxout Neural Network (DMCN). Because of the depth of CNN, each of their layers can assess complicated features that imitate larger and more complex object parts. CNN performs better than modified quadratic discriminant functions (MQDFs).

[5] Yanyan Zou, Wei Lu "Text2Math: End-to-end Parsing Text into Math Expressions" Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing,- A unified structured prediction approach is proposed for Text to conversion. The proposed work can be applied to resolve distinct math-related problems along with arithmetic word problems and equation parsing problems.

[6] Chuanjun Li, Robert Zeleznik, Timothy Miller, Joseph LaViola "Online recognition of handwritten mathematical expressions with support for matrices" 2008 19th International Conference on Pattern Recognition- Presented interactive computational tool math paper. Segmentation & recognition using the spacing algorithm, that leverages symbol identification, and size. relevant location. The system is designed for 7 subjects each having 890 symbols (a total of 6237) in forty-three different expressions. The average result is 91.6%.

[7] Sanjay S. Gharde, Pallavi V. Baviskar, K. P. Adhiya "Identification of Handwritten Simple Mathematical Equation Based on SVM and Projection Histogram" International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-3, Issue-2, May 2013- Projection Histogram &OCR(SVM). Bounding box and labeling. With projection histogram features and SVM classifier, they have presented results of 98.4%.

[8] M Abirami; Suresh Jaganathan "Handwritten Mathematical Recognition Tool" Second International Conference on Computational Intelligence in Data Science (ICCIDS-2019)- In the proposed work

segmentation was done using the Histogram approach of the given data, Symbol Classification using a support vector machine (SVM), and extreme learning machine ELM. Symbol recognition has very high accuracy: results for SVM were About 90% and for ELM was about 95%.

[9] Nicolas D. Jimenez, Lan Nguyen " Recognition of Handwritten Mathematical Symbols with PHOG Features" ID - cs22 Stanford education published 2013- Transforming handwritten formula to Latex. Support vector machines (SVM) are trained using The Pyramid Histogram of Oriented Gradients (PHOG) features. CHROME-12 dataset is used. Presented result 92%.( images of 75 handwritten symbols and 1400 equations).

[10] Prathamesh Tope, Sarvesh Ransubhe, Mohammad Abdul Mughni, Chinmay Shiralkar, Mrs. Bhakti Ratnaparkhi " Recognition of Handwritten Mathematical Expression and Using Machine Learning Approach" International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056,p-ISSN: 2395-0072 Volume: 08 Issue: 12 | Dec 2021- The purpose of this study is to provide an overview of handwritten mathematical expression recognition and its applications. Mathematical expressions are routinely input by hand into a computer, which is significantly slower than writing them down with a pen on paper. To recognize a handwritten expression on a piece of paper, machine learning technology is utilized. For handwritten mathematical expression recognition, the Convolutional Neural Network (CNN) Method provides the highest accuracy.

## 3. Proposed Methodology

The steps in the proposed work are as follows: data collection, data augmentation to expand the dataset, partitioning the data into training and testing sets, pre-processing the data, and training the CNN model to ultimately produce text that is comparable to mathematical expression. The proposed system's framework is shown in figure 3.4.

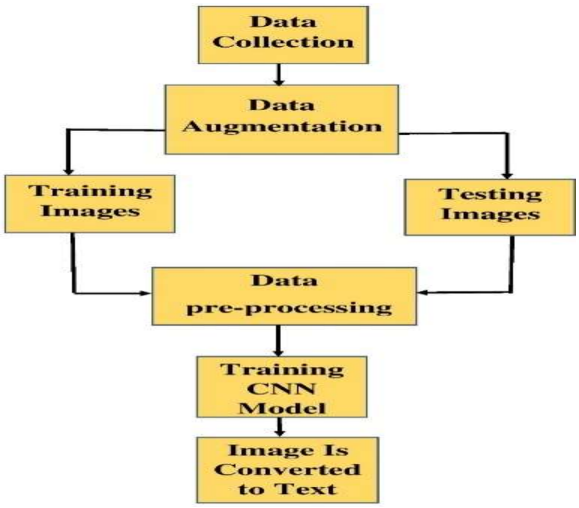



**Figure 3.1: System Architecture**

**3.1 Database**: We compiled pictures of people's handwritten mathematical expressions and divided them into 30 categories. In our dataset, there are 30,000 photos. Figure 3.2 shows a few examples of the same.

**3.2 Data Augmentation:** When analyzing data, data augmentation refers to increasing the amount of data by combining copies of the current data that have undergone minor changes or by creating new synthetic data from the existing data. To improve photographs for data augmentation, we can apply geometric adjustments, flipping, cropping, rotation, noise injection, and random erasure. An example of the expanded dataset is shown in figure 3.3.

**3.3 Data Processing:** It is a process used to convert unclean data into clean data sets. Handwriting datasets need to be pre-processed before training due to their varied character.

- Resize images: Since some images have different sizes, we set a standard scale for all images and gave that size to our CNN model. 128 * 128 has been utilized as the foundation size.
- Convert the JPG content into an RGB grid of channels.
- Normalization, also known as data rescaling, is the process of extending the intensity of picture data pixels to a predetermined range, often (0,1). The first image has numbers from 0 to 255, which we normalize to a range of 0 to 1.
- Exploratory Data Analysis (EDA) is a data analytics method to comprehend the data in depth and discover the various data features, typically utilizing visual means.

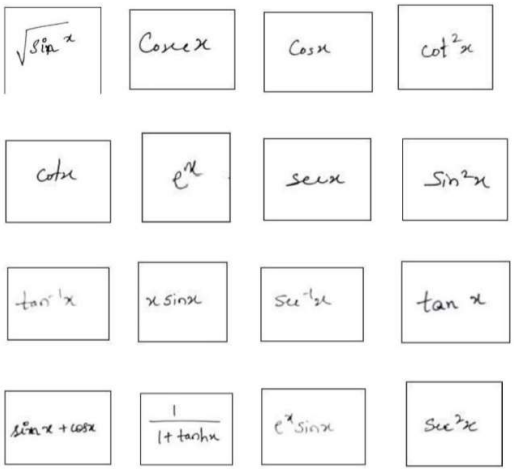


Figure 3.2: Sample idols of the dataset

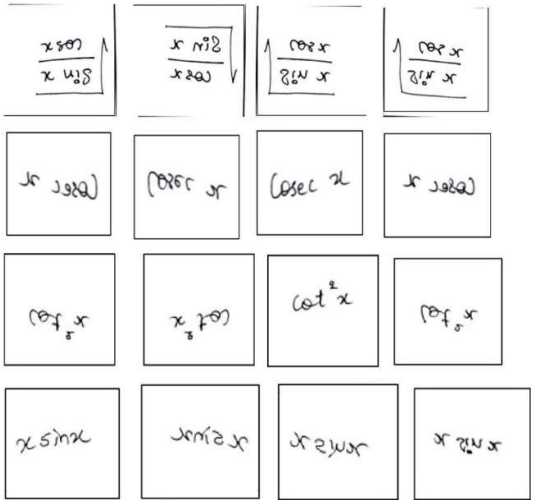


Figure 3.3: Sample image of augmented dataset

**3.4 Convolutional Neural Network (CNN): A** popular deep neural network design, is a type of deep neural network that can be used to do HME Recognition. There are input, hidden, and output layers in CNN. Convolutional, ReLU, pooling, and fully linked layers are typically included in the hidden layers.

(a) Input Layer: This layer accepts an image with a size of 128x128 and converts it into a number of hidden layers.

(b) Hidden layer:

- The Convolutional Layer extracts a property from the input image. By analyzing visual attributes with the help of tiny squares of input data, convolution preserves the connection between pixels. A numerical format is applied to the image. When a convolution layer is applied to a picture, the output of the first layer becomes the input for the second layer, and so on through all subsequent convolutional layers. The proposed work contains four convolution layers and a 3X3 convolution mask.

- Rectified Linear Unit (ReLU) layer: this layer has a non-linear activation function. The main disadvantage of employing the ReLU function over other activation mechanisms is that not all of the neurons are activated at once. The outcome is zero for negative input values, meaning the neuron isn't engaged. This layer's primary goal is to change negative numbers to zero.

- The purpose of the pooling layer is to reduce the matrix size by avoiding the 0s while maintaining the characteristics of the map needed for classification. The plot of 0s is obtained from the preceding layer. There are numerous methods for pooling. In our work, we have used both max pooling and mean pooling.By using max pooling, we select the segment's biggest pixel value. Max pooling has been done four times. The next step is to flatten each pooled image into a solitary lengthy vector. Figure 4 displays a sample from a maximum pooling.

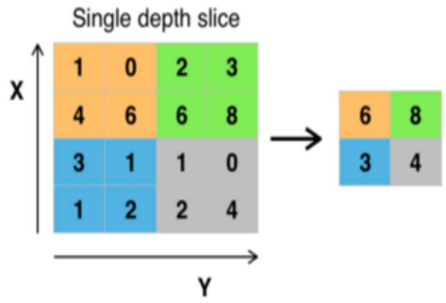



Figure 3.4: Example of max pooling

(c) Fully Connected layer / Output layer: It's crucial to fix a fully connected layer following the execution of a series of convolutional, nonlinear, and pooling layers. The output facts from convolutional networks are connected by this layer. In this case, the value of N is 30, and connecting a completely connected layer to the network's end yields a 1 * N-D vector, where N is the number of classes from which the model chooses the needed class.

The loss and accuracy plot of the trained CNN module, which has a 98% accuracy, is displayed in the graphs below. Figure 3.6 displays the CNN model's Donut chart of the thirty classes and their percentage contribution to the entire dataset.

## 4. Results

The dataset comprises of 30,000 handwritten mathematical images that have been divided into 30 classes. 70% of the photos are used for training, while the remaining 30% are used for testing using the two algorithms Xception and CNN. For the Xception model, we achieved 90% accuracy, and for the CNN model, 98% accuracy. Thus, we draw the conclusion that the CNN model is appropriate for our research. Here are a few examples of photos and the text results that correspond to them. Figure 4.1 shows the final outcome, while figure 4.2 compares the record sizes for 30 classes.

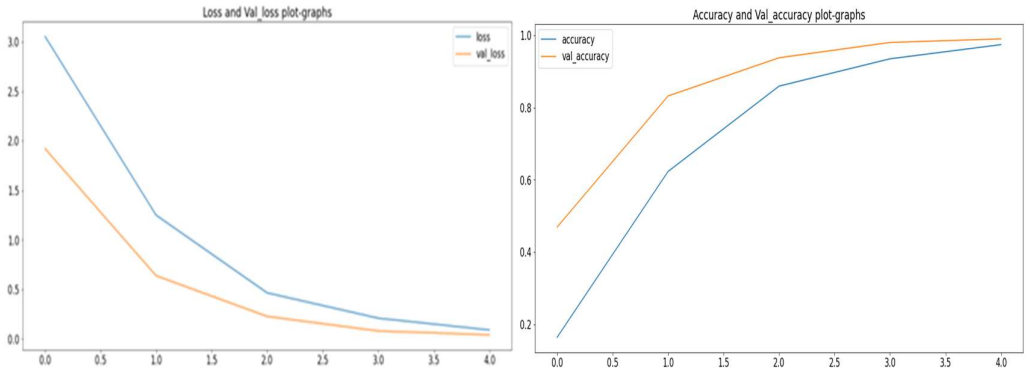



**Figure 3.5: Loss and Accuracy function**

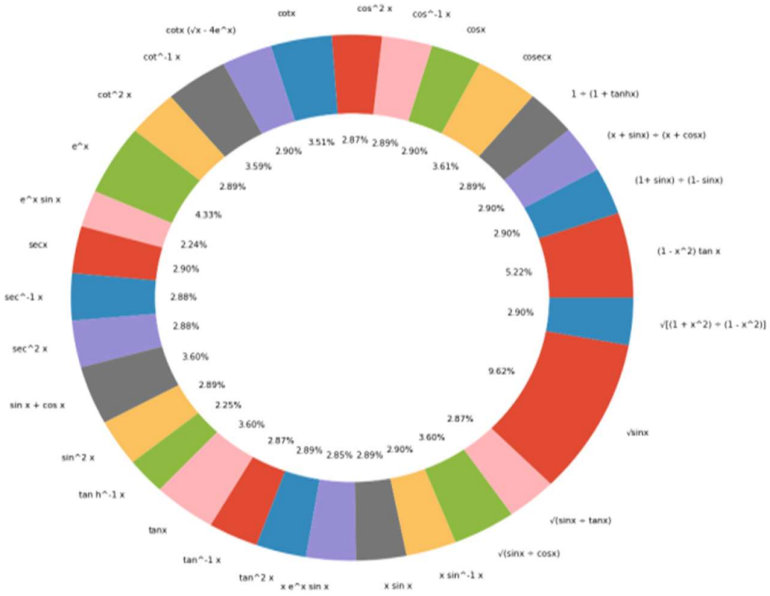



Figure 3.6: Donut chart of the dataset

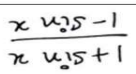
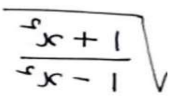
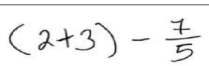
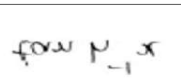
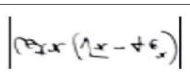
| INPUT IMAGES | RESULTS |
|---|---|
|  | e^x |
|  | (1+ sinx) ÷ (1- sinx) |
|  | √[(1 + x^2) ÷ (1 - x^2)] |
|  | y= ax + a^2 |
|  | (2 + 3) – (7 ÷ 5) |
|  | tan h^-1 x |
|  | cotx (√x - 4e^x) |

Figure 4.1: Results of proposed work

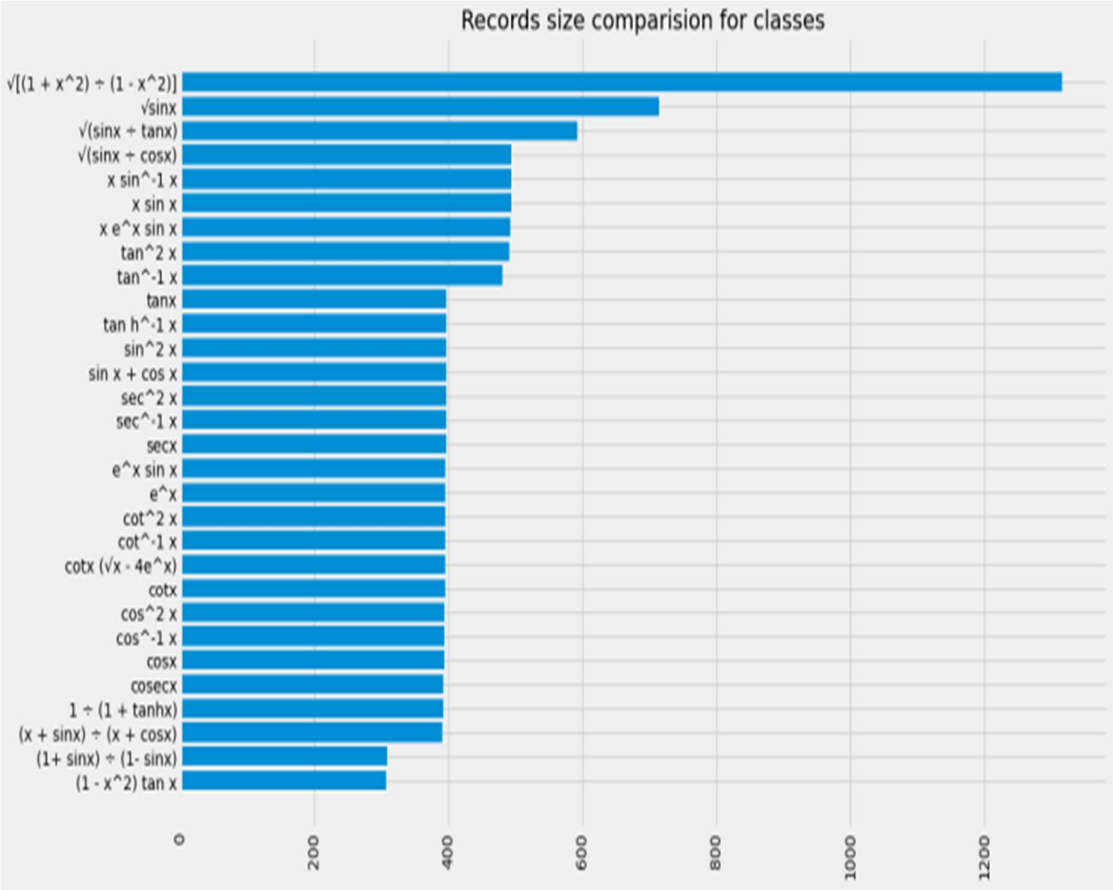



Figure 4.2: Bar graph for record size comparison of classes

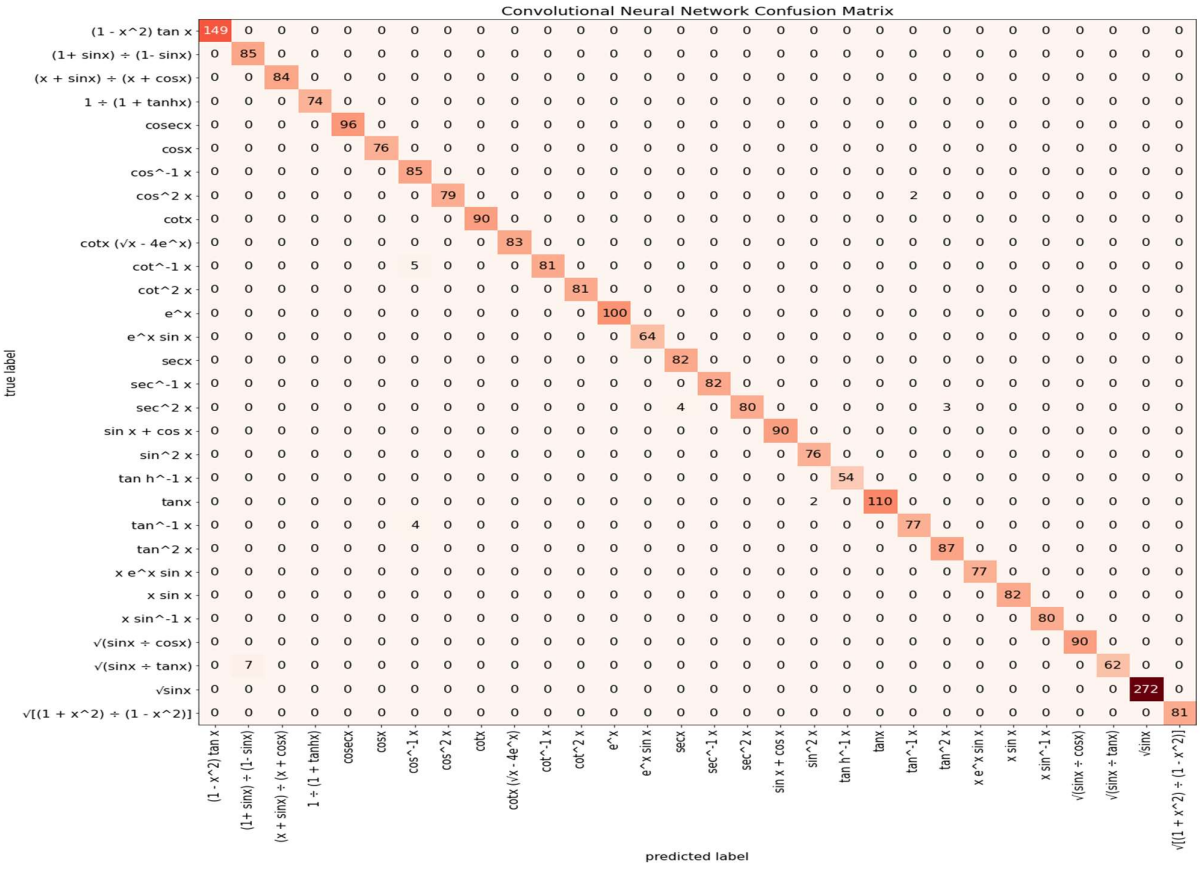



Figure 4.3: Confusion matrix of CNN Algorithm

## 5. Conclusion

We have discovered that CNNs are a powerful method for tackling the recognition of handwritten mathematical expressions. The proposed model achieved a result of 98% accuracy while converting the image of a handwritten mathematical expression to its counterpart text. The following areas, such as identifying photos with complicated content inside the square root, exponential expression, limit function, etc., showed difficulties. To solve this issue in the future, a better algorithm must be proposed.

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