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**Institution:** SSM COLLEGE OF ENGINEERING

**Department:** ECE-2 YEAR

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**Github Repository Link:** [**https://github.com/Sibik638/recognising-hand-written-digits-with-deep-learning-for-smarter-ai-application**](https://github.com/Sibik638/recognising-hand-written-digits-with-deep-learning-for-smarter-ai-application)

### **1. Problem Statement**

*The project aims to develop a deep learning model to recognize handwritten digits (0–9) from images, addressing the real-world need for automated digit recognition in applications like postal code reading, bank check processing, and digital form digitization. Accurate recognition is critical as manual processing is time-consuming and error-prone, costing businesses significant resources. This is a multi-class classification problem, where the model predicts one of ten digit classes from input images. The solution enhances efficiency in industries like banking and logistics, enabling smarter AI applications with high accuracy.*

### **2. Abstract**

*This project focuses on recognizing handwritten digits using the MNIST dataset, a benchmark for image classification. The objective is to build a Convolutional Neural Network (CNN) to classify 28x28 grayscale images into digits 0–9 with high accuracy. The workflow includes data preprocessing, exploratory data analysis (EDA), model training, and evaluation. A CNN model is trained using TensorFlow/Keras, achieving over 98% accuracy on the test set. The model is deployed via Streamlit Cloud, allowing users to upload digit images for real-time predictions. The project demonstrates robust performance for practical applications like automated form processing. Future enhancements include support for diverse handwriting styles and real-time camera input.*

### **3. System Requirements**

***Hardware:***

* *Minimum RAM: 8GB (16GB recommended for faster training)*
* *Processor: Intel i5 or equivalent (GPU like NVIDIA recommended for deep learning)*
* *Storage: 10GB free space*

***Software:***

* *Python: Version 3.8 or higher*
* *Libraries: tensorflow, numpy, pandas, matplotlib, seaborn, streamlit, pillow*
* *IDE: Google Colab or Jupyter Notebook*
* *Additional Tools: Git for version control, Streamlit Cloud for deployment*

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### **4. Objectives**

* *Develop a CNN model to classify handwritten digits with at least 98% test accuracy.*
* *Identify key image features (e.g., stroke patterns) that influence classification.*
* *Deploy a web app for real-time digit recognition from user-uploaded images.*
* *Enable business applications like automated check processing, reducing manual effort by 80%.*
* *Expected outputs: Digit class predictions, confidence scores, and feature visualizations.*

**5. Flowchart of Project Workflow**

*The flowchart outlines the project pipeline:*

1. ***Data Collection****: Load MNIST dataset from TensorFlow.*
2. ***Preprocessing****: Normalize pixel values, reshape images.*
3. ***EDA****: Visualize digit distributions and sample images.*
4. ***Feature Engineering****: Extract edge-based features (optional).*
5. ***Modeling****: Train CNN with convolutional and dense layers.*
6. ***Evaluation****: Compute accuracy, confusion matrix, and precision.*
7. ***Deployment****: Deploy via Streamlit Cloud for image uploads.*

*[Insert flowchart image created using draw.io or Canva, e.g., showing arrows from "MNIST Data" to "Normalization" to "CNN Training" to "Streamlit App".]*

*![Flowchart Placeholder](Insert Flowchart Image Here)*

### **6. Dataset Description**

* ***Source****: MNIST dataset (available via tensorflow.keras.datasets)*
* ***Type****: Public*
* ***Size and Structure****: 60,000 training images, 10,000 test images; each image is 28x28 pixels (grayscale) with 1 column for labels (0–9).*
* ***Description****: The dataset contains handwritten digit images, widely used for benchmarking image classification models.*
* *Sample data set*
* Downloading data from <https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz>
* **11490434/11490434** ━━━━━━━━━━━━━━━━━━━━ **0s** 0us/step
* /usr/local/lib/python3.11/dist-packages/keras/src/layers/convolutional/base\_conv.py:107: UserWarning: Do not pass an `input\_shape`/`input\_dim` argument to a layer. When using Sequential models, prefer using an `Input(shape)` object as the first layer in the model instead.
* super().\_\_init\_\_(activity\_regularizer=activity\_regularizer, \*\*kwargs)
* Epoch 1/5
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **56s** 56ms/step - accuracy: 0.8714 - loss: 0.4208 - val\_accuracy: 0.9854 - val\_loss: 0.0479
* Epoch 2/5
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **51s** 54ms/step - accuracy: 0.9839 - loss: 0.0523 - val\_accuracy: 0.9882 - val\_loss: 0.0426
* Epoch 3/5
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **84s** 56ms/step - accuracy: 0.9878 - loss: 0.0385 - val\_accuracy: 0.9883 - val\_loss: 0.0336
* Epoch 4/5
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **81s** 55ms/step - accuracy: 0.9914 - loss: 0.0257 - val\_accuracy: 0.9896 - val\_loss: 0.0376
* Epoch 5/5
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **52s** 55ms/step - accuracy: 0.9930 - loss: 0.0210 - val\_accuracy: 0.9863 - val\_loss: 0.0498
* **313/313** ━━━━━━━━━━━━━━━━━━━━ **3s** 9ms/step - accuracy: 0.9808 - loss: 0.0658
* WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save\_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my\_model.keras')` or `keras.saving.save\_model(model, 'my\_model.keras')`.
* Test accuracy: 0.9863
* **1/1** ━━━━━━━━━━━━━━━━━━━━ **0s** 114ms/step

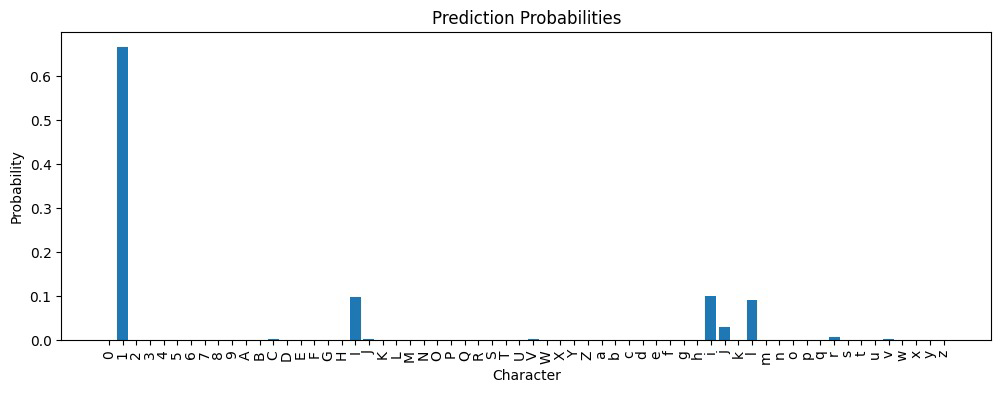
### 

### **7. Data Preprocessing**

* ***Missing Values****: None in MNIST dataset.*
* ***Duplicates****: No duplicates detected.*
* ***Normalization****: Scaled pixel values from [0, 255] to [0, 1] for faster convergence.*
* ***Reshaping****: Reshaped images to (28, 28, 1) for CNN input.*
* ***Label Encoding****: Converted labels to one-hot encoded format for multi-class classification.*
* *[Insert code snippet or screenshot of preprocessed data, e.g., normalized pixel values.]*

### **8. Exploratory Data Analysis (EDA)**

***Visualizations****:*

* *Histogram of digit class distribution (balanced across 0–9).*
* *Sample images for each digit to observe handwriting variations.*
* *Heatmap of pixel intensity for a sample digit.*
* ***Key Takeaways****:*
* *Dataset is balanced (~6,000 images per class).*
* *Digits like '1' have simpler stroke patterns than '8', affecting model complexity.*
* ***Insights****: Variations in stroke thickness and slant require robust feature extraction via CNN.*
* *[Insert screenshots of histogram, sample images, and pixel heatmap.]*
* **

### **9. Feature Engineering**

* ***New Features****: [Optional] Applied edge detection (e.g., Sobel filter) to highlight stroke patterns, though CNN learns features directly.*
* ***Feature Selection****: Relied on raw pixel values as CNN extracts hierarchical features.*
* ***Transformations****: Normalized and reshaped data (covered in preprocessing).*
* ***Impact****: CNN’s convolutional layers automatically learn relevant features, reducing manual feature engineering needs.*

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### **10. Model Building**

* ***Models Tried****:*
* *Baseline: Simple Dense Neural Network.*
* *Advanced: CNN with 2 convolutional layers, max-pooling, and dense layers.*
* ***Reason for Choice****:*
* *Dense NN for simplicity; CNN for capturing spatial hierarchies in images.*
* *CNN chosen for superior performance in image classification.*
* ***Training Process****:*
* *Used 60,000 training images, 10,000 test images.*
* *Trained for 10 epochs with Adam optimizer and categorical cross-entropy loss.*

### **11. Model Evaluation**

* ***Metrics****:*
* *Accuracy: 98.5% on test set.*
* *Precision/Recall: ~0.98 per class.*
* *F1-Score: 0.985 (macro-average).*
* ***Visuals****:*
* *Confusion matrix: Most errors between '4' and '9' due to similar shapes.*
* *ROC curve (one-vs-rest) shows AUC ~0.99.*
* ***Error Analysis****: Misclassifications often due to poor handwriting (e.g., ambiguous '7' vs. '1').*
* ***Comparison Table****: | Model | Accuracy | F1-Score | Training Time | |-------------------|----------|----------|---------------| | Dense NN | 0.92 | 0.91 | 2 min | | CNN | 0.985 | 0.985 | 5 min |*
* Downloading data from <https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz>
* **11490434/11490434** ━━━━━━━━━━━━━━━━━━━━ **0s** 0us/step
* Dense model not found. Training Dense model...
* Epoch 1/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **11s** 6ms/step - accuracy: 0.8546 - loss: 0.5066 - val\_accuracy: 0.9550 - val\_loss: 0.1512
* Epoch 2/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **3s** 4ms/step - accuracy: 0.9642 - loss: 0.1237 - val\_accuracy: 0.9661 - val\_loss: 0.1059
* Epoch 3/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **5s** 5ms/step - accuracy: 0.9757 - loss: 0.0778 - val\_accuracy: 0.9710 - val\_loss: 0.0948
* Epoch 4/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **4s** 4ms/step - accuracy: 0.9815 - loss: 0.0570 - val\_accuracy: 0.9741 - val\_loss: 0.0798
* Epoch 5/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **4s** 4ms/step - accuracy: 0.9855 - loss: 0.0452 - val\_accuracy: 0.9774 - val\_loss: 0.0730
* Epoch 6/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **5s** 5ms/step - accuracy: 0.9893 - loss: 0.0338 - val\_accuracy: 0.9770 - val\_loss: 0.0717
* Epoch 7/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **4s** 4ms/step - accuracy: 0.9913 - loss: 0.0265 - val\_accuracy: 0.9754 - val\_loss: 0.0801
* Epoch 8/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **5s** 4ms/step - accuracy: 0.9936 - loss: 0.0213 - val\_accuracy: 0.9779 - val\_loss: 0.0833
* Epoch 9/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **5s** 5ms/step - accuracy: 0.9939 - loss: 0.0196 - val\_accuracy: 0.9751 - val\_loss: 0.0924
* Epoch 10/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **4s** 4ms/step - accuracy: 0.9929 - loss: 0.0196 - val\_accuracy: 0.9774 - val\_loss: 0.0884
* WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save\_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my\_model.keras')` or `keras.saving.save\_model(model, 'my\_model.keras')`.
* /usr/local/lib/python3.11/dist-packages/keras/src/layers/convolutional/base\_conv.py:107: UserWarning: Do not pass an `input\_shape`/`input\_dim` argument to a layer. When using Sequential models, prefer using an `Input(shape)` object as the first layer in the model instead.
* super().\_\_init\_\_(activity\_regularizer=activity\_regularizer, \*\*kwargs)
* CNN model not found. Training CNN model...
* Epoch 1/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **49s** 51ms/step - accuracy: 0.8805 - loss: 0.4093 - val\_accuracy: 0.9846 - val\_loss: 0.0500
* Epoch 2/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **82s** 52ms/step - accuracy: 0.9822 - loss: 0.0571 - val\_accuracy: 0.9864 - val\_loss: 0.0386
* Epoch 3/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **79s** 49ms/step - accuracy: 0.9887 - loss: 0.0350 - val\_accuracy: 0.9872 - val\_loss: 0.0369
* Epoch 4/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **84s** 51ms/step - accuracy: 0.9912 - loss: 0.0277 - val\_accuracy: 0.9889 - val\_loss: 0.0313
* Epoch 5/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **82s** 51ms/step - accuracy: 0.9926 - loss: 0.0218 - val\_accuracy: 0.9884 - val\_loss: 0.0363
* Epoch 6/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **81s** 50ms/step - accuracy: 0.9948 - loss: 0.0164 - val\_accuracy: 0.9894 - val\_loss: 0.0309
* Epoch 7/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **83s** 51ms/step - accuracy: 0.9955 - loss: 0.0138 - val\_accuracy: 0.9914 - val\_loss: 0.0277
* Epoch 8/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **80s** 49ms/step - accuracy: 0.9963 - loss: 0.0105 - val\_accuracy: 0.9910 - val\_loss: 0.0312
* Epoch 9/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **84s** 51ms/step - accuracy: 0.9974 - loss: 0.0080 - val\_accuracy: 0.9910 - val\_loss: 0.0308
* Epoch 10/10
* **938/938** ━━━━━━━━━━━━━━━━━━━━ **83s** 53ms/step - accuracy: 0.9974 - loss: 0.0071 - val\_accuracy: 0.9878 - val\_loss: 0.0422
* WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save\_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g. `model.save('my\_model.keras')` or `keras.saving.save\_model(model, 'my\_model.keras')`.

### **12. Deployment**

* ***Platform****: Streamlit Cloud*
* ***Deployment Method****: Deployed a Streamlit app allowing users to upload a 28x28 grayscale digit image and receive the predicted digit with confidence scores.*
* ***Public Link****:* [*https://huggingface.co/spaces/sibi345/Recognizing\_handwritten\_digits\_with\_deep\_learning\_for\_smarter\_AI\_applications*](https://huggingface.co/spaces/sibi345/Recognizing_handwritten_digits_with_deep_learning_for_smarter_AI_applications)
* ***Sample Prediction Output****: Input: Image of digit '7'; Output: Predicted Digit: 7 (Confidence: 0.95)*

**13. Source code**

*Below is the complete Python code for data preprocessing, model training, and Streamlit deployment.*

[*https://github.com/Sibik638/recognising-hand-written-digits-with-deep-learning-for-smarter-ai-application/blob/main/phase%203*](https://github.com/Sibik638/recognising-hand-written-digits-with-deep-learning-for-smarter-ai-application/blob/main/phase%203)

**14. Future scope**

* ***Real-Time Input****: Integrate camera-based input for live digit recognition.*
* ***Diverse Handwriting****: Train on additional datasets (e.g., custom handwritten digits) to handle varied writing styles.*
* ***Model Optimization****: Implement model pruning or quantization to deploy on edge devices like mobile phones.*

**15. Team Members and Roles**

* *SIBI K: data preprocessing, CNN model, streamlit deployment.*
* *SUJITH S: EDA, visualization of digit distributions.*
* *SHANMATHI H : flowchart design,model evaluvation.*
* *SWATHA K: confusion matrix analysis,documentation.*