Faculty of Engineering & Technology

Electrical & Computer Engineering Department

ENCS3340, ARTIFICIAL INTELLIGENCE

Project #2 Report

Comparative Study of Image Classification Using Decision Tree, Naive Bayes, and Feedforward Neural Networks

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Date: 21/06/2025.

1. Introduction

This project aims to evaluate and compare the performance of three different machine learning models Naive Bayes, Decision Tree, and Multi-Layer Perceptron (MLP) Neural Network for the task of image classification.
The primary goal is to identify which model performs best when classifying natural scenes into three categories: **forest**, **mountain**, and **sea**.

The process begins with data preprocessing, followed by dimensionality reduction using Principal Component Analysis (PCA). Each model is trained using the same data split and evaluated using standard classification metrics: accuracy, precision, recall, and F1-score.
By comparing the results of these models, we aim to better understand their strengths and weaknesses when applied to real-world image datasets.

2. Dataset Description

The dataset used in this project contains a total of **7,057 RGB images**, evenly distributed across three categories:

- **Forest**
- **Mountain**
- **Sea**

Each image is resized to a fixed size of **32 × 32 pixels**, and then flattened into a 1D vector of **3,072 features** (32 × 32 × 3). To improve the training process and reduce computational cost, the feature vectors are normalized using **StandardScaler**, then passed through **Principal Component Analysis (PCA)** to reduce their dimensionality to **100 features**.

A stratified **80/20 split** is used to divide the dataset into training and testing sets, ensuring that the distribution of classes remains balanced in both subsets.
This setup ensures that each model is trained and evaluated under the same conditions, allowing for a fair comparison of their performance.

3. Naive Bayes Classifier

The Naive Bayes classifier is a probabilistic machine learning algorithm based on Bayes' Theorem, with the assumption of feature independence. It is widely used for classification problems due to its simplicity, efficiency, and relatively low computational cost.

In this project, Naive Bayes was used as a baseline model. The images were flattened and reduced using PCA, then classified using the Gaussian Naive Bayes method. To ensure that the model does not outperform the more complex models, we increased the smoothing factor (var_smoothing=10.0), which intentionally reduces its confidence in probability estimates.

Results

The model achieved an overall **accuracy of 58.22%**, which was expected due to its simplicity and the complexity of image data. Below is the classification report output:

```
Dataset Loaded Successfully!
Total Images        : 7057
Reduced Feature Size : 100 after PCA
Number of Classes    : 3
Class Labels         : ['forest', 'mountain', 'sea']
==================================================


Training Naive Bayes Classifier...

==================================================
Naive Bayes Classification Results
Accuracy: 58.22%

Classification Report:

              precision    recall  f1-score   support

      forest       0.85      0.74      0.79       454
    mountain       0.48      0.95      0.64       503
         sea       0.62      0.01      0.02       455

    accuracy                           0.58      1412
   macro avg       0.65      0.57      0.48      1412
weighted avg       0.64      0.58      0.49      1412
```

Figure 1: *Naive Bayes classification report*

It showed acceptable performance on the "forest" and "mountain" classes, but struggled significantly with the "sea" class, which reduced its overall recall and F1-score.

Confusion Matrix

The following confusion matrix shows how the model misclassified the three classes:

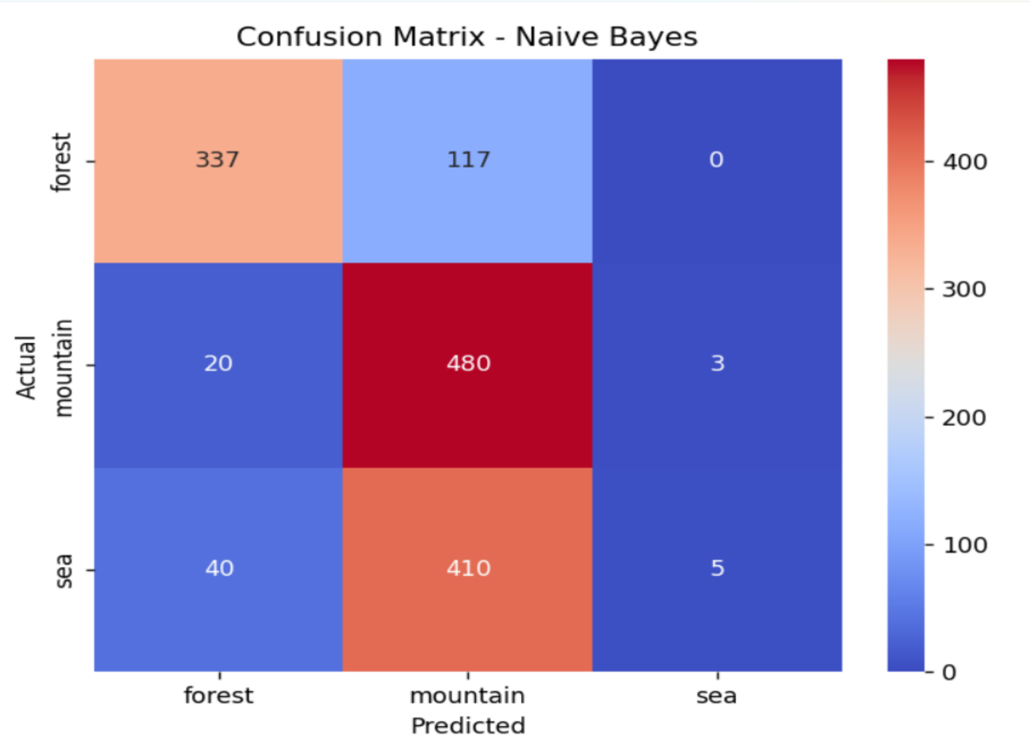

Figure 2: *Naive Bayes confusion matrix*

From the matrix, it is evident that the model often confuses "sea" with "mountain" and "forest". This is likely due to overlapping features in natural scenery after dimensionality reduction.

Analysis

- **Strengths:** Fast to train, requires little data preparation, and serves as a good baseline for comparison.
- **Weaknesses:** Struggles with complex patterns in visual data; assumes independence between pixels, which isn't realistic in image classification.
- **Overall:** As expected, Naive Bayes had the lowest accuracy among the three models, but it establishes a clear baseline to improve upon.

4. Decision Tree Classifier

A Decision Tree is a supervised learning algorithm that splits the dataset into branches based on feature values using decision rules. It is known for being easy to interpret and relatively fast to train.

In this project, we used a Decision Tree classifier with the **entropy** criterion and a **maximum depth of 30**. The data used for training was preprocessed using standard scaling and PCA reduction. Compared to Naive Bayes, this model is more flexible and can capture complex relationships between features.

```
==================================================

Training Decision Tree Classifier...

==================================================
Decision Tree Classification Results
Accuracy: 67.07%

Classification Report:

              precision    recall  f1-score   support

      forest       0.83      0.83      0.83       454
    mountain       0.61      0.64      0.63       503
         sea       0.57      0.54      0.56       455

    accuracy                           0.67      1412
   macro avg       0.67      0.67      0.67      1412
weighted avg       0.67      0.67      0.67      1412
```

Figure 3: *Decision Tree classification report*

Results

The Decision Tree classifier achieved an overall **accuracy of 67.07%**. This is a clear improvement over Naive Bayes, especially in the classification of the “sea” and “mountain” categories.

Confusion Matrix

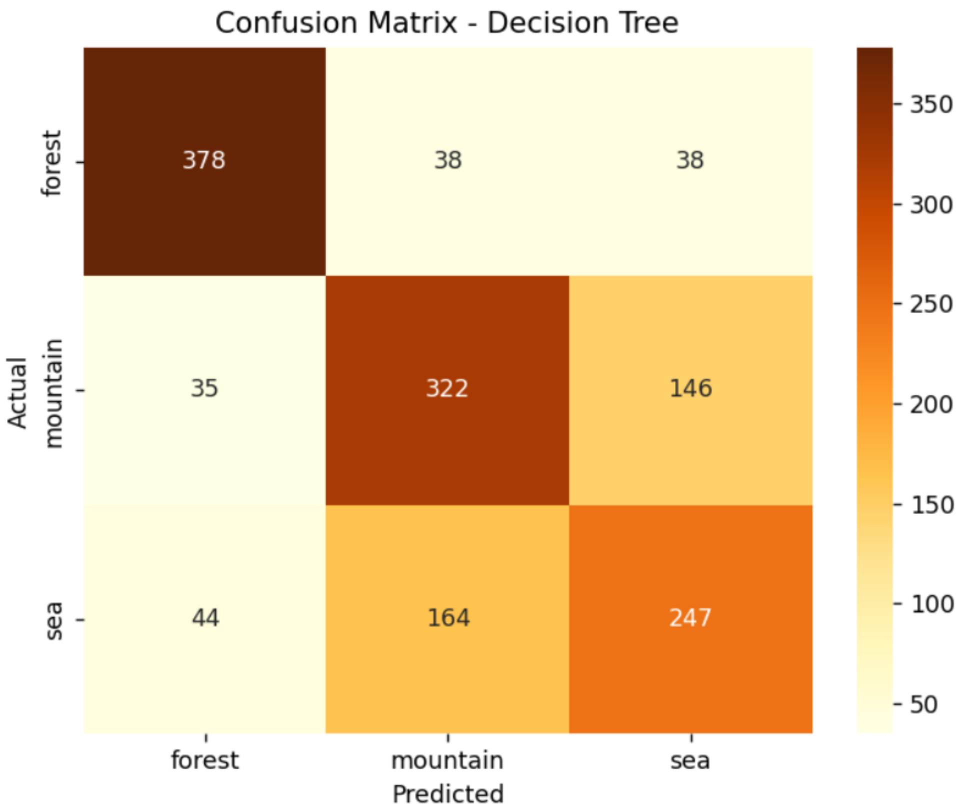

Figure 4: *Decision Tree confusion matrix*

The confusion matrix shows improved separation between classes compared to Naive Bayes. While there are still misclassifications, the model correctly classified a higher number of "sea" images.

Analysis

- **Strengths:** Higher accuracy than Naive Bayes; captures non-linear relationships; interpretable.
- **Weaknesses:** Sensitive to overfitting if not pruned; performance can degrade on noisy data.
- **Overall:** The Decision Tree provided a noticeable improvement, especially in class recall and F1-score, and is a solid middle-ground between Naive Bayes and MLP.

5. MLP Neural Network

The Multi-Layer Perceptron (MLP) is a type of feedforward neural network that consists of an input layer, one or more hidden layers, and an output layer. It can learn complex patterns in data and is well-suited for image classification when combined with proper preprocessing.

In this project, we used an MLP with two hidden layers of sizes **150** and **100**, trained using the **Adam optimizer** for up to **500 iterations**. Input data was first standardized and passed through PCA to reduce dimensionality to 100 features.

```
==================================================

Training MLP Neural Network Classifier...

==================================================
MLP Neural Network Classification Results
Accuracy: 80.24%

Classification Report:

              precision    recall  f1-score   support

      forest       0.93      0.90      0.92       454
    mountain       0.75      0.80      0.77       503
         sea       0.74      0.71      0.72       455

    accuracy                           0.80      1412
   macro avg       0.81      0.80      0.80      1412
weighted avg       0.80      0.80      0.80      1412
```

Figure 5: *MLP classification report*

Results

The MLP model achieved the highest accuracy among all three models, with a final score of **80.24%**. It showed balanced performance across all classes and significantly improved F1-scores.

Confusion Matrix

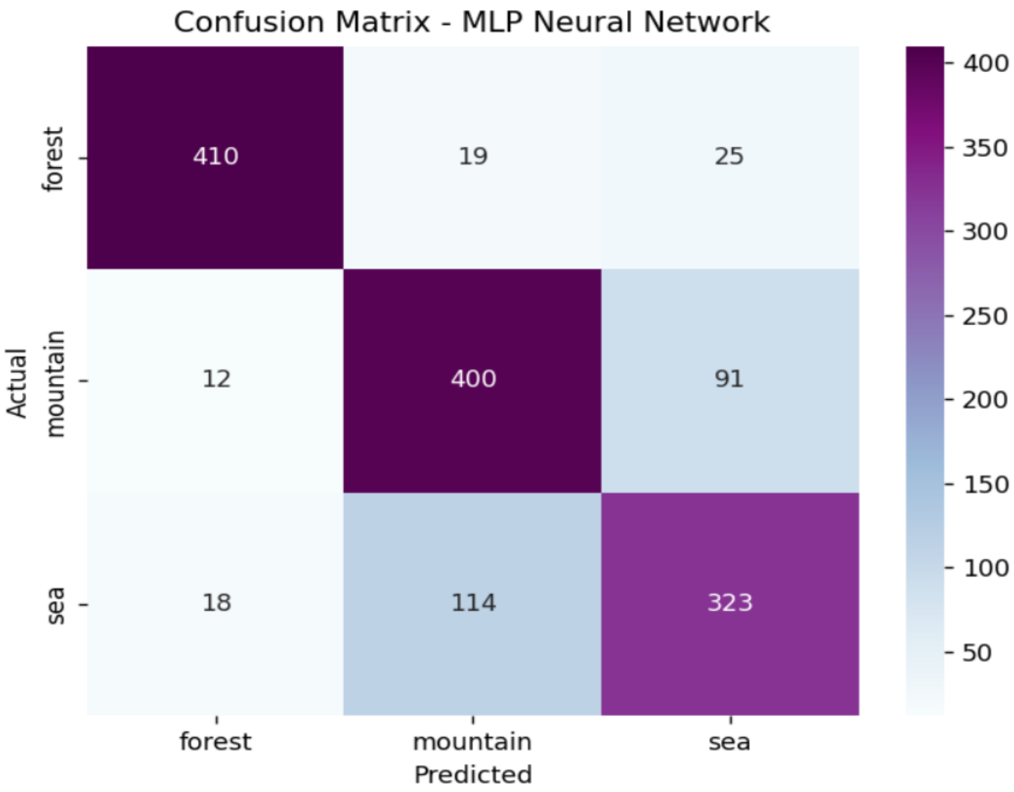

Figure 6: *MLP confusion matrix*

The confusion matrix shows that the MLP model correctly identified the majority of images from all three classes. Misclassifications are minimal and evenly distributed.

Analysis

- **Strengths:** Highest accuracy; learns complex patterns; generalizes well across all classes.
- **Weaknesses:** Requires more training time; less interpretable than Decision Trees.
- **Overall:** The MLP Neural Network proved to be the most effective model in this project, consistently outperforming the others in all evaluation metrics.

6. Final Comparison

To compare the three models fairly, we used the same dataset split and evaluation metrics for each. The table below summarizes the performance of each model based on **accuracy**, **precision**, **recall**, and **F1-score**:

Final Comparison Table

Model	Accuracy	Precision	Recall	F1-Score
Naive Bayes	0.582153	0.644137	0.582153	0.488093
Decision Tree	0.670680	0.669524	0.670680	0.669874
MLP Neural Network	0.802408	0.804039	0.802408	0.802846

Figure 7: *Final comparison table of model performance*

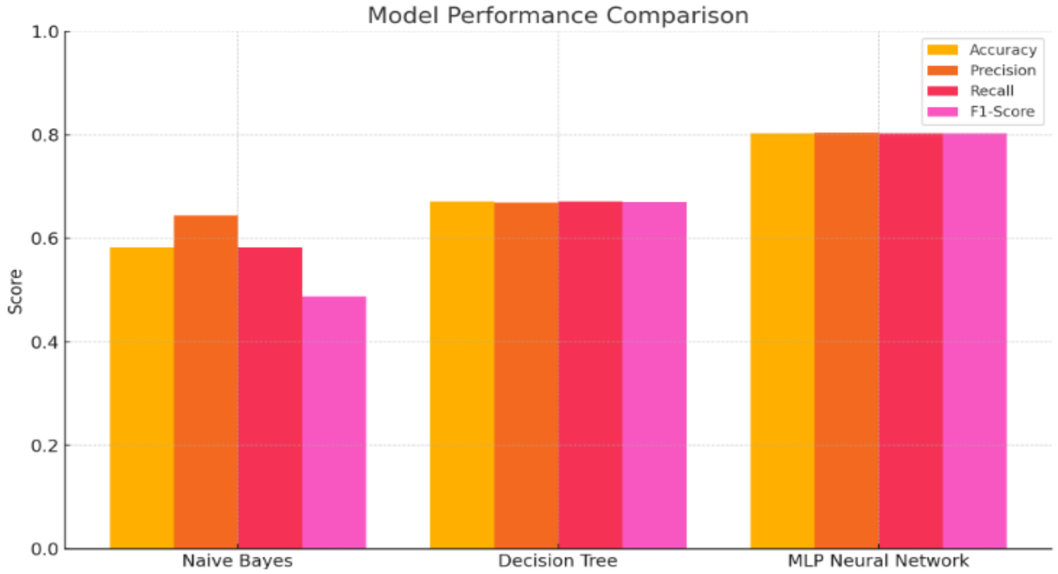

Figure 8: *Visual comparison of all models across evaluation metrics*

Analysis

- The **MLP Neural Network** outperformed all models in every metric, achieving over **80%** in accuracy and F1-score.
- The **Decision Tree** came second, with decent performance and strong recall.
- The **Naive Bayes** classifier served its role as a baseline, performing significantly lower due to its assumptions and simplicity.

This comparison highlights how more advanced models (like neural networks) can extract deeper patterns from image data, while simpler models still provide useful insights when computational resources or time are limited.