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Deep Learning based Identification of Medicinal Plants using Morphology

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Abstract

Identification of medicinal plants is highly significant for healthcare applications, agricultural activities, and biological diversity management. Correct identification of plants is difficult due to the existing morphological similarities between different plant species and variations in image capturing scenarios. This research work proposes a deep learning model, VanaOshadhi, which uses the morphological properties for successful identification of medicinal plants. The VanaOshadhi system includes a pretrained Xception deep neural network model to extract discriminatory features and XGBoost to classify the plant species effectively. The process involves image preprocessing, deep feature extraction, feature classification, and identification of multiple plants, followed by the deployment of the framework using a mobile application designed with Flutter framework and Flask REST API. The proposed system offers the ability to identify plants in real-time and provide information about identified plants in multiple languages.
Keywords: Medicinal Plant Identification, Morphological Feature Analysis, Xception Network, XGBoost Classification, Multi-Plant Recognition, Flutter-based Mobile Application.

1. Introduction

Medicinal plants play a significant role in traditional health care practices and have continued to be one of the most significant sources of natural treatment in countries that practice natural medicine. Proper identification of medicinal plant species is critical in ensuring their correct usage. Morphological similarities between various species of medicinal plants make manual identification difficult and labor-intensive while being highly dependent on expertise.

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Deep learning and computer vision techniques have made it possible to design automated systems for plant identification that increase classification accuracy while minimizing human involvement. Even though these techniques have proven to be efficient, most of them are focused on recognizing single plants, using only CNN classifiers, and not providing multilingual capabilities or mobile usability.

In addition to that, the capability to recognize multiple medicinal plants from a single image is a topic that has been relatively ignored by previous researchers. Hence, the applicability of such frameworks to real-world scenarios has been declined. This research work aims to overcome these limitations and present a new framework known as "VanaOshadhi", which is a deep learning based mobile framework for medicinal plant identification by considering morphological properties. This framework utilizes a combination of the Xception network along with XGBoost for feature extraction and classification respectively, and includes multilingual and multi-plant identification capability to improve its accessibility and usability.

2. Related Works

Medicinal plants have been considered as an important element of traditional medicine leading to the increasing need for precise plant identification techniques [1]. Recent developments in deep learning technology have greatly enhanced image-based plant analysis due to the possibility of automatic extraction of discriminatory visual features and their successful implementation in plant disease detection and other classifications [2]. Deep learning has achieved good results in medicinal plant identification although the performance of the models depends on the dataset used [3].

While mobile plant recognition systems have made automated plant recognition more accessible, the existing systems are mostly restricted to recognizing only one plant at a time and also have limited multilingual support [4]. Lightweight deep learning models, such as MobileNet, have been developed for easy deployment on mobile phones [5], and the use of XGBoost has been shown to improve the performance of classification when deep features are used [6].

Likewise, the Xception architecture provides high feature extraction capability with the use of depth-wise separable convolutions, and the residual learning method improves image classification accuracy of deep neural networks [7], [8]. Publicly available plant image datasets have enabled the creation of accurate recognition systems [9], whereas traditional machine learning algorithms are restricted to the manual feature extraction process [10]. The research work described in this paper is motivated by the need for a framework that can accurately recognize and classify medicinal plants with multilingual support.

Despite the recent advances made in plant image classification and medicinal plant recognition using deep learning, the focus remains only on controlled single-plant recognition using standalone CNN classifiers and does not take advantage of complementary machine learning approaches for achieving better classification accuracy [2]-[10]. Furthermore, mobile-based systems focus more on basic recognition capabilities and provide little in terms of multilingual support and extensive information about the medicinal properties of the plants, as well as recognition of several plant species in the same image. Such constraints make the real-time utilization impractical, especially in linguistically and financially deprived regions. Hence, there is a need for developing an integrated framework for medicinal plant recognition that uses deep feature extraction and efficient hybrid classification along with multilingual support and multi-plant recognition.

3. Proposed Methodology

3.1 Overall Framework

The proposed framework of VanaOshadhi uses the deep learning pipeline for identifying the medicinal plants based on their morphological features. As shown in Figure 1, the pipeline includes the steps starting from image collection, where the user acquires the images of the plant with a mobile phone camera, or selects an existing image from the mobile gallery. Depending on the choice of the user, there are two prediction modes that can be used, which are either single or multi-plant prediction.

The pre-processing stage ensures that the input image is standardized with respect to its size, normalized intensity values, and the output tensor, which becomes ready for giving as an input to the deep learning model. The standardized tensor is used as input to the pre-trained Xception Convolutional Neural Network (CNN) that generates higher order morphological features of the leaf.

Rather than classifying the images using the CNN directly, the deep feature vector obtained is sent to the XGBoost classifier, where the probability of belonging to each species of the medicinal plants is computed. In case of classification of a single plant, the class having the maximum probability is chosen, while in multi-plant classification, threshold logic based on confidence levels is used to determine several plant species from the same image. Plant labels obtained through the above process are then used to retrieve botanical information from the medicinal plant database. The final step involves constructing a JSON response by the Flask REST API that includes predicted plant labels, confidence values, medicinal use, and descriptions in different languages.

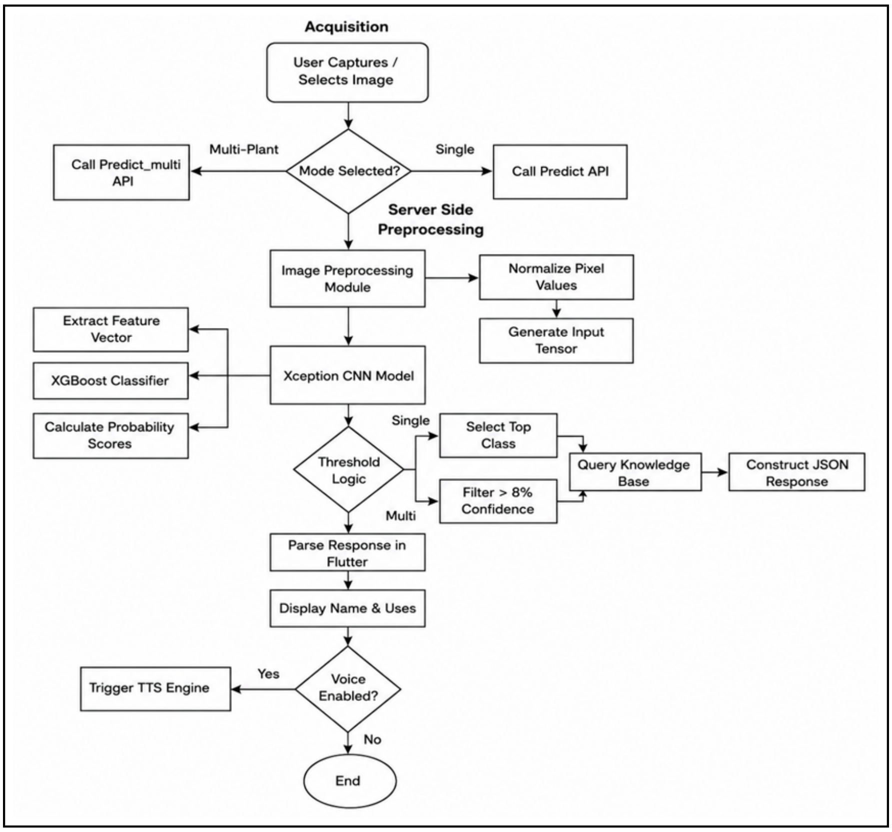

Figure 1. Overall architecture of the proposed VanaOshadhi framework

3.2 Medicinal Plant Dataset

The proposed model framework is tested on a medicinal plant dataset consisting of 38 Indian medicinal plants. The dataset is taken from Indian Medicinal Leaves Image Dataset [11], while additional images have been acquired from public domain to increase the diversity of the plants in terms of their appearance under various environmental conditions. The images collected vary in terms of illumination, viewing angle, background, and orientation of leaves. The characteristics of the dataset are listed in Table 1.

Table 1. Dataset description

Parameter	**Description**
Dataset Source	Indian Medicinal Leaves Image Dataset [11]
Number of Plant Species	38
Images per Species	150–300
Image Variations	Illumination, viewing angle, background, and leaf orientation
Training Set	80%
Validation Set	10%
Testing Set	10%

3.3 Image Preprocessing

The processed medicinal plants images were used to generate the standard input for the suggested model. The first step involved resizing of the image to 299 x 299 pixels, which corresponds to the input dimension of the pre-trained Xception network. Afterward, normalization of the pixel intensity values was done to ensure numerical consistency, which can be expressed as

$$I_n = \frac{I}{255} \tag{1}$$

where I and I_n denote the original and normalized image, respectively. The normalized images were then converted into input tensors and assigned their corresponding medicinal plant class labels before being forwarded to the feature extraction stage.

3.4 Deep Feature Extraction using Xception CNN

The proposed model uses the pretrained Xception Convolutional Neural Network as the backbone for feature extraction. The Xception architecture is an extension of the Inception model where traditional convolutions have been replaced by depthwise separable convolutions to decrease the amount of computations. Transfer learning will be used by loading the pretrained weights from the ImageNet dataset into the network.

The initial classifier of the pretrained model will be eliminated such that the model becomes only a feature extractor. During the forward pass, consecutive convolution layers of the network extract the hierarchical features of the medicinal plants, including:

- Leaf shape

- Leaf margin
- Venation pattern
- Surface texture
- Color distribution
- Structural morphology

The extracted feature maps were subsequently transformed into a compact feature representation using a Global Average Pooling (GAP) layer. The feature extraction process is expressed as

$$F = f_{\text{Xception}}(X) \tag{2}$$

where, X is the preprocessed image input and F is the deep feature vector produced using the Xception model. The deep features vector was thereafter fed into the XGBoost classifier for medicinal plants classification. The main parameters used for the Xception feature extractor are shown in Table 2.

Table 2. Xception network parameters

Parameter	**Value**
Backbone Network	Xception
Pretrained Weights	ImageNet
Input Size	299×299
Feature Extraction Layer	Global Average Pooling
Feature Vector Dimension	2048
Learning Rate	0.001
Batch Size	32

3.5 Medicinal Plant Classification using XGBoost

Instead of using the CNN's original Softmax classifier, the proposed framework employs XGBoost for final medicinal plant classification. XGBoost is a gradient boosting method that trains an ensemble of decision trees in order to minimize classification errors at each stage of tree building. The deep feature vector with dimension of 2048 extracted from the Xception network acts as the input for XGBoost classifier.

The predicted class is determined as

$$S = \{c_i \mid P(c_i) \geq T\}, \qquad T = 0.08 \tag{3}$$

where, $P_i(F)$ denotes the probability assigned to class i using feature vector F. The major parameters used for the XGBoost classifier are summarized in Table 3.

Table 3. XGBoost parameters

Parameter	Value
Booster	gbtree
Objective	Multi-class Classification
Number of Classes	38
Maximum Depth	6
Learning Rate	0.1
Number of Trees	100

3.6 Multi-Plant Identification

In order to facilitate the detection of multiple medicinal plants from an image, the framework considers the prediction probability obtained from the XGBoost classifier. Instead of choosing only the class with maximum probability, all the classes detected are checked against a threshold value of confidence level. Plant species with confidence levels greater than or equal to 8% are deemed to be acceptable predictions, and the classes are then arranged according to confidence level in decreasing order. Maximum of three plant species are selected per input image.

The confidence-based selection is defined as

$$S = \{c_i \mid P(c_i) \geq T\}, \qquad T = 0.08 \tag{4}$$

where, $P\ (c_i)$ represents the prediction probability of the i^{th} plant class, T is the confidence threshold, and S denotes the set of selected medicinal plant species. The selected predicted values and confidence levels were then sent to the application layer to display the plant details.

3.7 Mobile Application and System Deployment

The proposed framework has been implemented using a Flutter mobile app connected to a Flask REST API that performs real-time medicinal plant identification. The app facilitates the process of capturing the plant image using the camera of the phone or uploading the pre-existing image stored in the gallery. The uploaded image is sent to the Flask REST API where the trained identification model performs inference and sends back the results.

The predictions are then sent to the mobile application in JSON format. The app shows the result including the name of the medicinal plant, the confidence score, medicinal uses, and botany in the form of a user interface. For better accessibility, the system supports multi-language content in English, Tamil, and Hindi along with text-to-speech features. The deployment flow and the interface of the application are shown in Figure 2.

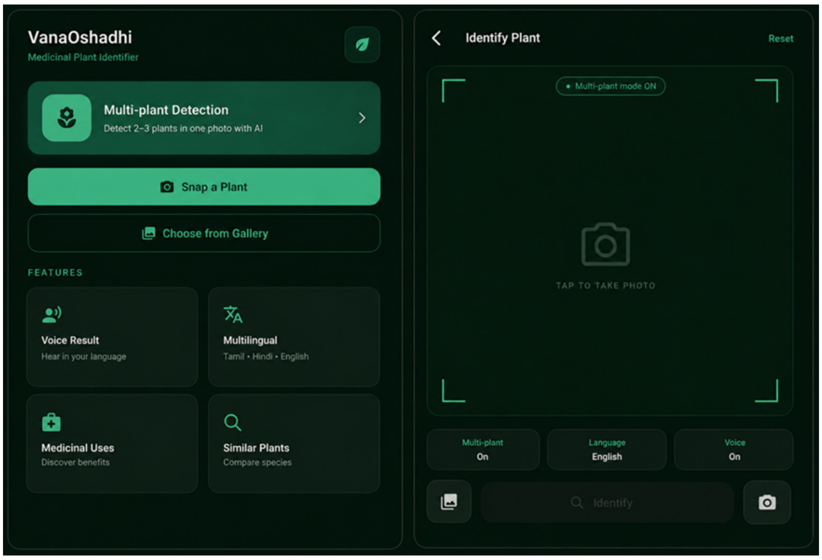

Figure 2. Flutter-based mobile application interface for medicinal plant identification

4. Results and Discussion

The proposed VanaOshadhi system was analyzed using medicinal plants images to determine the accuracy of classification and applicability of the framework. The performance of the trained Xception-XGBoost model was evaluated under various conditions of the images to determine the capability of recognizing medicinal plants from their morphological features. The experimentation analysis comprises the environment for implementation, classification performance, confusion matrix analysis, class-wise performance analysis, and real-time analysis.

4.1 Experimental Setup

The pretrained Xception network was used to extract features, and the classifier was provided by XGBoost. The whole model was implemented using Python, TensorFlow, and Keras packages, and then connected to the mobile application based on Flutter using a Flask REST API.

4.2 Overall Performance Evaluation

The classification effectiveness of the proposed VanaOshadhi framework was measured on the basis of four commonly used evaluation metrics, namely accuracy, precision, recall, and F1-score. These metrics give a comprehensive overview of the classification effectiveness of the model in classifying the various medicinal plants while ensuring that there is no imbalance in the classification process. The overall evaluation results are summarized in Table 4.

Table 4. Overall classification performance of the proposed framework

Metric	Value (%)
Accuracy	93.4
Precision	92.8
Recall	93.1
F1-Score	92.9

The proposed VanaOshadhi framework achieved consistently high performance across all evaluation metrics, demonstrating its capability to effectively distinguish medicinal plant species based on their morphological characteristics. The close agreement among the performance metrics indicates balanced classification behavior without significant bias toward any specific class. These results confirm that the extracted deep morphological features, together with the XGBoost classifier, provide a reliable representation for medicinal plant identification. To further investigate the classification behavior of individual plant species, the prediction results were analyzed using the confusion matrix.

4.3 Confusion Matrix Analysis

The confusion matrix provides a clear visualization of the classification result by showing the relationship between the true and predicted medicinal plant classes. The confusion matrix generated is shown in Figure 3, with the clustering of the numbers along the main diagonal revealing the fact that most of the medicinal plants were classified properly using the designed algorithm.

However, there was a few misclassification cases for the species of the plants with similar morphological features such as similar leaf shape, texture, and veins. Despite these similarities, the implemented model was able to classify the most species, which shows its ability to distinguish the discriminating morphological features without causing any confusion in classification. Therefore, the confusion matrix proves the robustness of the designed algorithm and helps to understand the class-wise behavior of the classification results. In order to assess the performance of each medicinal plant class, a class-wise performance evaluation is done in the next stage.

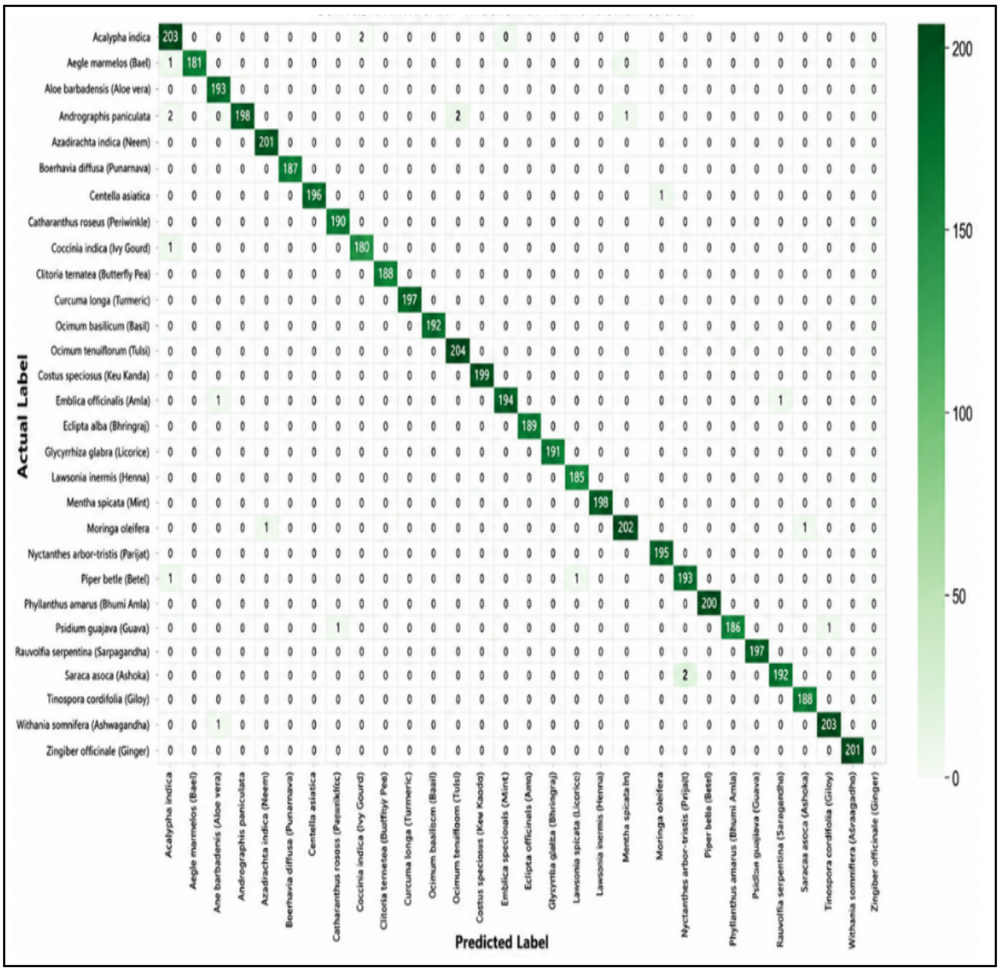

Figure 3. Confusion matrix for medicinal plant species classification

4.4 Per-Class Performance Analysis

The class-wise performance of the proposed framework was analyzed in terms of the F1-score for each medicinal plant species, as shown in Figure 4. The F1-score gives an equal representation of precision and recall, thus allowing for complete analysis of the classification performance for individual classes of plants.

Plant species with unique morphology, texture, and vein pattern have been detected by the suggested framework with consistent high performance. Some species having similar characteristics have demonstrated comparatively low F1-scores due to the presence of overlapping morphological characteristics. Still, the class-wise performance shows the stable performance of the suggested framework for all medicinal plant classes.

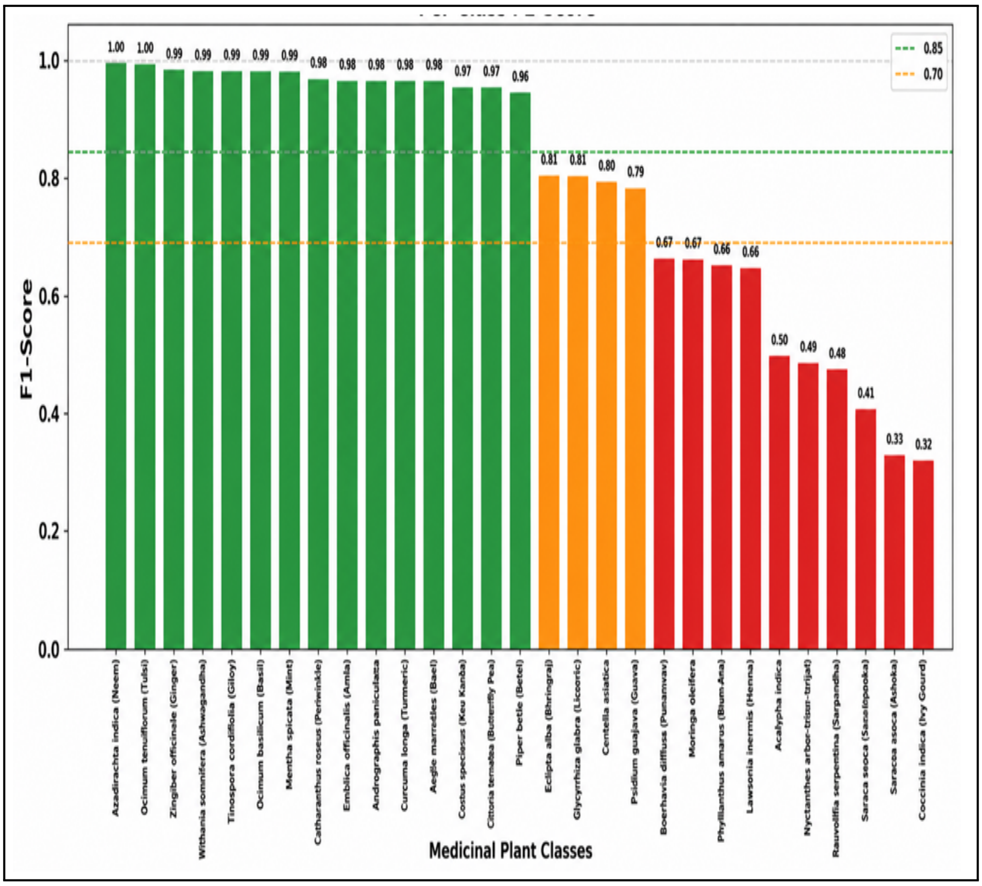

Figure 4. Class-wise F1-score of the proposed Xception–XGboost framework

4.5 Mobile Application Validation

The mobile application offers a user-friendly interface that helps present the results of predictions through which one can easily access all relevant information about the identified medicinal plant. Apart from the text information, there is also a provision for text-to-speech, which is helpful in providing voice-assisted explanations in the language chosen by the user. The application output is shown in Figure 5.

Figure 5. Real-time prediction results of the VanaOshadhi mobile application

5. Conclusion and Future Work

This research work has proposed VanaOshadhi, an image classification framework utilizing deep learning techniques, where a pretrained Xception model is used for deep feature extraction coupled with an XGBoost classifier for reliable classification of medicinal plants based on the morphological characteristics. This framework integrates image preprocessing, confidence-based multi-plant identification, and a mobile application created through the Flutter framework along with the Flask REST API to support medicinal plant recognition in real time. The experimental study on the test set which contains images of 38 medicinal plants showed high accuracy of the developed method which reached 93.4% for the accuracy rate, 92.8% for the precision rate, 93.1% for the recall rate, and 92.9% for the F1-score, which confirms that the proposed model is quite balanced and has a high efficiency. Successful testing of the mobile application proves that the proposed system can be used in practice for educational, medical, agricultural, and other purposes. Further research aims to expand the dataset, improve detection in complex environments, create lightweight models for faster mobile processing, and develop multilingual functionality.

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