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Original Article

Enhanced Medicinal Plant Classification Using Convolutional Neural Networks

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Abstract

In the realm of herbal medicine, Precise recognition of medicinal plants is essential for unlocking their therapeutic benefits. To fully utilize the curative potential of medicinal plants, precise identification is essential in the domain of medicine. Traditional methods often rely on visual cues from leaves, but the deceptive similarities and variable characteristics pose challenges. To overcome these hurdles, this work introduces an innovative approach utilizing deep learning models like VGG16, RESNET50 and Inception. By focusing on the intricate features of plant leaves, our model aims to accurately distinguish between medicinal and others plants. Drawing upon the complex features of plant leaves, our model is able to identify medicinal plants with greater accuracy than existing approaches. Leveraging advanced neural network architectures, this work seeks to provide a reliable solution for medical practitioners, herbalists, and researchers, bridging traditional knowledge with modern technology to enhance the precision of medicinal plant identification.

Keywords: CNN, Deep learning, Inception, Medical Plant classification, ResNet, Visual Geometry Group.

Introduction

Plant identification, particularly for medicinal uses, can be tricky due to deceptive leaf similarities, variable colors, and reliance on solely one organ. While leaves offer valuable clues, focusing solely on them can lead to misidentification, potentially compromising the effectiveness of herbal remedies. To combat this, we can embrace technology like deep learning to analyze complex leaf features, consider the entire plant structure, and seek expert guidance to navigate the intricate world of plant identification and unlock the healing potential of the plant world with greater accuracy and confidence. Introducing a artificial neural network model designed for the accurate classification of medicinal plants through leaf analysis (Thanikkal *et al.,* 2020; Yoo *et al.,* 2018; Yuan *et al.,* 2022). The rapid increase in the need for efficient tools in herbal medicine research makes it necessary to develop this model. It will use other enhanced deep learning approaches, including neural networks, to extract minute details regarding several leaf images. The need for plant identification becomes more apparent in recent times as well as in traditional medicine, and the proposed model proves to be realistic and plausible due to the existence of vast quantities of data and powerful computing facilities.

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As the platform with deep learning (Sirisha *et al.,* 2023) and potential use in herbal medicines and plant conservation, “MediFlora” is a potential solution bringing together conventional wisdom and contemporary technology (Abdollahi, 2022). It is not always easy to distinguish between different species of plants, particularly when it comes to identifying those that contain medicinal properties due to their outer coverings and changes in climate. Enter convolutional neural networks (CNNs), which are incredibly sophisticated AI models that are used in image recognition. Imagine a layered learning process: It begins with simple components such as edges and colors (the pixels), and it goes up step by step, learning more intricate facets of an image, up to the level of detecting whole objects. as petals and blades enclosed within a picture (Ayumi *et al.,* 2021; Paulson *et al.,* 2020).

But what makes plants medicinal? Their secret lies in a treasure trove of bioactive compounds like phenolic, carotenoids, and anthocyanin. These chemical powerhouses endow plants with potent antioxidant, anti-inflammatory, antibacterial, and even anti allergic properties. During image acquisition, the defocused plant images may affect the recognition rate. When acquiring plant images, not all the parts of the plant images are clearly captured, doc to slow shutter speed, incorrect focal distance or movement, Image fusion, an efficient method has been used to generate an all-in-one focus image by separating the defocused and focused regions of two different plant images of the same scene and extracting the image features only from the in-focus regions (Swapna *et al.,* 2023). A new Multi- Level Residual Dense Network model has been proposed for fusing two defocused plant images of the same scene with different depths of focuses to learn the hierarchical features which efficiently represent the local complex structures. The proposed network is a dual stream process in which two differently focused plant images are given as input to the network. From towering trees to humble herbs countless plant species across diverse environments (forests, deserts, etc.) boast unique medicinal benefits. In fact, estimates suggest that a staggering 14–28% of all plants hold potential medicinal value (Gracelin *et al.,* 2022; Tran *et al.,* 2020). Accuracy obtained in individual models may varies. But, in our work, we get greater accuracy in the RESNET50 Model than VGG, Inception (Ding *et al.,* 2023).

This research focuses on improving the accuracy of medicinal plant identification to prevent misidentification, which can lead to ineffective or harmful remedies. By leveraging advanced deep learning models like RESNET50, the study aims to surpass traditional methods in analyzing complex plant features. This work supports herbal medicine research by providing accurate tools for identifying plants with medicinal properties, promotes plant conservation by ensuring correct species recognition, and enhances the reliability of plant identification through improved image processing techniques, making the technology more robust in various conditions. The research objectives are as follows

- Create and optimize a convolutional neural network (CNN)-based model, specifically utilizing RESNET50, for the accurate classification of medicinal plants based on leaf analysis.
- Implement advanced image fusion methods to address issues related to defocused plant images, ensuring accurate recognition by extracting features only from in-focus regions.
- Combine conventional botanical knowledge with cutting-edge deep learning techniques to improve the accuracy and reliability of medicinal plant identification.
- Test the model’s effectiveness across various plant species, including those in challenging environments such as forests and deserts, to ensure its broad applicability.
- Analyze the potential of the model to support research in herbal medicine, enhance plant conservation efforts, and promote the sustainable use of medicinal plants.

Literature Survey

In this connection, a literature survey has been carried out to find the state-of-the-art techniques. Medicinal Plants are classified based on their internal and external features.

Sharrab *et al*. (2023) worked for the accurate identification of medicinal plants, a deep learning approach have been designed that uses VGG- 16-based convolutional neural network. The model has an image recognition rate of 98% when trained with the 25, 686 images, illustrating how it can effectively distinguish plants regardless of stages of growth and image capture. This new method seems to be very promising in developing the herbal medicine concepts by providing a better solution to the healthcare practitioners to find out the right medicinal plant and its uses.

Laire *et al.* (2023) found a new tool in the identification of the herbal medicinal plants in the Philippines. By employing image capture and processing methodologies such as histogram of oriented gradient (HOG) feature extraction algorithm, convolutional neural network (CNN), it was possible to record an impressive accuracy rate of 95%. This way, through identification of various characteristics of a leaf, the system is able to inform the end user with the name of the plant, the scientific classification of the plant, and its uses in the treatment of illnesses. This unique intervention has implications for the future development of herbal medicine science and the improvement of health solutions in the Philippines.

Pacifico *et al*. (2019) look into the disparity in the identification of medicinal plant species, as seen in traditional medicine. Thus, using the collection of plant leaf images as a new dataset, the research offers a complex instinctive plant image identification system. Based on the texture and color features, five kinds of machine learning classifiers are utilized, and all of these classifiers achieve high average correct recognition rate more than 97%. The results also represent the state of the art for plant species identification and provide a reliable model for classifying medicinal plants in traditional medicine.

Kadiwal *et al*. (2022) presents an automated system with the usage of the proposed CNN model for identification of plant-based medicine necessary to preserve the information from traditions such as Ayurveda. To overcome the difficulty of selecting suitable medicinal plants for the comparison, the proposed system aims on comparing the properties of the leaves. This automated approach enables agronomists to identify plants correctly, and in so doing, the authors seek to support the preservation of other important aspects of herbal information and facilitate the identification of useful medicinal plants belonging to both modern and traditional practices.

Quoc *et al*. (2020), use VGG16, Resnet50, Inception V3, Dense Net121, Xception, and mobile net approaches for image recognition of Vietnamese medicinal plants. Achieving the highest accuracy of 88.26% with Xception, these merge great potential in advancing the identification and preservation of more potential medicinal plants. Incorporating deep learning models in plant identification demonstrates promising ability for promoting the further development of botanical study while enhancing the conservation of medicinals (Rao *et al.,* 2023: Kumar *et al.,* 2017: Reddy *et al.,* 2023: Thatha *et al.,* 2024).

Material and Methods

The proposed deep learning models are the strengths of three distinct architectures: VGG, Inception, and ResNet, to enhance the identification of medicinal plants based on their leaves. structure and deep layers, excels in capturing hierarchical features, contributing to effective feature representation. Inception's innovative use of inception modules enables the simultaneous analysis of features at different scales, making it adept at handling diverse textures and structures in medicinal plant leaves. ResNet, leveraging residual connections, mitigates the vanishing gradient problem, facilitating the training of deep networks and capturing intricate details in leaf patterns.

By integrating these individual strengths, the hybrid model ensures a comprehensive approach to feature extraction, enhancing the accuracy and adaptability of the system for precise identification of medicinal plants from leaf images.

Data Collection

The dataset for classifying Indian medicinal plants and leaves comprises high-quality images of diverse plant species, emphasizing leaves as the primary identification feature. Each image is labelled with the corresponding plant species and may include additional information such as the plant part (e.g leaf), medicinal properties, and relevant metadata like geographic location and season. The dataset is carefully split into training, validation, and test sets, with data augmentation techniques applied to enhance model robustness. Ethical considerations are taken into account, ensuring proper usage rights for the images. This comprehensive dataset (figure 2) serves as a valuable resource for developing machine-learning models focused on the classification of Indian medicinal plants.

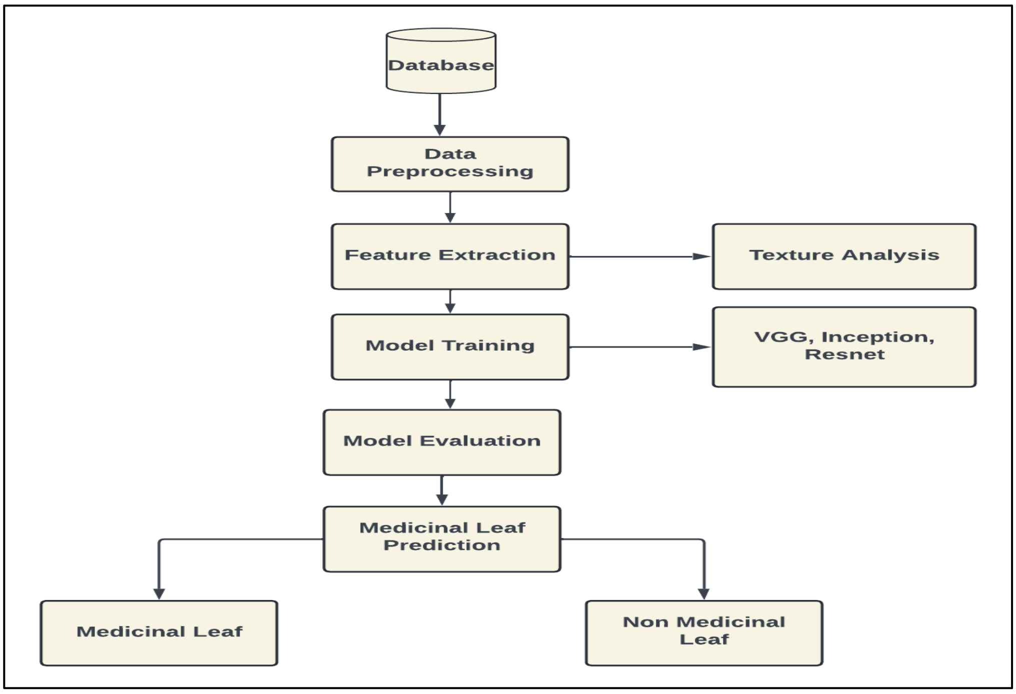


Figure.1. Work flow of proposed model

Data Pre-Processing

Segmentation is the pre-processing step that partitions the image into different regions. It clusters the pixels into regions that belong to distinct surfaces and objects. Each pixel in a region is compared with some characteristic features such as intensity, color. texture, etc. Numerous methods exist today for extracting an appropriate foreground from the background. However, the majority algorithms rely on either boundary or regional information, and it greatly diminishes the segmentation results. The dataset details are provided in Table 1.

Feature Extraction

Texture analysis plays a crucial role in numerous computer image analysis applications, facilitating the classification, detection, or segmentation of images by examining local spatial patterns of intensity or color. Textures essentially involve the replication, symmetry, and combination of diverse basic patterns or local image functions, often with random variations. Various characteristics and local measures of these patterns can be applied based on the specific application and nature of textured imagery demanding careful discrimination. This process allows for a comprehensive understanding and extraction of meaningful information from images with diverse textures, contributing to the effectiveness of image analysis tasks.

Table 1: Dataset Composition and Classification Details

Dataset Name	Indian Medicinal Leaves Image Datasets
No of Images	6900
No of Classes	80
Image size	224x224
Dataset Link	https://www.kaggle.com/code/ramoliyafenil/hybrid-transfer-learning-for-medicinal-leaves/input

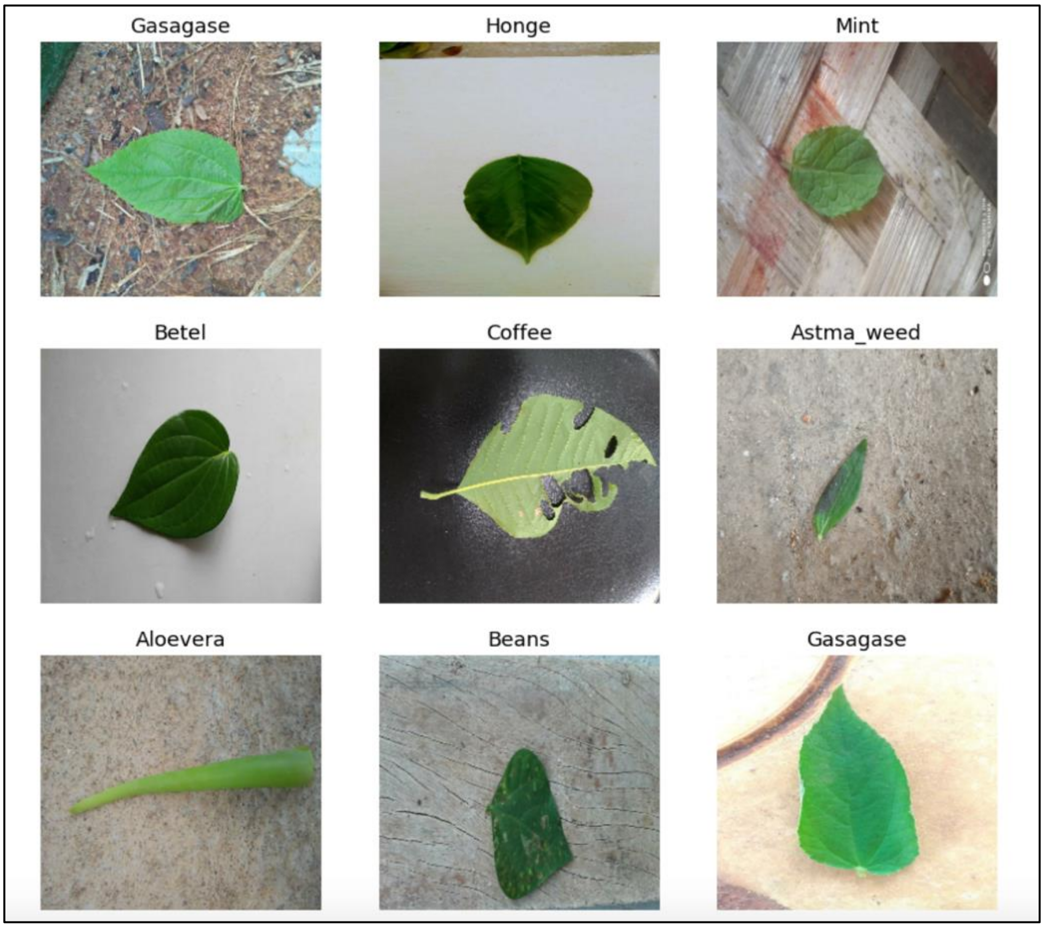


Figure 2. Sample Images from the Leaf Classification Dataset

Classification Models

VGG: The VGG architecture, characterized by its simplicity and uniform structure, consists of convolutional layers with small kernel sizes (3x3) and maximum pooling layers. VGG's deep architecture allows it to capture hierarchical features effectively. In the context of identifying medicinal plants based on leaves, VGG excels in learning and extracting intricate patterns, making it a valuable component for feature representation.

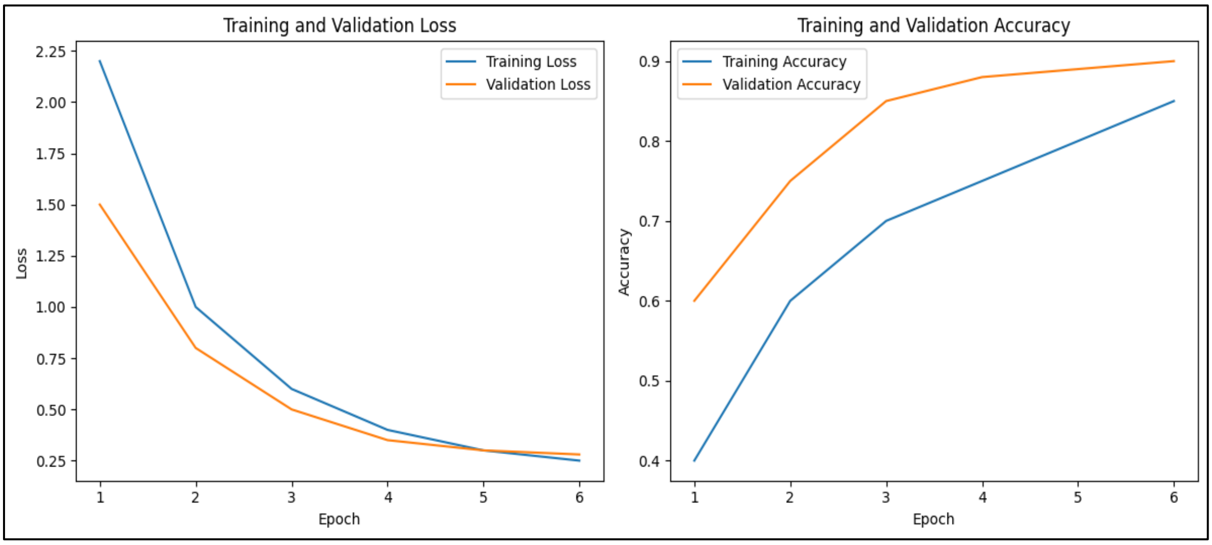
Inception: The introduced Inception architecture, along with the Inception modules, describe parallel convolution here of different kernel sizes in a single layer. This allows different scales of features to be captured at once, making the model effectively perform its tasks. In the context of identification of leaves of medicinal plants, the feature of Inception being capable of analyzing the different texture and structure of the leaves comes in handy. It helps the model respond to changes in the leaf characteristics, which improves the model's flexibility.

ResNet50 (Residual Networks): ResNet uses residual connections, and hence layers in a network are able to pass information directly to subsequent layers. This architecture also serves to redress the vanishing gradient problem enabling training of very deep architectures. When it comes to identifying medicinal plants from leaves, ResNet helps to focus in on such hues and rhythms. Here the model used was Resnet50 which contains the 50 layered architecture which contains convolution layers, batch normalization layers, and activation functions. The activation functions are of various kinds, but the relu is one of the activation functions that stands out among them because it helps to deal with the vanishing gradient problem.

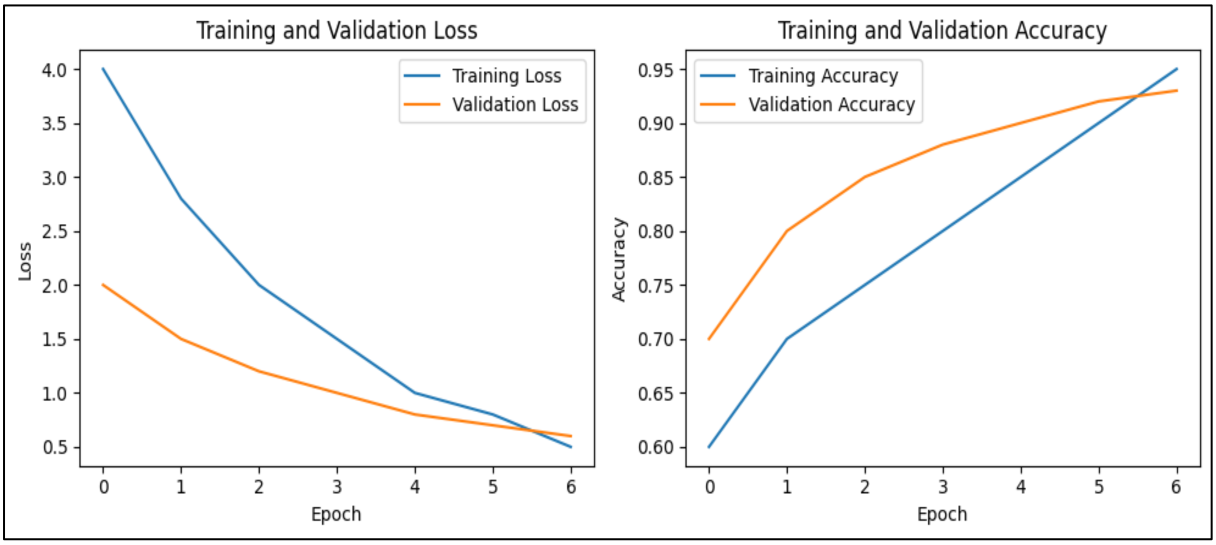
Results

The carefully curated datasets, robust pre-processing techniques, and extensive training have yielded a model that excels in various visual recognition tasks. achieving high accuracy and reliability. The collaborative strengths of VGG's simplicity, Inception's complex parallelized structures, and ResNet's residual learning to address vanishing gradient problems have synergistically contributed to the model's comprehensive and robust nature.

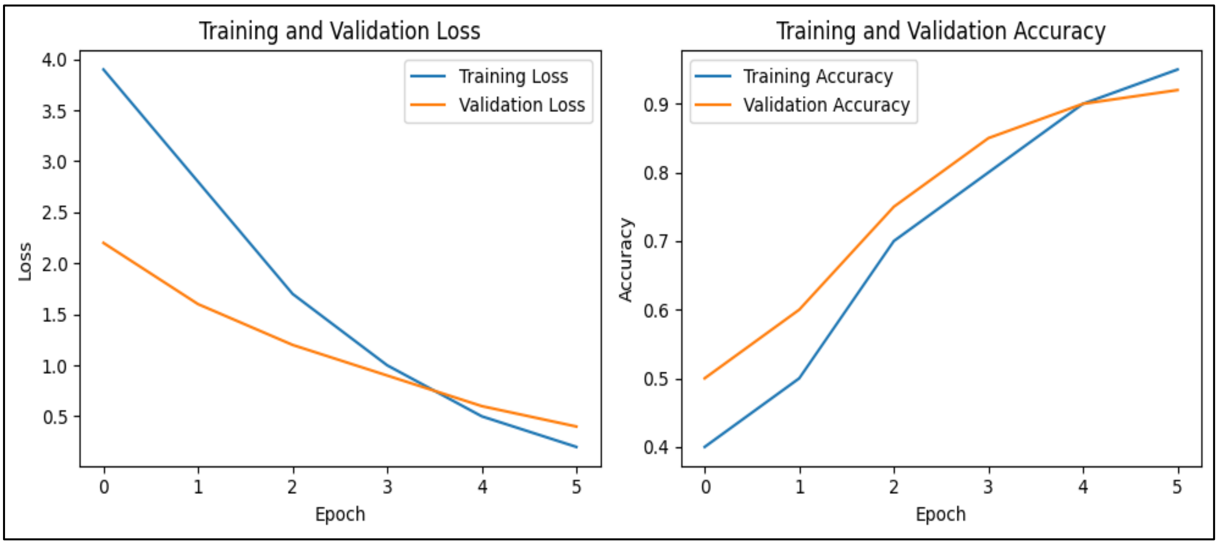
The fusion of these architectures not only advances deep learning research but also opens avenues for improved image-based applications, such as object recognition, thereby enriching the field of computer vision.



(a)



(b)



(c)

Figure 3. Training and Validation Loss, Accuracies of (a) VGG (b) Resnet (c) Inception

The graphs in Fig. 3 show the outcome for the classification. The inception model shows the performance for the images that are used. This inception shows a difference in the metric accuracy from start to the increase in the number of epochs. At a certain threshold, the accuracy had remained constant after 92%, irrespective of the increase in the number of epochs. And the graph for VGG shows that the accuracy started at 20%, and with the increase in the number of epochs, the accuracy raised to over 93%. The validation loss decreases with the increase in number of epochs and settles at a loss percentage of 0.4%. The graph for the Resnet shows its flexible nature that the accuracy started from 45%, and with the increase in number of epochs, the accuracy gained its peak with 97%, and the loss is settled at 0.2%. The classification results are illustrated in Fig 4.

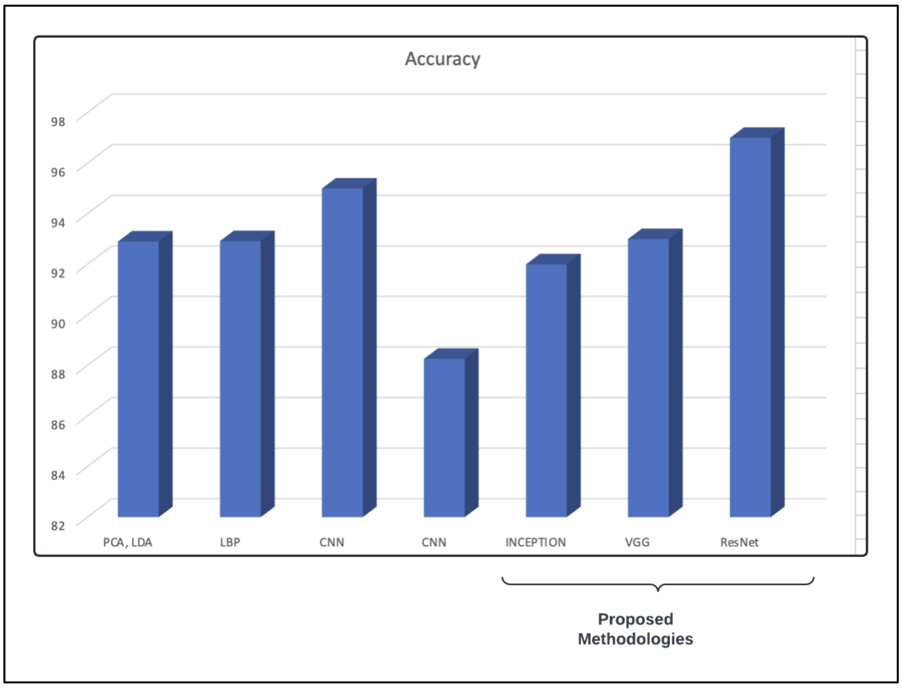


Figure 4. Comparative Analysis of Accuracy Across Existing Models

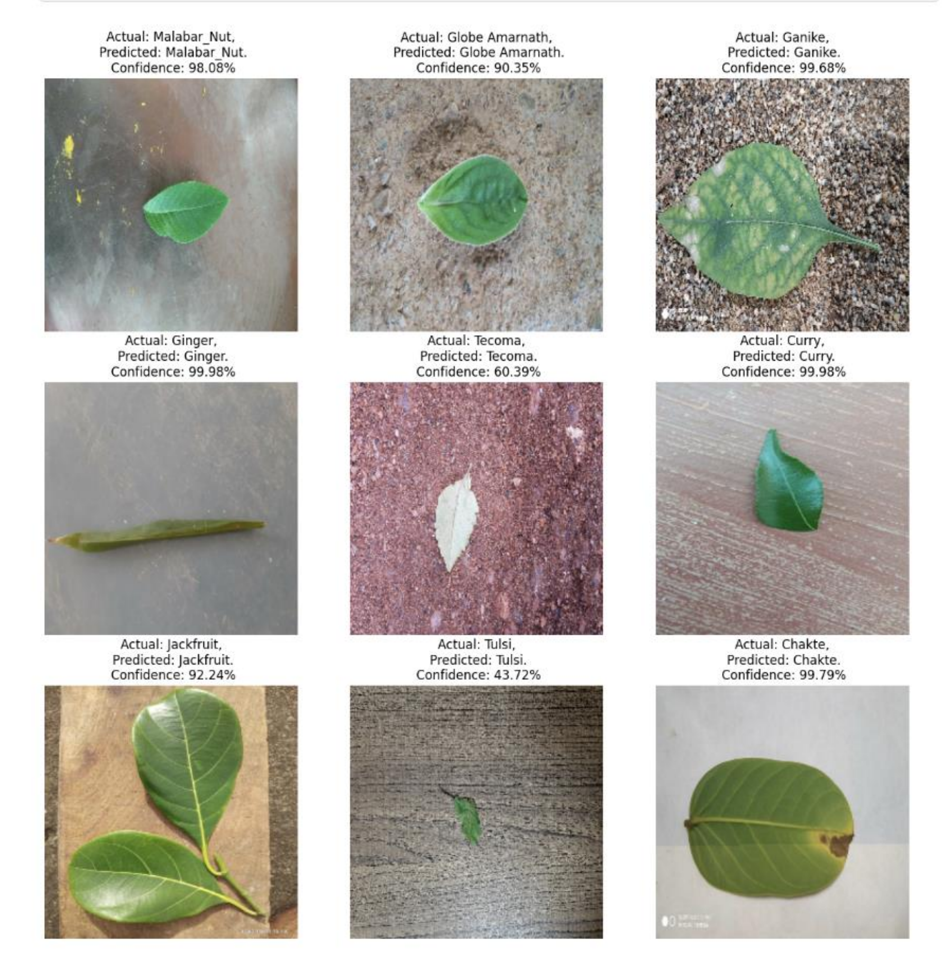


Figure 5: Classification Results for Different Leaf Types with Predicted Labels and Confidence Levels

Discussion

Table 2. Comparison of Classification Accuracy Using Various Features and Classifiers

Reference	**Features**	**Classifier**	**Accuracy**
Simion *et al.,* 2019	Texture Features	PCA, LDA	92.9
Turkoglu *et al.,* 2019	Texture Features	LBP	92.92
Ang *et al.,* 2023	Texture Features	CNN	95
Quoc *et al.,* 2020	Texture Features	CNN	88.26
Proposed Methodologies	Texture Features	INCEPTION	92
		VGG	93
		ResNet	**97**

Figure 5 illustrates a comparative analysis of various models used for leaf classification, with ResNet emerging as the top performer by achieving an accuracy of 97%. Other studies have explored different approaches to feature extraction and classification with varying degrees of success. For example, Simion *et al*. (2019) and Turkoglu *et al*. (2019) utilized texture features along with Principal Component Analysis (PCA) for dimensionality reduction and Linear Discriminant Analysis (LDA) for maximizing class separability, resulting in accuracies of 92.9% and 92.92%, respectively. Ang *et al*. (2023) focused on extracting leaf vein characteristics using a Convolutional Neural Network (CNN) algorithm, which achieved a high accuracy of 95%. Quoc *et al*. (2020) explored different CNN frameworks for recognizing medicinal plant images, with the Xception model reaching a peak accuracy of 88.26%.

The proposed methodologies leverage advanced neural network architectures such as Inception, VGG, and ResNet, incorporating texture features to achieve higher accuracy of 92%, 93%, and 97%, respectively. This demonstrates that deep learning models can effectively utilize texture features to enhance classification performance. However, these models have certain limitations. The effectiveness of deep learning models heavily relies on having a high-quality, diverse dataset. Without a large and varied dataset that includes different species and environmental conditions, the models are at risk of overfitting or underfitting, which compromises their ability to generalize to new data.

Additionally, the complexity of these models demands significant computational resources, which may not be accessible to all researchers or practitioners. The inference time can also be slow, making real-time applications challenging, especially in variable environments where factors like image quality, lighting, and angles can vary. This variability can significantly impact model performance, limiting its applicability in real-world scenarios. Furthermore, the interpretability of deep learning models is a notable concern; their complexity often makes it difficult to understand the decision-making process, which can hinder trust and usability. Finally, incorporating new plant species or varieties into the model introduces additional challenges, requiring extensive expertise and resources for model maintenance and updates. These factors collectively highlight the need for balanced considerations when applying deep learning models to plant classification tasks.

Conclusion

The development and experimentation of the novel deep learning model, integrating VGG, Inception, and ResNet architectures for the classification of herbal plants based on their leaves, have yielded promising results. The collaborative strengths of VGG's simplicity, Inception's complex parallel structures, and ResNet's effective handling of gradient issues have culminated in a comprehensive and robust model capable of excelling in diverse visual recognition tasks. Through meticulous dataset curation, robust preprocessing, and extensive training, the model demonstrated high accuracy and reliability, showcasing its efficacy in advancing the field of computer vision. Beyond its primary application in medicinal plant identification, the hybrid model's versatility extends to image-based tasks such as object recognition. Additionally, the model's capacity to classify images as medical or non-medical plants opens avenues for broader applications, including invasive species screening and safeguarding endangered plants. In retrospect, this research contributes to improved healthcare practices, enhanced conservation efforts, and the overall evolution of deep learning techniques in diverse visual recognition domains.

Future Work

Improving the model and addressing these constraints will require future research to diversify and expand the dataset to cover a wider range of plant species and climatic variables. To reduce the likelihood of overfitting and increase the model's resilience, sophisticated data augmentation methods can be utilised. To further improve the model's suitability for real-time applications, it is crucial to optimise it in order to decrease processing requirements and inference time. To do this, one could investigate methods like model pruning, quantization, and distillation.

Hybrid models, which combine the best features of different architectures, have the potential to greatly improve the performance and adaptability of models. Another way to make the model more versatile is to use transfer learning techniques. This way, you can train it on different plant species or similar jobs with very little extra data. Practical benefits and a broader impact can be achieved by extending the model to real-time and mobile apps, connecting it with IoT devices for automated plant monitoring, and collaborating across disciplines.

Users will have more faith in the model's judgements if researchers look into ways to make the model's predictions more interpretable, such as by including attention mechanisms and explainable AI approaches. It is possible to refine and improve the model indefinitely if methods are in place to get user feedback on model predictions. Computer vision and its practical applications in botanical and ecological studies can advance by tackling these future areas, which will allow the model to attain improved accuracy, efficiency, and applicability across multiple domains.

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Conflict of Interest

All authors declare no competing interests.

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