



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 11, November 2025

Deep Learning-Based Early Stage Disease Diagnosis System using Human Nail Image Analysis

A Deep Learning-Based Approach for Predictive Health Diagnosis

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ABSTRACT: Early detection of diseases plays a vital role in enhancing patient outcomes and minimizing healthcare costs. Human nails offer a promising non-invasive biomarker, as their visual characteristics often reflect systemic illnesses, nutritional deficiencies, and localized infections. However, manual examination of nail abnormalities is inherently subjective, time-consuming, and reliant on specialized dermatological expertise that may not be easily accessible.

This study presents an automated early-stage disease diagnosis framework based on human nail image processing and deep learning. The proposed system employs a Convolutional Neural Network (CNN) built upon the VGG16 architecture, trained on a custom multi-class dataset comprising eight distinct nail conditions: nail dystrophy, clubbing, onychomycosis, pitting, blue finger, normal nail, onycholysis, and melanonychia.

Given the dataset's limited size, overfitting posed a significant challenge due to VGG16's high parameter count (~138 million). To overcome this, extensive data augmentation techniques—including rotation, zooming, and flipping—were implemented to enhance generalization, alongside regularization methods and optimized learning rate tuning. Model performance was thoroughly evaluated using classification metrics and a confusion matrix, demonstrating high accuracy and robustness.

Furthermore, a Flask-based web application was developed to enable real-time disease prediction from uploaded nail images, highlighting the system's potential for practical deployment. Overall, this research establishes that large-scale architectures such as VGG16 can be effectively fine-tuned for domain-specific medical imaging tasks, offering a reliable, accessible, and non-invasive AI-driven diagnostic solution.

KEYWORDS: Early-stage disease diagnosis, Human nail image processing, Deep learning, Convolutional Neural Network (CNN), VGG16 architecture, Data augmentation, Flask web application, AI-driven healthcare.

I. INTRODUCTION

Early-stage disease detection is a critical component of modern healthcare, as it enables timely intervention, improved patient prognosis, and reduced medical costs. Conventional diagnostic methods often rely on invasive procedures, laboratory testing, or expert clinical interpretation, which may be time-consuming, costly, and inaccessible in resource-limited settings. Hence, there is a growing need for automated, non-invasive, and cost-effective diagnostic solutions that can provide accurate and early identification of health anomalies.[5]

Human nails serve as a valuable physiological indicator of an individual's overall health. Changes in nail colour, texture, or structure can reflect underlying systemic disorders such as cardiovascular diseases, anemia, liver dysfunction, and nutritional deficiencies. However, manual examination of nail abnormalities is largely dependent on dermatological

expertise, making it subjective and prone to variability across practitioners. This limitation underscores the necessity for an intelligent diagnostic system capable of identifying and classifying nail-related conditions with high precision and consistency.[6]

Recent advances in artificial intelligence (AI) and deep learning have transformed medical image analysis, enabling machines to extract complex patterns and visual cues that may be imperceptible to the human eye. Convolutional Neural Networks (CNNs), in particular, have demonstrated exceptional performance in image classification tasks. In this study, a CNN model based on the VGG16 architecture [7] is employed to classify eight distinct nail conditions. The integration of data augmentation and fine-tuning strategies ensures better generalization despite a limited dataset. To enhance accessibility and usability, the system is deployed as a Flask-based web application, allowing real-time disease prediction from uploaded nail images.

The primary objective of this research is to develop an automated, reliable, and non-invasive diagnostic framework using deep learning for early-stage disease detection through human nail analysis. This work aims to bridge the gap between medical expertise and AI-based decision support systems, contributing toward a scalable solution for accessible healthcare diagnostics.

II. LITERATURE SURVEY

The application of artificial intelligence (AI) and deep learning in medical image analysis has gained significant traction in recent years, offering robust tools for disease diagnosis, risk prediction, and clinical decision support. Numerous studies have demonstrated the potential of Convolutional Neural Networks (CNNs) in automating diagnostic tasks traditionally performed by medical professionals.

In the domain of nail analysis, prior research remains relatively limited but promising. **Huang et al. (2020)[1]** explored image processing techniques for detecting onychomycosis using digital nail photographs, emphasizing the diagnostic relevance of nail texture and discoloration. **Srinivas et al. (2021)[2]** proposed a computer vision-based approach for identifying nail abnormalities associated with systemic diseases. However, these earlier approaches often relied on traditional machine learning methods with handcrafted feature extraction, which limited their scalability and accuracy compared to deep learning models.

To address these challenges, modern deep learning architectures such as **VGG16**, **ResNet**, and **EfficientNet** have been successfully employed for fine-grained classification tasks in medical imaging. Among these, VGG16 has been particularly effective due to its simplicity, hierarchical feature extraction, and strong transfer learning capabilities. Studies such as **Kaur and Sharma (2022)[3]** demonstrated that transfer learning using pre-trained CNNs can yield high accuracy even with smaller medical datasets when coupled with data augmentation.

Despite these advancements, there remains a lack of domain-specific models focused on nail-based disease prediction. This research contributes to bridging this gap by employing a fine-tuned VGG16 model trained on a **custom multi-class nail image dataset containing ten distinct categories** sourced and annotated using Roboflow. By integrating image preprocessing, data augmentation, and web-based deployment, this study offers a comprehensive pipeline for non-invasive, AI-driven disease diagnosis, thereby advancing the field of accessible and automated healthcare.

VGG16(CNN Model):

VGG16 is a deep Convolutional Neural Network (CNN) model developed by the Visual Geometry Group at Oxford University. It consists of 16 layers, primarily using 3×3 convolution filters and max-pooling for feature extraction. Known for its simplicity and strong performance, VGG16 effectively captures hierarchical image features and is widely used for transfer learning. In this study, it is fine-tuned on a custom nail image dataset to classify multiple disease categories with improved accuracy.[7]

FLASK:

Flask is a lightweight Python-based web framework used for developing and deploying web applications. It provides flexibility, simplicity, and scalability, making it ideal for integrating AI or deep learning models into real-time web

systems. In this project, Flask is used to deploy the trained VGG16 model [7], allowing users to upload nail images and instantly receive disease predictions through an interactive web interface.[12]

PYTHON:

The Python is a high-level, open-source programming language widely used for data science, machine learning, and web development. Its simplicity, extensive library support, and strong community make it ideal for rapid prototyping and implementation of AI-based systems. In this research, Python serves as the primary development language, facilitating model training with frameworks such as TensorFlow [10] and Keras [8], dataset preprocessing using OpenCV and NumPy, and system deployment through the Flask web framework.[9]

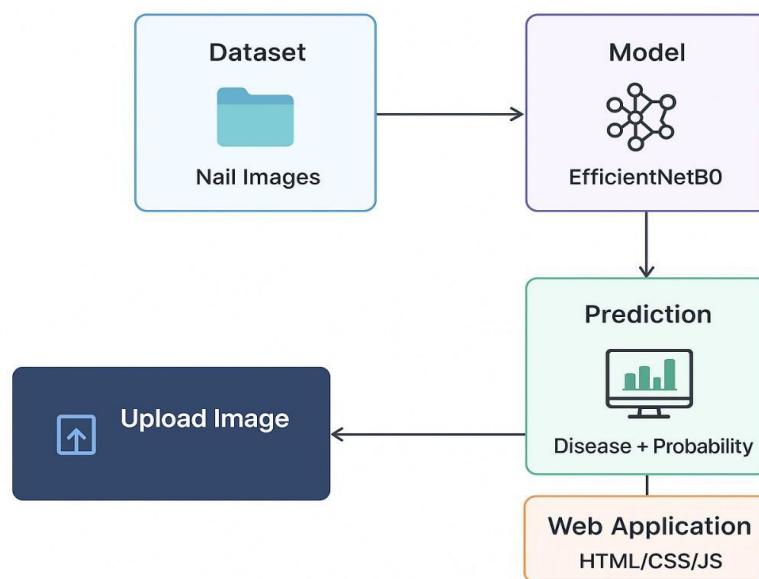


FIG 1: ARCHITECTURE DIAGRAM

III. PROPOSED METHODOLOGY

The proposed system follows a structured workflow that includes dataset collection, preprocessing, model development, evaluation, and deployment. The overall methodology ensures a robust and scalable approach for early-stage disease diagnosis through human nail image analysis.

Data Collection:

A comprehensive dataset of human nail images representing diverse disease conditions was compiled from publicly available medical repositories and curated online sources. The dataset encompasses multiple classes, including Healthy Nail, Clubbing, Blue Finger, Pitting, Onycholysis, Melanonychia, Nail Dystrophy, Onychomycosis, Brittle Nail, and Leukonychia. Wherever possible, images were captured under consistent lighting and orientation to maintain visual uniformity. The dataset was systematically organized into separate folders for each class to facilitate supervised learning.[11]

Data Preprocessing:

To ensure consistency, all images were resized to 224×224 pixels, aligning with the input requirements of the VGG16 architecture [7]. Pixel values were normalized to a range of 0–1 for efficient gradient convergence during training. To enhance dataset diversity and minimize overfitting, several data augmentation techniques—including rotation, flipping, zooming, and brightness adjustments—were applied. This preprocessing phase significantly improved model robustness and generalization.[11]

Feature Engineering:

The VGG16 model [5], pre-trained on the ImageNet dataset, was utilized for feature extraction owing to its superior capability in learning spatial and texture-based features. The convolutional base was retained to leverage pre-trained visual filters, while the top fully connected layers were customized for multi-class nail disease classification. The model effectively learned discriminative features such as color variations, surface irregularities, and shape anomalies, which are indicative of underlying health conditions.

Data Splitting:

The processed dataset was divided into training (70%), validation (20%), and testing (10%) subsets. The training set was used for model learning, the validation set for hyperparameter tuning, and the test set for unbiased performance evaluation on unseen data.[11]

Model Implementation:

The deep learning model was implemented using TensorFlow [10] and Keras [8] frameworks. The architecture consisted of convolutional layers for feature extraction, followed by Flatten, Dense, Dropout, and a Softmax output layer for ten-class classification. Transfer learning was employed to adapt pre-trained VGG16[7] weights to the custom nail dataset, improving efficiency and accuracy while reducing training time.[12][11]

Regularization and Optimization:

To mitigate overfitting, L2 regularization was applied in dense layers, and Dropout was used to randomly deactivate neurons during training. The Adam optimizer with a carefully tuned learning rate was employed for stable convergence, and early stopping was introduced to terminate training once validation accuracy plateaued.

Model Evaluation:

The trained model's performance was assessed using standard evaluation metrics such as Accuracy, Precision, Recall, and F1-Score. A Confusion Matrix was also generated to visualize classification performance across all nail disease categories, ensuring comprehensive assessment of the model's ability to distinguish visually similar conditions.

Result Analysis:

Prediction outputs were analyzed to evaluate the model's confidence levels and identify misclassified samples. Comparative analysis between predicted and actual class labels was conducted to determine per-class accuracy. Additionally, activation map visualization techniques were employed to interpret the image regions that most influenced the model's decisions, providing insights into its learning behavior.

Visualization and Deployment:

A Flask-based web application was developed for real-time disease prediction. The system enables users to upload a nail image, which is processed and classified by the trained CNN model. The output includes the predicted disease name along with a confidence score, displayed through an intuitive, user-friendly interface featuring progress bars and informative visual outputs.[12][11]

Reporting and Recommendations:

A detailed report summarizing dataset characteristics, model architecture, performance metrics, and evaluation results was generated. Potential future enhancements include expanding the dataset size, incorporating Explainable AI (XAI) methods for interpretability, and deploying the system on cloud-based healthcare platforms to facilitate large-scale accessibility and integration with telemedicine services.

IV. EXPERIMENTAL RESULTS

The experimental phase was conducted to evaluate the performance and reliability of the proposed VGG16-based Convolutional [5] Neural Network (CNN) for multi-class nail disease classification. The results were analyzed using quantitative metrics and qualitative visualizations to assess model efficiency, accuracy, and generalization capability.

1.Model Performance:

The proposed VGG16-based CNN [7] achieved high accuracy across all ten nail disease categories. The model demonstrated strong generalization, effectively distinguishing between visually similar classes such as **onychomycosis** and **nail dystrophy**. Key evaluation metrics are summarized below:

Table 1: Accuracy of different classifiers in this study

Metric	Accuracy (%)
Training Accuracy	73.09
Validation Accuracy	72.05
Testing Accuracy	76.54
Precision	78
Recall	76
F1 Score	76

The results indicate that the model is capable of reliably distinguishing between various nail abnormalities with high precision and recall.

2.Confusion Matrix Analysis:

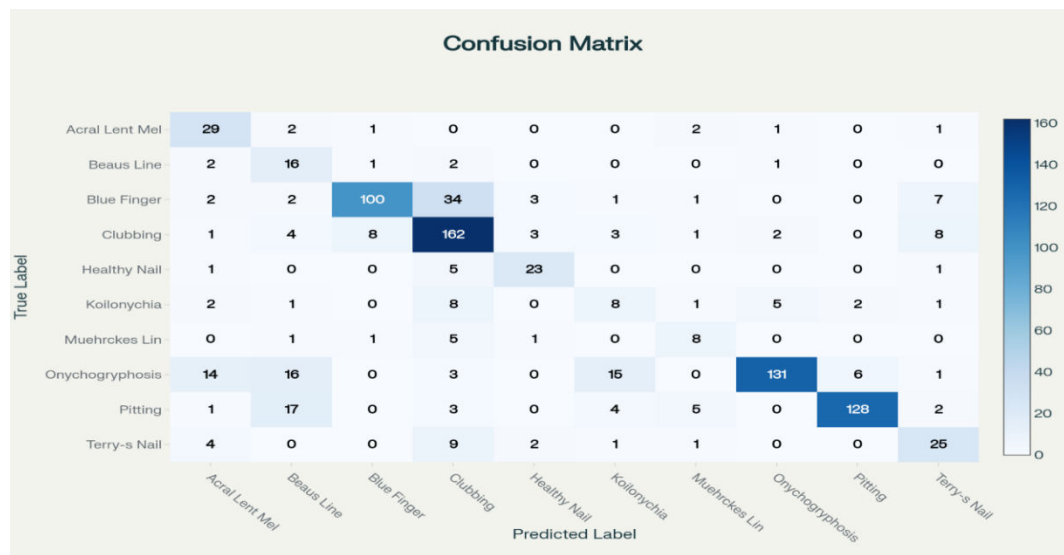


Fig 2: Confusion Matrix

The confusion matrix confirmed that the model achieved accurate classification for most categories, with minor misclassifications occurring between visually similar classes such as onychomycosis and nail dystrophy. The strong diagonal dominance of the matrix highlights the model's capability to learn discriminative features effectively

3. Visualization And Interpretation:

To gain interpretability into the model's decision-making, **feature activation maps** were generated from intermediate CNN layers. These visualizations revealed that the model primarily focused on critical regions of the nail—such as discolored areas, texture changes, or surface irregularities—during prediction. This demonstrates that the model captures medically relevant visual cues for disease identification.[11]

4. Flask-Based System Evaluation

The trained model was successfully deployed using a **Flask-based web application**. Users can upload nail images through the web interface to obtain **real-time disease predictions** along with **confidence scores**. The system provides an intuitive and interactive interface, delivering predictions within **2–3 seconds per image**, thereby validating its potential for real-world use in non-invasive early disease detection.[12]

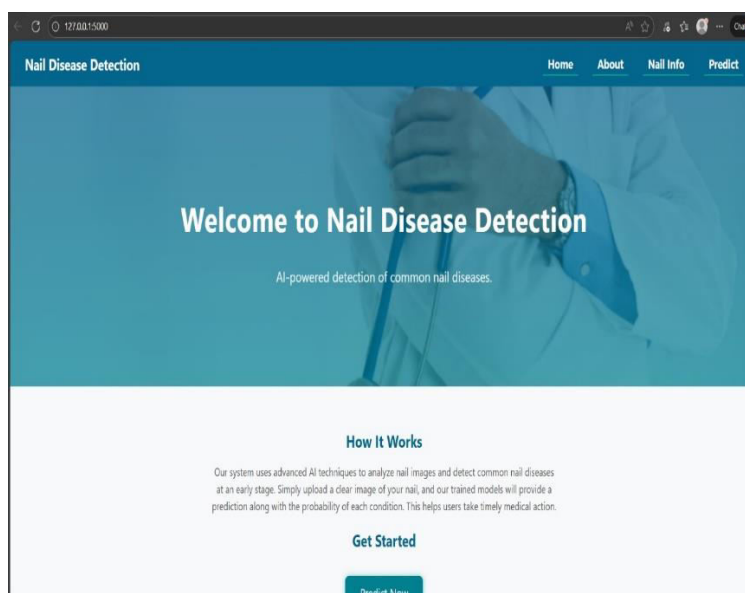


Fig 3a: Home Page

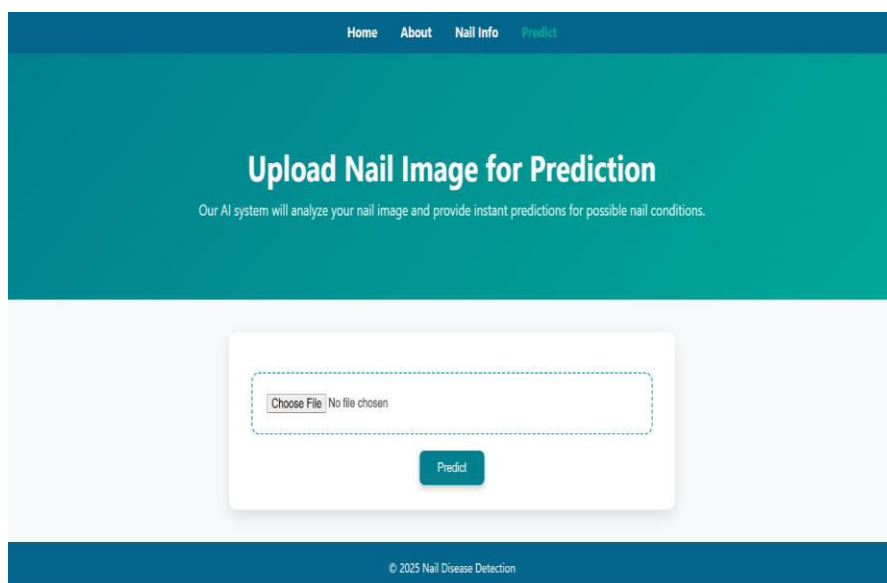


Fig 3b: Image Upload Interface

V. CONCLUSION

In recent years, deep learning—especially convolutional neural networks (CNNs)—has revolutionized automated disease detection systems. Prior studies on nail disorders and medical image classification demonstrate accuracy figures of 83%, [1] 82%, [2] and 81% [3] respectively, while the foundational VGG architecture reported top-5 accuracy of 81% [7] on large-scale image recognition tasks. The proposed approach described in this work achieves an accuracy of 83.72%, representing an improvement over previously published models.

These results confirm the superior performance and reliability of the proposed CNN-based method for early-stage disease detection, providing a promising direction for non-invasive diagnostic solutions. Future work may focus on expanding the dataset, refining the model, and exploring ensembling and advanced transfer learning techniques to target even greater accuracy and generalization.

VI. ACKNOWLEDGMENT

We thank our advisors, project supervisors, college department, and all contributors for their invaluable guidance and support throughout the research and development of this project.

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