Title:

Optimized AI-Driven Framework for Hyperspectral Imaging-Based Early Detection and Classification of Crop Diseases Using Deep Learning and Explainable AI

Aim of the Project:

The primary objective of this research is to develop an optimized AI-powered framework that leverages hyperspectral imaging (HSI) for the early detection and classification of crop diseases. The project integrates advanced deep learning techniques with explainable AI (XAI) to improve model interpretability and decision-making transparency. Additionally, the research aims to enhance computational efficiency and accuracy through feature selection and optimization algorithms, ensuring real-time and field-deployable solutions.

Statement of the Problem:

Crop diseases significantly impact global food security and agricultural productivity, leading to substantial economic losses. Traditional disease detection methods, such as visual inspection and laboratory testing, are time-consuming, subjective, and often ineffective for early-stage detection. While hyperspectral imaging provides high-dimensional spectral data that can reveal subtle disease symptoms, extracting meaningful insights from this data remains a challenge. Existing AI models struggle with computational inefficiency, overfitting, and lack of interpretability, making real-world deployment difficult. This research addresses these limitations by developing an optimized AI framework that enhances disease detection accuracy, reduces computational complexity, and integrates XAI for model transparency.

Overview of Literature:

Existing literature highlights the effectiveness of hyperspectral imaging in plant disease detection, with studies demonstrating the potential of machine learning and deep learning models in analyzing spectral data. However, challenges such as high dimensionality, redundant spectral bands, and computational constraints remain unresolved. Recent advancements in feature selection, transfer learning, and explainable AI offer promising solutions to these challenges. Additionally, hybrid models combining convolutional neural networks (CNNs) with attention mechanisms, generative adversarial networks (GANs), and reinforcement learning have shown improvements in classification accuracy. This study builds upon these foundations while introducing novel optimization techniques to improve model efficiency and interpretability.

Conceptual Framework:

The conceptual framework of this research is structured as follows:

1. Hyperspectral Data Acquisition – Collecting multispectral and hyperspectral images of healthy and diseased crops under controlled and field conditions.

2. Preprocessing & Feature Extraction – Applying dimensionality reduction techniques (PCA, t-SNE) to eliminate redundant bands and enhance computational efficiency.

3. AI Model Development – Designing a hybrid deep learning model (CNN + Transformer + GAN) to classify disease patterns with high precision.

4. Optimization & Explainability – Implementing optimization algorithms (Bayesian optimization, genetic algorithms) to fine-tune model parameters and integrate explainable AI techniques (SHAP, LIME) for decision transparency.

5. Deployment & Validation – Testing the model in real-world agricultural environments and benchmarking its performance against traditional methods.

Research Hypothesis:

H1: Hyperspectral imaging integrated with AI can detect crop diseases at an earlier stage compared to conventional methods.

H2: An optimized deep learning model with feature selection will improve classification accuracy while reducing computational cost.

H3: Explainable AI techniques will enhance trust and adoption of AI-based disease detection models in the agricultural sector.

Research Methodology:

- Data Collection: Hyperspectral image datasets will be collected from agricultural research centers and publicly available repositories.

- Model Development: A hybrid deep learning model will be trained using supervised and semi-supervised learning approaches.

- Feature Engineering: Spectral band selection and augmentation techniques will be applied to optimize input features.

- Optimization & Evaluation: The model will be optimized using evolutionary algorithms and evaluated using performance metrics such as accuracy, F1-score, and inference time.

- Field Testing & Deployment: A mobile or edge AI-based application will be developed for real-time disease detection.

Implications of the Research:

- Scientific Contribution: Advancing AI-driven hyperspectral imaging techniques for crop disease detection.

- Practical Applications: Enabling farmers and agronomists to detect and mitigate crop diseases at an early stage.

- Policy & Socioeconomic Impact: Reducing agricultural losses and promoting food security through precision agriculture.

References: