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Digital horticulture: Artificial intelligence revolutionizing plant disease detection for healthier harvests

Artificial Intelligence (AI) has become a powerful tool in the field of plant disease detection, offering numerous benefits for improving horticultural practices and ensuring food security. AI techniques, particularly machine learning (ML) and deep learning (DL) along with internet of things (IoT), can help in the early detection and diagnosis of plant diseases, leading to timely and effective disease management practices.

THE horticulture sector plays a pivotal role in ensuring food and nutritional security, rural employment and environmental sustainability. However, plant diseases continue to pose significant threats to productivity and profitability, often leading to heavy economic losses. Traditionally, plant diseases are detected through manual visual observation of symptoms on plant parts. However, this method often misled the farmers that results in indiscriminate usage of pesticides due to a lack of proper knowledge on diseases. Consequently, there is an urgent need to leverage technology for accurate disease diagnosis, ensuring the correct type and number of pesticides are used. This review explores various machine learning (ML) and image processing-based techniques and presented in the article for diagnosing plant diseases, which analyze the leaf images that are plant diseases apparent primarily on leaves.

METHODS AND TECHNOLOGIES

Image recognition and deep learning

Convolutional neural networks **(CNNs):** These are deep learning models particularly effective in analyzing plant images to detect diseases. They can classify images of leaves, fruits and stems to identify symptoms and signs of various diseases.

Mobile applications: Farmers can use smartphone apps that utilize AI to capture and analyze images of their crops in real-time, providing instant diagnosis and recommendations.

Sensor data analysis

Internet of things **(IoT) devices:** IoT sensors can monitor environmental conditions such as temperature, humidity and soil moisture, which can be critical in predicting disease outbreaks.

Remote sensing: Drones and satellites equipped with advanced sensors can capture high-resolution images of large orchards, which AI algorithms can analyze to detect disease patterns.

Predictive analytics

Machine learning models: These models can analyze historical data on weather, plant health and disease occurrence to predict future outbreaks and recommend preventive measures.

Big data: Aggregating and analyzing huge amounts of horticultural data helps in understanding trends and making more accurate predictions about disease outbreaks.

Steps in AI-based plant disease detection

Data collection: Collect images of healthy and diseased plants from various sources. Annotate these images to create a labelled dataset.

Data pre-processing: Pre-process images to enhance quality, remove noise and normalize sizes. Techniques like image augmentation can be used to increase the diversity of the training dataset.

Model training: Split the dataset into training, validation and test sets. Train a deep learning model, such as a CNN, on the training data. Validate the model using the validation set and fine-tune hyperparameters.

Model evaluation: Evaluate the model's performance on the test set using metrics like accuracy, precision, recall and F1-score. Ensure the model generalizes well to unseen data.

Deployment: Deploy the trained model to an edge device, cloud service, or mobile application. The model can then process new images in real-time to detect plant diseases.

Integration and decision support: Integrate the AI model with decision support systems to provide farmers with actionable advisories. For example, the system can recommend specific treatments or preventive measures based on detected diseases.

Applications

Early disease detection: An IoT and AI integrated systems can detect diseases at early stages, even before symptoms are visible to the naked eye, enabling timely intervention and reducing yield losses.

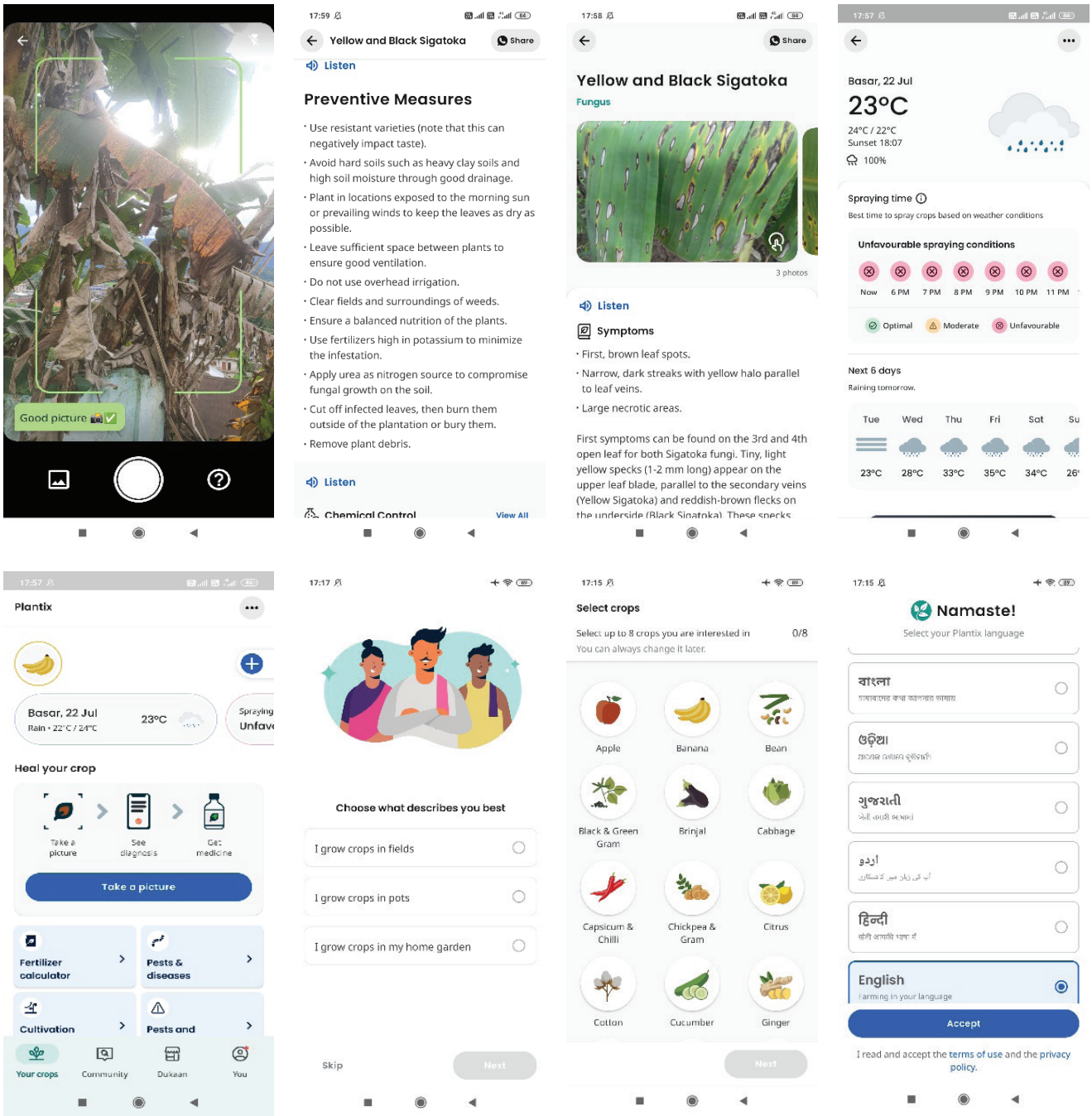
Precision horticulture: By precisely identifying affected areas, AI helps in targeted application of treatments, minimizing the use of pesticides and reducing costs.

Yield improvement: Early and accurate disease detection helps in maintaining plant health, which directly contributes to higher yields and better-quality produce.

Disease management strategies: AI can assist in developing integrated pest management (IPM) strategies by predicting disease outbreaks and suggesting optimal times for planting, harvesting and applying treatments.

Research and development: AI aids researchers in analyzing large datasets to understand disease patterns and subsequently helps in developing resistant plant varieties.

Integration with national pest surveillance system (NPSS): The national pest surveillance system (NPSS), established by the Government of India, serves as a coordinated platform for real-time pest and disease monitoring across the country. AI technologies can enhance NPSS by: Automating the identification of pest and disease symptoms from field images. Integrating data from remote sensors, weather stations and mobile applications. Providing predictive alerts to the farmers and policymakers for proactive management. This AI–NPSS integration can revolutionize surveillance by enabling real-time, location-specific forecasting of disease outbreaks and supporting national biosecurity and crop protection initiatives.



Digital horticulture assistant (Plantix app)-Banana sigatoka disease detection & their control measures

Examples of AI in plant disease detection

Plantix app: An AI-powered app that helps farmers diagnose plant diseases by uploading photos. The app provides information on disease symptoms, causes and treatment options.

Deep learning algorithms: Research projects using deep learning to classify diseases in various crops like banana, tomatoes and potatoes. These projects have shown high accuracy rates in disease detection.

AI models in greenhouses: Implementing AI systems in controlled environments like greenhouses to continuously monitor plant health and optimize growing conditions.

Advantages of AI-based plant disease detection

Accuracy: AI models can achieve high accuracy in identifying and classifying plant diseases, often surpassing traditional manual methods.

Efficiency: Automated detection systems can process large volumes of data quickly, enabling real-time monitoring and early disease detection.

Consistency: AI systems provide consistent results, reducing the variability associated with human observation and diagnosis.

Resource optimization: Accurate disease diagnosis helps optimize the use of pesticides and fertilizers, reducing costs and minimizing environmental impact.

Challenges

Data quality and quantity: High-quality, annotated datasets are essential for training effective AI models. There is a need for large, diverse datasets covering various plant species and disease conditions.

Model generalization: Ensuring that AI models generalize well to different environmental conditions, lighting and plant varieties is challenging.

Integration with farming practices: AI-based solutions need to be user-friendly and easily integrable with existing farm management practices to encourage widespread adoption.

Future directions

Multimodal approaches: Combining image data with other data types, such as environmental sensor data, to improve disease detection accuracy.

Explainable AI: Developing AI models that provide explanations for their predictions to gain farmer trust and improve decision-making.

Integration with NPSS and digital platforms: Strengthening linkages between AI models and NPSS databases to facilitate nationwide pest alerts and disease forecasting.

Scalability and cost-effectiveness: Ensuring AI tools are affordable and adaptable to varied cropping systems and farm sizes.

Collaborative networks: Encouraging partnerships among ICAR institutes, state departments, start-ups and AI developers to promote rapid field deployment.

SUMMARY

The integration of IoT and AI technologies into horticultural disease diagnostics marks a new era of digital horticulture. AI-driven tools offer accurate, efficient and scalable solutions for early disease detection, contributing to precision farming and sustainable crop protection. Strengthening national initiatives such as the national pest surveillance system (NPSS) through AI integration will further enhance India's capability for proactive pest and disease management.

By bridging plant pathology, data science and sensor technology, AI empowers farmers to make informed decisions, reduce losses and ensure healthier harvests for a sustainable future.

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