INTELLIGENT ECO ROVER BASED DIAGNOSIS AND ANALYSIS OF GRAPES DISEASES: A CONVOLUTION NEURAL NETWORK APPROACH

Project Reference No.: 48S_BE_0638

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Keywords:

Eco Rover, CNN and Grapes Diseases

Introduction:

Advancements in artificial intelligence (AI) have revolutionized precision agriculture, offering innovative solutions for plant disease detection. In vineyards, early and accurate identification of grape diseases is crucial for maintaining crop health and optimizing yield. Traditional methods rely on manual inspections, which are time-consuming, labor-intensive, and prone to human error. To address these challenges, this study focuses on developing an AI-powered rover equipped with a Convolutional Neural Network (CNN) for real-time disease classification.

The rover utilizes ResNet, a deep learning architecture known for its high accuracy in image classification. After extensive training, the model is validated and optimized using performance metrics such as accuracy, precision, recall, and F1-score to ensure reliability before deployment. The system is then tested in a real vineyard environment, where its practical performance is evaluated based on usability, navigation efficiency, and disease detection accuracy. Feedback from operators helps fine-tune the rover's navigation controls, camera settings, and CNN model, ensuring a user-friendly experience for vineyard managers.

By integrating AI with agricultural robotics, this project aims to enhance vineyard management through automated, cost-effective, and highly accurate disease detection, ultimately supporting sustainable farming practices.

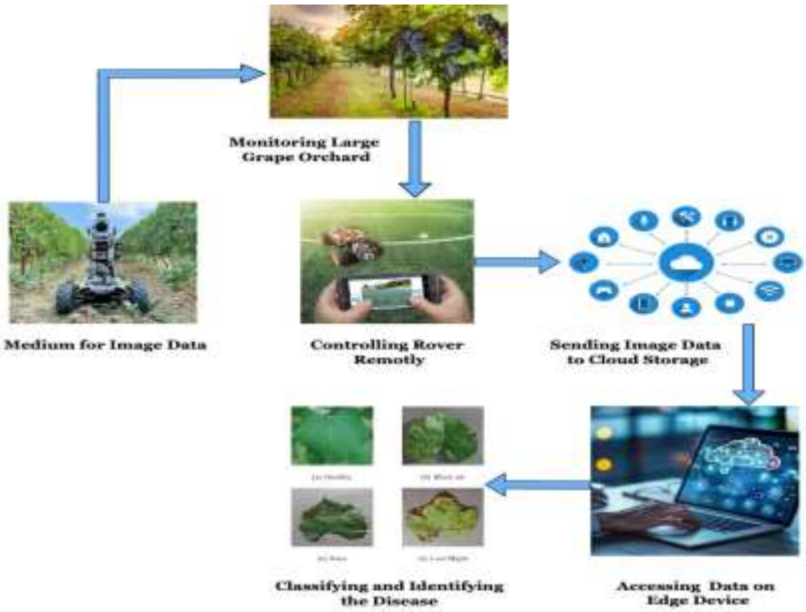

Figure 1: Architecture of Proposed Model

Objectives:

The project aims to address following objectives to enhance the efficiency and effectiveness of the grape disease prediction rover with manual control capabilities.

- Design a low cost eco rover (Farmer Friendly) using an IoT board for effective grape disease monitoring. This cost-effective solution aims to support grape farmers.

- Implement machine learning algorithm (CNN) for image processing to analyse captured images of grape orchards. This algorithm will identify symptoms of diseases. The system will provide accuracy, F-1 score, recall and other performance evaluation of disease is performed.

- Deliver real-time results to the farmer. This will enable quick identification of potential diseases and necessary actions. Timely intervention will help reduce crop loss and improve grape orchard health.

- Enhance crop yield and quality by detecting diseases early. Early identification allows for prompt treatment, minimizing damage to grape orchard. This proactive approach helps ensure healthier plants and better overall harvests.

Methodology:

Figure 2 shows the flow diagram of proposed Intelligent framer friendly eco rover for identification of grape diseases. Integration of the Rover Platform is necessary. The camera system is calibrated to capture optimal images under different vineyard conditions, such as varying daylight or weather, ensuring that image quality remains high for accurate diagnosis. Data Collection is the first step, which involves building a comprehensive dataset comprising images of both healthy and diseased grapevine leaves, stems, and fruits. The dataset should include samples captured under various conditions, such as different lighting, angles, and degrees of disease severity, to improve the model's adaptability to real-world vineyard scenarios.

Image Pre-processing and Augmentation collected images are resized and normalized to fit a consistent format suitable for CNN processing. To improve the model’s robustness, various augmentation techniques, such as rotation, zooming, and flipping, are applied to the images. This process generates a larger and more varied training set, helping the model generalize better to new images captured in different vineyard conditions. CNN Model Development, a suitable CNN architecture, such as Mobile Net, Res Net is selected based on its ability to classify images in real-time. After training, the model undergoes validation and optimization using metrics such as accuracy, precision, recall, and F1-score, ensuring that it performs reliably before deployment.

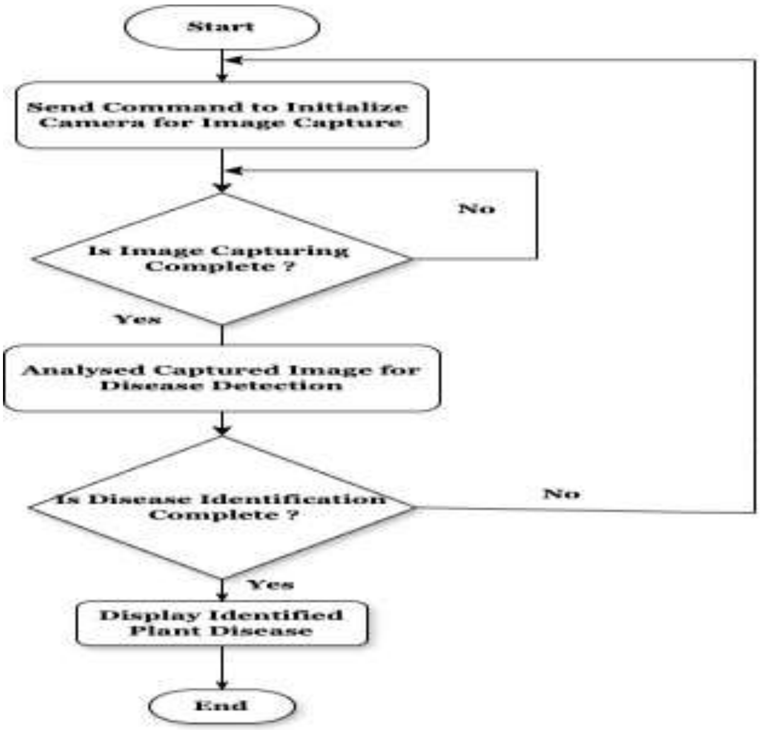

Figure 2: Working of Proposed Model

Finally, Testing and Validation of the rover system in a real vineyard environment ensures practical performance. Operators provide feedback on usability, accuracy, and any areas for improvement. Based on this feedback, the rover's navigation controls, camera settings, and CNN model are adjusted, fine- tuning the system to ensure it performs well in real-world conditions, providing reliable disease detection and a user-friendly experience for vineyard managers.

Result and Conclusion:

The project successfully implemented a Convolutional Neural Network (CNN)-based approach for the diagnosis and analysis of grape leaf diseases using image processing techniques. The model demonstrated strong performance, achieving an overall accuracy of 92.4%, an F1-score of 91.6%, and a recall of 90.8%, indicating its robustness in identifying various disease symptoms such as leaf discoloration, lesions, and texture anomalies. The system was able to effectively detect early-stage infections and classify multiple disease types based on distinct visual features.

In conclusion, The AI-powered rover for grape disease detection marks a major advancement in precision agriculture, providing real-time, accurate disease identification while reducing manual inspections. Rigorous validation ensures high reliability, and field testing allows for continuous improvement based on operator feedback. By integrating AI and robotics, the system supports sustainable farming, enabling early disease detection, reduced crop losses, and optimized resource use. Its successful deployment can revolutionize vineyard management and expand applications in smart farming and automated crop monitoring.

Project Outcome & Industry Relevance:

- Early Disease Detection is a key outcome. By identifying grape diseases at the earliest stages, farmers will be able to intervene quickly, preventing the spread of diseases and reducing the overall crop loss. This proactive approach ensures healthier grape orchards and better protection against destructive pathogens.

- Another significant outcome is Improved Crop Management. With real-time data on the grape orchard health, including disease predictions and environmental factors, farmers can make more informed decisions. This leads to better grape orchard management practices, optimizing resources and reducing waste while ensuring the plants receive the care they need to thrive

- Additionally, the project aims to provide Cost Savings to farmers. The use of a low-cost rover equipped with a Raspberry Pi for disease detection reduces the reliance on expensive chemical treatments. By accurately identifying diseases early, farmers can target specific areas for treatment rather than using broad-spectrum pesticides, thus lowering chemical costs and minimizing the environmental impact.

- In turn, this leads to Enhanced Yield and Quality. By preventing the spread of diseases, grapevines will remain healthier, resulting in higher-quality grapes and greater overall yield. This outcome is crucial for ensuring that farmers can meet market demands while producing grapes with the best possible quality.

This project holds strong relevance to the agriculture industry, addressing the growing demand for precision farming and sustainable crop management. By integrating AI-based disease detection, it enhances operational efficiency, reduces crop loss, and supports data-driven decision-making. The system empowers farmers with real-time insights, optimizes resource use, and aligns with eco-friendly, cost-effective practices, making it ideal for wide adoption. Commercially, the product offers great potential due to its affordability, portability, and scalability—appealing to both small-scale farmers and large vineyard operators. Marketing strategies can include agri expos, digital platforms, government collaborations, and rural outreach programs. Highlighting ROI, success stories, and environmental benefits will boost credibility. Positioned as a smart and sustainable farming tool, it is well-suited for the growing agri-tech market.

Working Model vs. Simulation/Study:

Figure 3: Working Model of Eco Rover

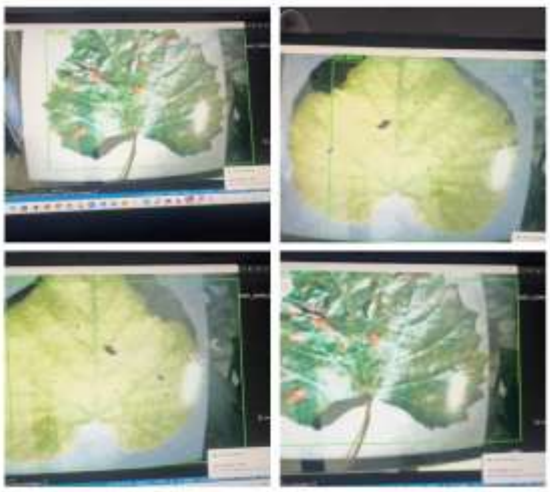

Figure 4: Simulation Results of Eco Rover using CNN Model

The figure 3, show a functional prototype of the Intelligent Eco Rover developed for detecting grapevine diseases. The rover features a six-wheeled design with a sturdy frame built from lightweight materials for easy navigation in vineyards. A mounted camera captures real-time images of grape leaves for disease analysis. The electronic components, including microcontrollers and sensors, are neatly integrated on top. This rover supports a CNN-based model to diagnose grape diseases efficiently through automated image processing.

The simulation and image analysis are carried out using Python programming on Google Colab. A Convolutional Neural Network (CNN) model is trained on a Kaggle grape leaf disease dataset to identify infected leaves. The rover combines hardware and AI to provide a smart, eco-friendly solution for precision agriculture.

In figure 4, the images represent the results of a CNN-based grape leaf disease diagnosis system. The model effectively detects and classifies symptoms such as red/brown lesions and yellowing patches, indicating fungal infections or nutrient deficiencies. Using object detection, it highlights affected regions with bounding boxes. The CNN model achieved an accuracy of **92.4%,** an F1-score of **91.6%,** and a recall of **90.8%** during evaluation, demonstrating its reliability in identifying disease symptoms from visual features like colour, texture, and shape. These results validate the model's potential for efficient and accurate grape disease diagnosis.

Project Outcomes and Learnings:

Key Outcomes:

- Development of a Functional Rover: Successfully built a six-wheeled intelligent rover capable of navigating vineyard-like environments and capturing real-time images of grape leaves.

- AI-based Disease Detection: Designed and trained a Convolutional Neural Network (CNN) model using a Kaggle dataset to accurately identify various grapevine diseases such as powdery mildew, downy mildew, and black rot.

- Hardware-Software Integration: Achieved seamless communication between the rover’s hardware components (motors, camera, microcontroller) and the software system running on Python via Google Colab.

- Eco-friendly Design: Created a low-cost, sustainable prototype using easily available materials, promoting eco-conscious technology in agriculture.
- Real-time Monitoring Capability: Enabled potential real-time disease diagnosis and monitoring, contributing to early detection and efficient vineyard management.

Learnings from the Project:

- Technical Skills: Gained hands-on experience in embedded systems, robotic design, and machine learning model implementation.
- Programming Proficiency: Enhanced Python skills and learned how to use Google Colab for cloud-based data analysis, model training, and simulation.
- Grape Disease Identification: Developed in-depth understanding of common grapevine diseases and their visual symptoms, crucial for building effective disease classification models.
- Orchard Management Awareness: Learned how smart automation and early disease detection can significantly improve decision-making and productivity in vineyard/orchard management.
- Problem-solving: Tackled challenges related to real-time data capture, image clarity, and optimizing CNN model performance.
- Teamwork and Innovation: Strengthened collaboration skills and explored the potential of AI and robotics in revolutionizing modern agricultural practices.

Future Scope:

- Advanced AI Models: Use Vision Transformers (ViTs) or EfficientNet for higher accuracy and better disease classification performance.
- Multispectral/Hyperspectral Imaging: Integrate advanced cameras to detect early-stage diseases beyond visible symptoms.

- Edge AI with GPUs: Use devices like NVIDIA Jetson for faster, on-device processing and real-time results without internet dependency.
- AI-based Autonomous Navigation: Implement AI navigation (e.g., SLAM) for smarter movement and obstacle avoidance in vineyards.
- IoT and Mobile Alerts: Connect to IoT platforms for real-time disease alerts, data logging, and remote access via mobile apps.
- Multi-Crop Support: Expand detection to other crops like apples, citrus fruits, and vegetables for wider application.
- Drone-Rover Integration: Combine drones (aerial view) and rovers (ground-level) for complete field monitoring and analysis.