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Agri-Inspect Rover: Sugarcane Disease Detection and Industrial Inspection System

Sufiyan Ahmed, G.Thilak, Rahul.P.S, Steve Mathew John, Naveen.S
Department of Mechatronics Engineering,
Hindusthan College of Engineering and Technology Valley campus,
Pollachi Main Road,
Coimbatore- 641032, India

Abstract
Agri-Inspect Rover (AIR) is a multipurpose and industrial robotic system that can detect diseases in sugarcane plants and monitor safety in industrial and commercial environments. The rover is controlled by a mobile application connected through Bluetooth and it uses ESP32, Arduino Mega and YOLO for real-time image analysis and object detection. Using supervised learning and Convolutional Neural Networks (CNNs), AIR is can be used to classify and can recognize various sugarcane diseases, including Mosaic, Red Rot, Rust, and Yellow Leaf Disease, allowing farmers to detect problems at an early stage and take preventive measures accordingly. The rover can also be used in industries to perform safety checks to ensure that fire extinguishers, emergency exits, and personal protective equipment are in compliance with safety regulations. It also consists of a moisture sensor which provides the soil moisture level, enabling the farmers for precision irrigation. The rover is integrated with a robotic arm mechanism, helping in a wider field of view.

Keywords: **Agri-Inspect Rover; Ai and Robotics-In-Agriculture; Industrial inspection.**

1. INTRODUCTION

Agriculture and industry are two key sectors that critically require continuous checks and monitoring regarding their functionality, as the operational efficiency of the industry or agriculture depends on safety, as well as, other regulatory standards. The standard inspection weakness across the two territories involve patterns of using time consuming manual processes requiring human intervention, a process that is not precise due to the propensity of human errors especially during the big assessments or priority periods. Due to such inspection limitations, advanced systems have developed to achieve improved performance coupled to better accuracy plus better consistency. This rover resolves these limitations using an AI and Internet of Things (IoT) and robotics based Agri-Inspect Rover (AIR), which performs examinations of industrial security and also inspects plant diseases in crops in an adaptable platform. A mobile application which can be isolated from the web based application is created for users to control AIR through manual rover controls and live streaming data and video footage in real time.

P. Kumar and M. Gupta implemented the ESP32-CAM module for real-time video streaming and combined it with the Arduino Mega microcontroller to handle sensor input and robot control, forming the foundation of AIR’s hardware architecture [1]. The system can perform real time object detection via YOLO (You Only Look Once) featuring object detection on safety element including fire extinguishers and emergency exits and safety signs and personal protective equipment [1,2]. AIR can offer good solutions for the real time monitoring operations at factories and industrial environments and warehouses. Machine learning algorithms combined with Convolutional Neural Networks (CNNs) are used by AIR to detect sugarcane leaf conditions for agricultural use. Banerjee [2] demonstrated that AI-powered robotics can significantly streamline such inspections, especially in environments demanding rapid decision-making. Zhang and Wang highlighted the effectiveness of CNN-based plant disease classification, noting its ability to distinguish diseased from healthy crops with high precision. Hence, the system here is trained to detect the four main sugarcane diseases which are Mosaic disease and Red Rot disease and Rust disease and Yellow Leaf Disease [3]. With AIR, farmers can diagnose infected plants early, and take certain interventions, such as fungicide application, or plant isolation, to limit disease spread and protect their crops. Integration of robotic arm in AIR system improves its performance specifically in improving accuracy of detection and reducing false negatives by allowing the camera to move to different leaf section with high accuracy. Precision irrigation for farmers comes with a soil moisture sensor that is part of the rover. AIR’s soil moisture sensors enable real time analysis of the moisture level on the soil and an optimized conditional irrigation leading to lesser water consumption without compromising on the plant growth. Being the device, when water conservation needs arise, it plays an essential part. By doing so, AIR’s mobile application control system creates an equilibrium between human input and automated operations consistent with other self-operating agricultural robots. Design of the system pursues cost efficiency and flexibility and is quite attractive to small or medium farms and to industry sites which have no

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extensive automation systems. The AIR system is a multipurpose instrument that does the consolidation of disease inspection with safety checks and monitoring of environmental conditions in one integrated method of operation. The functionality of this tool is to stream live videos and perform machine learning analysis to improve the efficiency of industrial operations combined with an intuitive interface that makes this operational with current agricultural demands.

2. DESIGN AND DEVELOPMENT

2.1 Hardware

The Agri-Inspect Rover is a combination of different key components that allow the system to perform the industrial inspection with great effectiveness and for precision agriculture. The operation of the Agri-Inspect Rover is centered on the ESP32-CAM microcontroller, which has timestamped transmission capability and image capture functions. It's second microcontroller, Arduino Mega, is the main controller which is managing the motor functions and controlling the motion of the robotic arm for controlled scanning and inspection tasks. The ESP32 camera module is of immense importance as it works to capture high-definition images that are used to detect plant diseases in agricultural applications [4]. A Motor Driver regulates and controls the various motors in the inspection rover and robotic arm, allowing proper positioning and stability of the operation. DC motors are used for the movement of the rover and Servo motors for the arm control [5]. The rover consists of a Soil Moisture Sensor which offers soil moisture level data on the area to be analyzed, which would allow farmers and researchers to make decisions regarding precision irrigation techniques. It is powered by a Lithium-ion Battery, granting long operational time and suitability for large-scale deployment. In addition, it contains a Bluetooth Module for remote control via mobile application, which offers the benefit of ease of operation and the flexibility of wireless management of the rover [6]. Such an assembly enables the Agri-Inspect Rover to be a highly efficient tool in industrial and agricultural use, improving accuracy, steering reductions in manual labor requirements, and aiding productivity. Fig 1 (a), (b), (c), (d) consists of the pictures of the final assembled rover.

Fig.1

(a)

(b)

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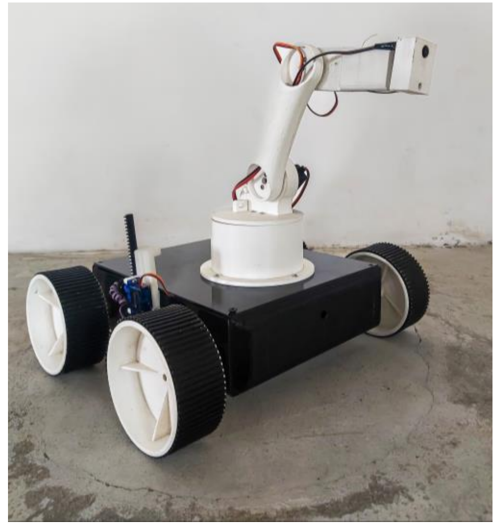
(c)



(d)

2.2 Software and Programming

The software framework of the Agri-Inspect Rover integrates various machine learning algorithms like YOLO for image processing, supervised learning for industrial inspection, and CNN-based machine learning for disease classification. YOLO (You Only Look Once) stands as a highly effective real time object detection algorithm which modifies the way machines interpret visual data. The forward processing of YOLO differs from traditional detection methods because it analyzes complete images instead of using a grid system in single-pass operations. The method provides extremely fast execution speeds with its accuracy-driven detection ability which produces superior results. The algorithm functions by dividing the image into a grid then uses each cell to evaluate object existence before determining specific object positions in the same cell. The system produces multiple bounding boxes together with confidences that rate the object presence likelihood and class likelihoods for object identification. Non-Maximum Suppression (NMS) enables detection quality improvement by eliminating redundant and overlapping boxes to find the optimal prediction outcomes. The system design included features that enable the production of clean results under multiple-object and visually obstructed scenarios.

Among detection systems YOLO provides the best performance while maintaining fast operation. The accuracy assessment of this method uses the mAP (Mean Average Precision) together with the IoU (Intersection over Union) metrics for evaluation. YOLO develops its ability to detect smaller objects and complex interlocking item patterns at each iteration while remaining fast. The YOLO 10 and YOLO 11 releases combine highly efficient network designs and enhanced training algorithms and scene crowding capabilities alongside fewer computational demands. The characteristics of YOLO make it an ideal system for real-time applications such as autonomous navigation and security surveillance and medical diagnostics and retail automation and agricultural monitoring because precision along with quick execution are fundamental requirements for reaching accurate decisions.

The YOLO algorithm is utilized for the detection of various safety equipment like fire extinguishers, emergency exits, personal safety equipment compliance in industrial applications, endowed with image preprocessing techniques including noise reduction, edge detection, and contrast adjustments for improved image quality and subsequent raised accuracy. [7]

A special Convolutional Neural Network (CNN) design, which shows a strong ability for finding sugarcane leaf diseases accurately, is implemented. The model was trained on multiple images from 5 disease classes using field and lighting condition image annotations for optimization. Different convolutional and pooling layers combined with dense layers were used to create the model design to extract complex visual elements corresponding to disease indications.

The model training was executed in a Conda environment using TensorFlow and finished with 50 epochs, each batch treated as 12 items (256×256 resolution input). These data augmentation strategies involving flipping and rotation provided extra value to the generalization performance [8].

Although the model can occasionally misclassify under weak lighting or if objects are fully obstructed, it has stable, broad ranging properties which make it ready for immediate use. Using Arduino Mega, the automated robotic arm and motors carry out the exact operations for fine movement during inspections, while the ESP32 platform enables remote monitoring, streaming image capture, and IoT-based data transfer, therefore making the rover extremely useful for industrial and agricultural purposes.

The Bluetooth module implemented is used in navigation and control to give the users, manual control via a mobile application, resulting in the rover being operated in very dynamic situations and environments. With these software elements combined, the Agri-Inspect Rover performs efficient industrial inspections and automated disease detection, thereby imposing an increase in the productiveness of the process by reducing manual labor and simplified decision-making due to analysis of live data.

3. SYSTEM IMPLEMENTATION

3.1 Industrial Inspection Mode:

The ESP32 camera helps the function that is mainly engaged in industrial inspection by taking live images of safety equipment, which are subjected to image processing using YOLO and supervised learning algorithms that analyze them. Such strategies enhance predictive maintenance and increase the life span of the equipment [9].

3.2 Sugarcane Disease Detection Mode:

The robotic arm efficiently places sugarcane leaf samples in the proper position for photography. CNN-based image processing enables extremely accurate diagnosis of Mosaic alongside Red Rot and Rust and Yellow Leaf diseases in sugarcane plants. Following each identification of plant disease, the system generates recommendations for farmers to implement fast actions which protect their crops from further infections [8].

3.3 Soil Monitoring System:

The Soil Monitoring System relies on real-time moisture sensor to enable precision farming by conducting ongoing measurements of soil condition. The measurements deliver information for checking soil well-being to help farmers determine proper irrigation needs. At the same time, IoT-based monitoring constantly tracks and analyzes soil conditions, thus helping optimize agricultural productivity and sustainability [10].

4. RESULTS AND DISCUSSION

During the evaluation of the test set, the CNN achieved a 95% peak accuracy and a 92.08% Mean Average Precision (mAP) indicating that it can reliably classify different disease patterns (Fig.2). Therefore, the model was able to classify leaves with excellent accuracy.

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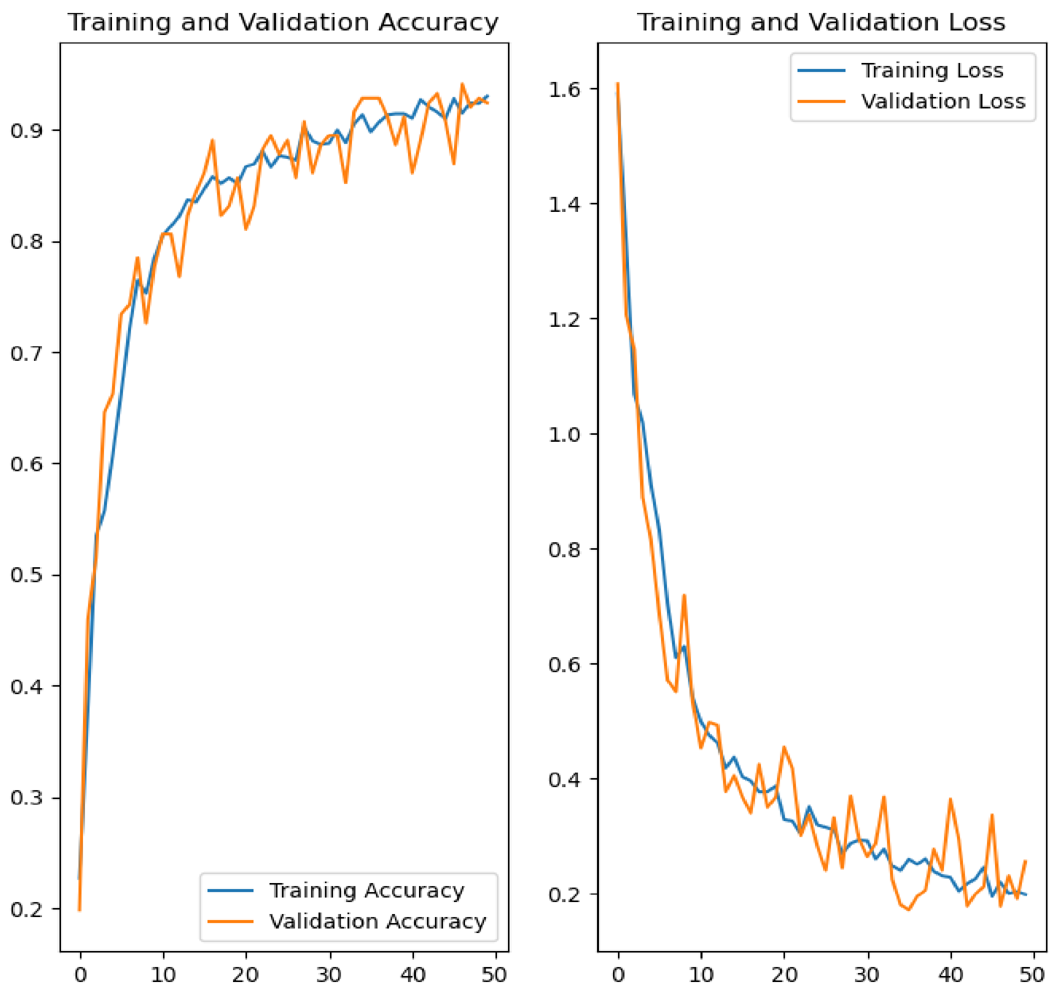

Fig.2

Initial experiments show that CNN-based models and supervised learning may accurately identify plant illnesses and monitor the industrial setting for safety compliance. The system has an improved accuracy in detecting unusual aspects through its combination of YOLO with custom-developed CNN model for enhanced visual feature extraction capabilities. Precision farming in the agriculture sector is made possible by using moisture sensors which enables real-time soil moisture level monitoring.

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Fig. 3.1

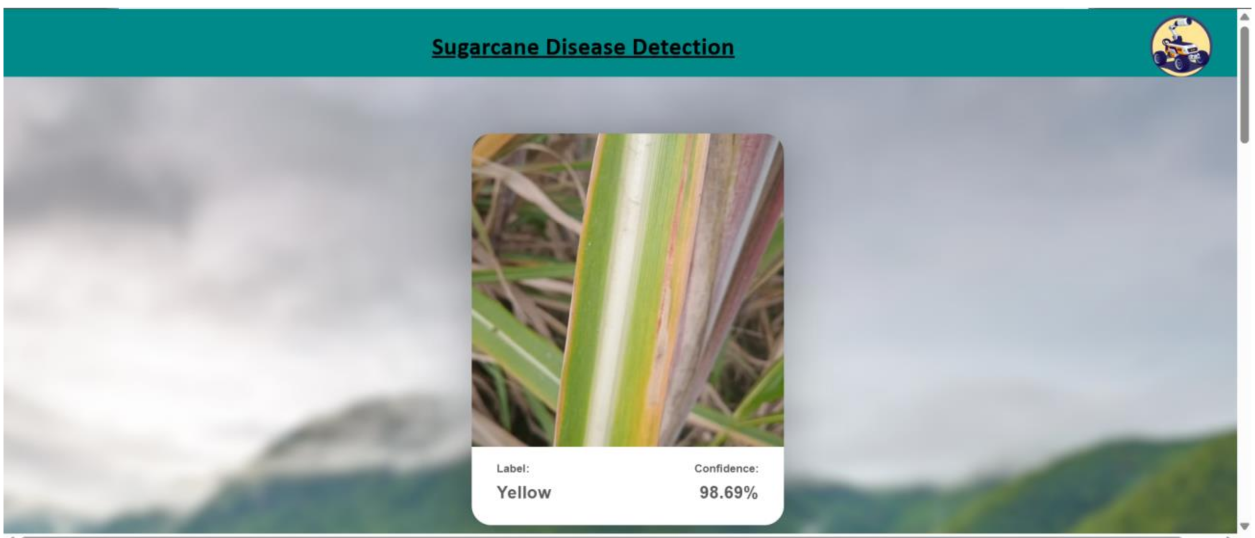

Fig. 3.2

The above Figures 3.1 and 3.2 show us the detected image along with its classification and confidence level. Its classified as Yellow leaf disease. Yellow Leaf disease (YLD) starts by turning the leaf midrib yellow before it leads to growth reduction and decreased sugar content. Sugarcane Yellow Leaf Virus (SCYLV) is the virus responsible for causing yellow leaf disease which aphids normally spread between sugarcane plants. The early stages of this condition frequently go unnoticed in the field despite its critical effect on yield losses. Crop protection against Yellow Leaf disease includes complete removal of infected plants alongside use of healthy seeds and vector insecticide control that uses thiamethoxam. [11]

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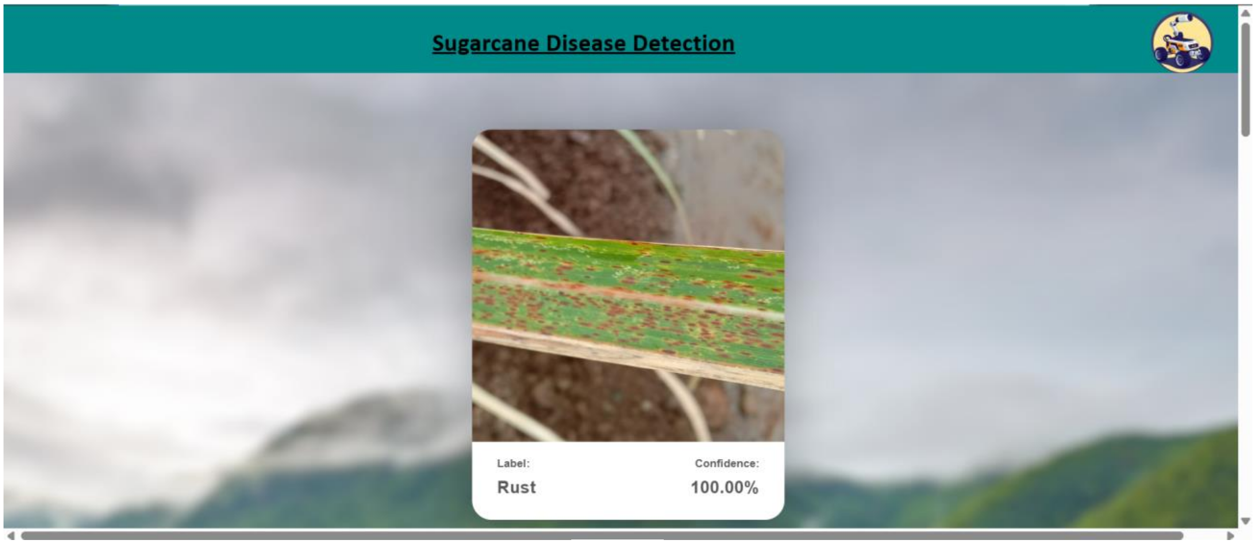

Fig. 4.1

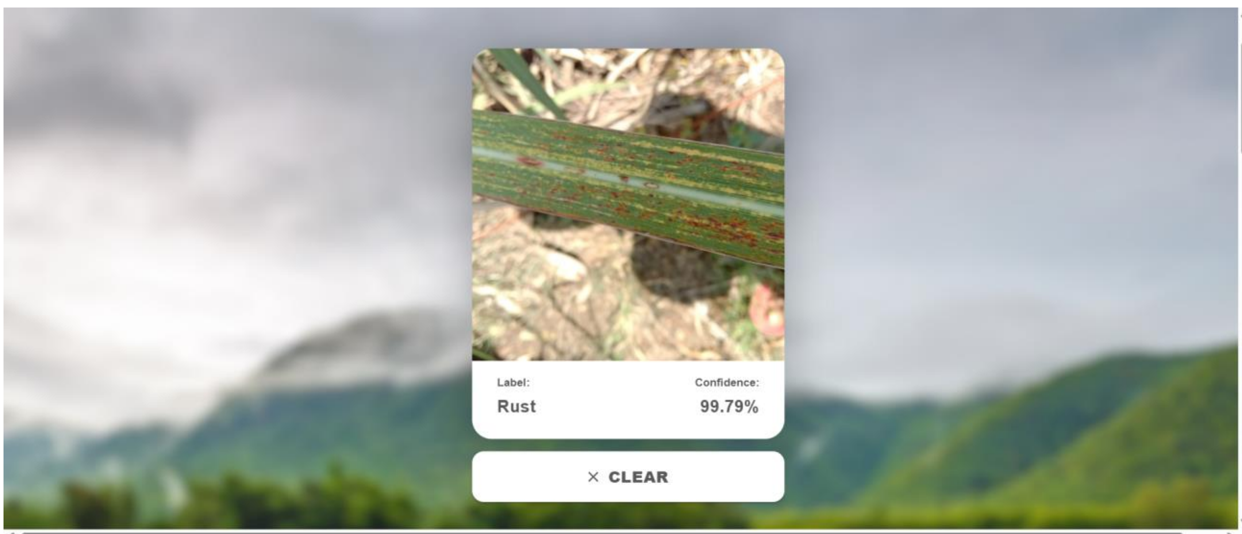

Fig 4.2

Fig 4.1 and 4.2 show the Rust disease in the sugarcane plants. Puccinia melanocephala fungi cause small brownish orange pustules on the leaves resulting in the development of rust disease. Dispersal of air borne spores from these growths allows for rapid dispersal throughout wide areas over a short time interval. Prematurely drying leaves that occur from intense infection result in decreased total plant productivity due to less leaf are a. Early intervention of fungicide (propiconazole) applications is necessary for the effective control of this spread. [12]

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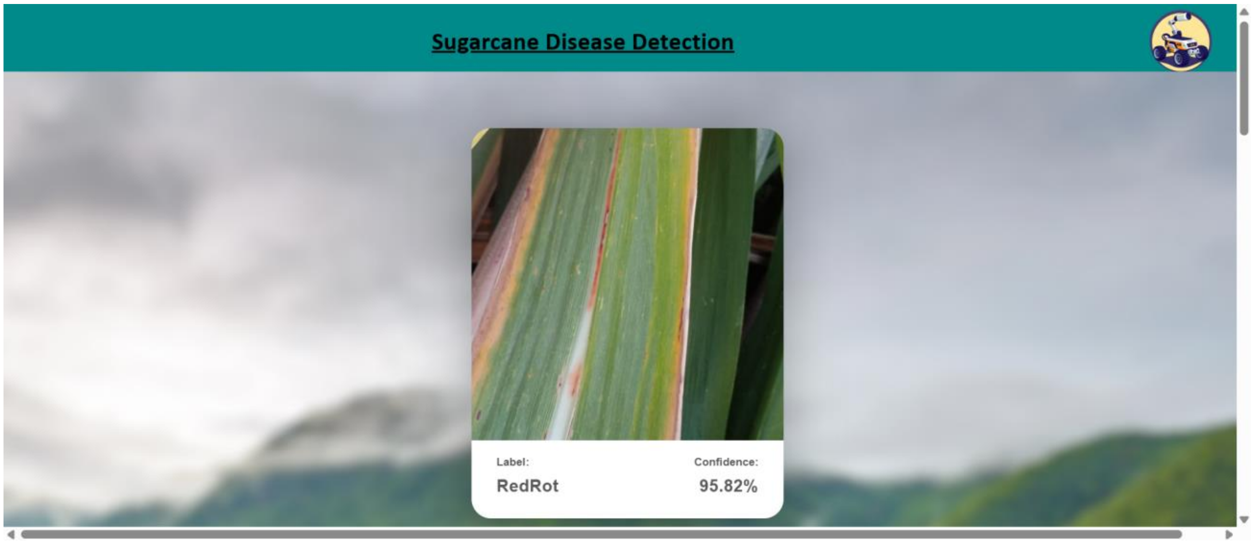

Fig 5.1

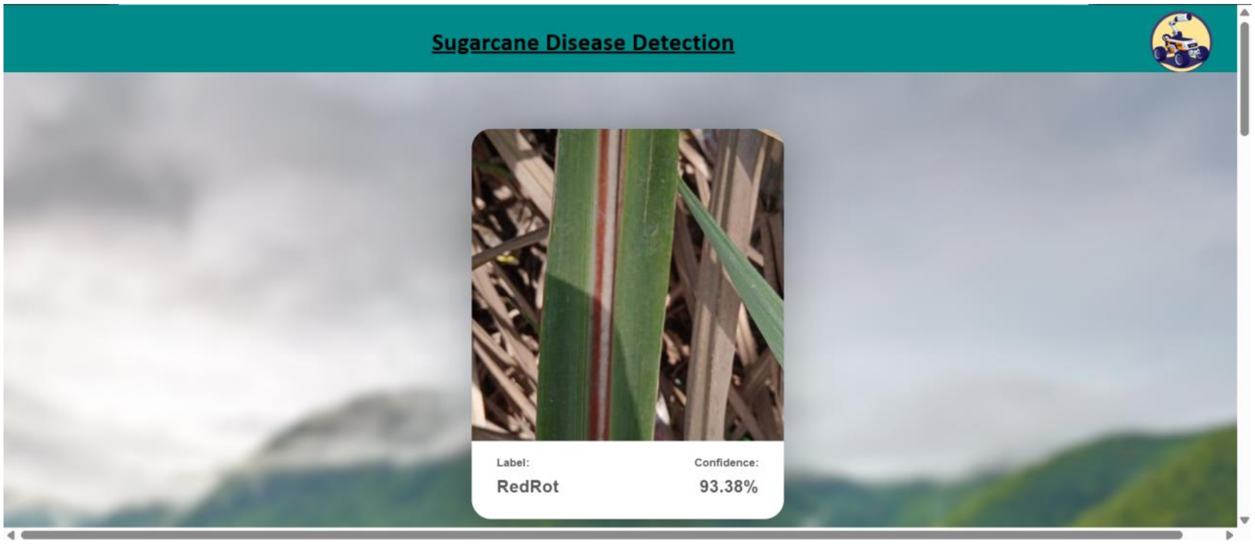

Fig 5.2

The Red Rot disease as shown in the Fig 5.1 and 5.2, arises due to *Colletotrichum falcatum* infections making it the most destructive fungal threat to sugarcane crops. The signs of diseased stalks in sugarcane include drying leaves along with a foul odor and reddish discolored stalks with white stem internal deposits. This disease not only destroys internal plant tissues but also causes restricted growth along with reduced sugar content in the juice. The management of red rot disease in sugarcane production depends on field sanitation practices and early detection methods and resistant plant varieties in addition to fungicide sprays using zincoxyl or carbendazim. [13]

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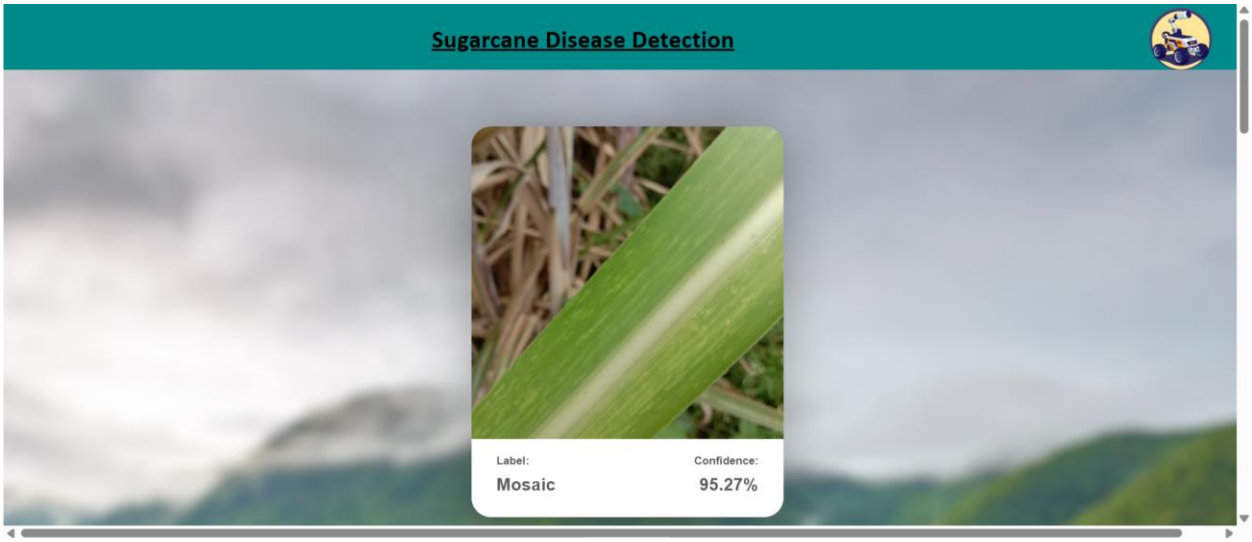

Fig 6.1

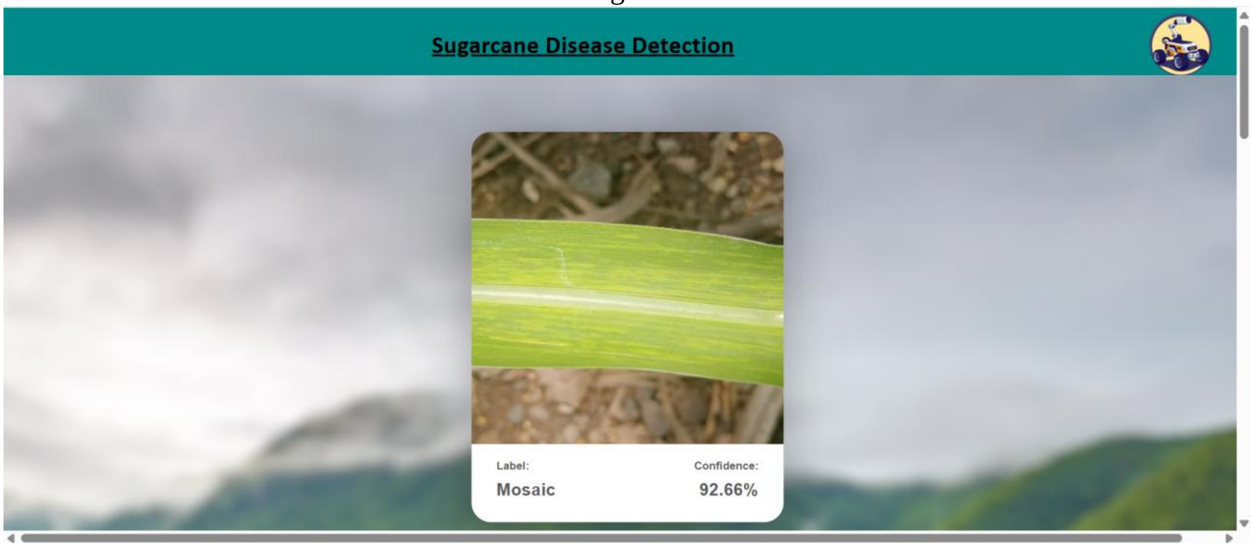

Fig 6.2

The above Figures 6.1 and 6.2 show us the detected image along with its classification and confidence level. The classified image is Mosaic. The Mosaic disease causes the plants to develop light green and dark green streak patterns on the leaf due to the Sugarcane Mosaic Virus (SCMV). In addition to having major yield reductions except for when detected early, photosynthetic processes are disrupted as plant health is damaged. Aphid transmission is the disease's main route of infection among plants and infected seed canes are vectors for transmission. Farmers use two types of strategies to combat mosaic disease; the use of certified disease free planting materials and treatments with neem preparations or chemical insecticides such as imidacloprid. [14]

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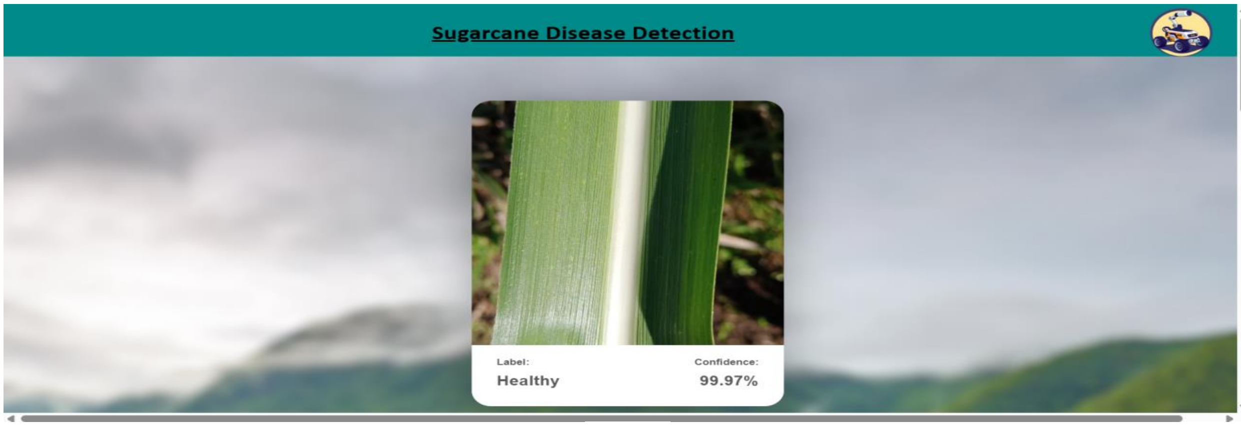

Fig 7.1

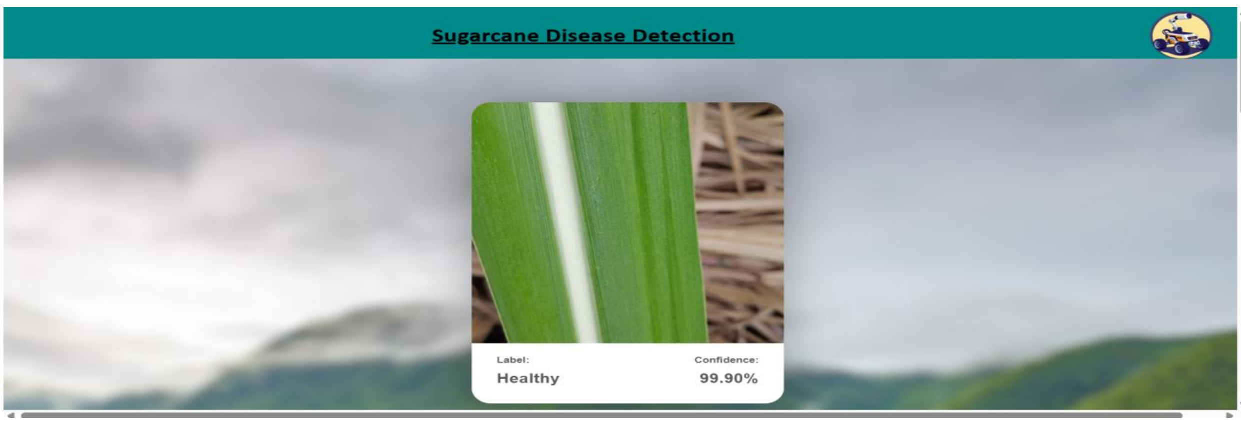

Fig 7.2

The Healthy class (as shown in Fig 7.1 and 7.2) includes sugarcane plants with uniform green foliage, no discoloration, and no visible signs of stress or infection. These images were important for training the CNN to understand what a normal plant looks like, helping it identify even subtle early-stage infections in other classes.

5. CONCLUSION AND FUTURE SCOPE

The Agri-Inspect Rover allows seamless integration of sugarcane disease detection with industrial inspections, making the system efficient and accurate for dual purposes. Combined with an IoT enabled real time monitoring, the rover offers high precision and fast reaction times in the industrial or agricultural fields with the help of YOLO, machine learning based on CNN and IoT enabled real time monitoring. This technology combination enables safety inspection, disease detection and smart farming solutions while reducing the need for manual intervention, and improving total production. By enabling safety inspection, disease detection, and smart farming solutions, this technology combination lowers the need for manual intervention while increasing total production.
However, despite great potential, the rover system is loaded with constraints. The ESP32-CAM module is compact and cheap, but it’s on board processing capacity is very limited for running those complex AI models that require server side instead of on board processing. The camera used for the rover (OV2640) has low resolution which may lead to decreased disease identification precision when lighting or movement conditions change. Open agricultural

fields present challenges to reliable Wi-Fi connectivity for this system. The problem with prolonged operations is that components heat to an unsafe level, and hardware stability is affected because of the power consumption. Since the rover lacks the capability to detect obstacles or plan paths based on GPS, basic movement is a rover's primary function. Future system improvements provide several upcoming changes which will enhance its operational potential even further. The model's functionality for broader agricultural applications will escalate when developers implement multi-crop disease detection abilities for the rover platform. Future rover operations will reach full autonomy after adding GPS modules along with navigation algorithms which allow the device to map specific field regions autonomously. Add ultrasonic or LiDAR sensors which perform obstacle detection to maintain smooth operation of the rover during conditions that include uneven or cluttered terrains. The system achieves easier scalability through the addition of environmental sensors which measure temperature and pH as well as air quality conditions. Additional investments in transformer-based vision system technology will enhance detection capabilities for diseases and anomalies in the field. A solar power addition with extended wireless connectivity will enable the rover to scale up its operations for broad agricultural areas.

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