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A Review of Disease Detection in Leaves Using Image Processing Techniques Based on Thermal Camera

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Abstract: Agriculture is the main source of vegetation to nourish the growing population of India. Plantation is the key source of energy and basic requirement for the prevention of global warming. The defects in the plant caused by several diseases becomes the vital problem for the economic, social and ecological development of the country. Hence, it is an important factor to diagnose the diseases that infect the plant at an earlier stage itself. Plant diseases pose significant threats to agricultural productivity and food security. Early detection and accurate diagnosis of these diseases are crucial for effective disease management. In the process of identification of diseases at an early stage quite number of imaging techniques are available. Some causes damage to the part of the plant considered for the detection of diseases. So, it is important to select the techniques that does not provide any harm to the plantation but at the same time act as an effective tool to identify the diseases with good accuracy. This review paper gives the brief evaluation of recent works carried out in early detection of diseases in plants using thermal imaging process and the analyzation of the imaging techniques by deep learning method. It also gives a detailed description of disease detection by different thermal imaging process and cataloguing technique with the assistance of machine learning mechanisms and image processing tools.

In recent years, image processing techniques based on thermal cameras have emerged as promising tools for non-invasive and efficient detection of plant diseases. This review aims to provide an overview of the application of image processing techniques, specifically those utilizing thermal cameras, for the detection of diseases in leaves. The review covers various aspects, including the principles of thermal imaging, data acquisition, image processing methods, and the challenges associated with disease detection. Furthermore, it discusses the potential of thermal imaging-based disease detection in precision agriculture and its future prospects

Keywords- *Thermal image; Electromagnetic spectrum; Healthy and diseased Leaves.*

1. Introduction

The vital source of food, economic development and employment depends widely on agriculture and its growth. It forms the significant contributor of the world’s economy. India being a developing country, hinge on crop production. Agriculture subsidizes about 18% to the nation’s income and enhances the employment rate to 53% [1]. The crop production depends on the climatic condition, environmental pollution as well as the plant diseases caused by various pathogens like virus, bacteria and fungus. To be precise each pest and the infection caused by it leaves a particular pattern which can ue utilized to identify the Most specifically, each infection and pest condition leaves unique patterns that can be used to anomalies. Thus, recognizing the plant disease needs well known personalities and manpower. The plant diseases seem to be a important threat to human society which may even lead to famines and droughts. In addition to it losses in farming causes the nation to decline in commercial and economic level. Thus, the practice of technology such as machine learning and computer vision aids to wrangle against plant leaf diseases at the earliest [2-4]. The main issues faced by the agriculturist is to identify and analyze the plant leaf diseases. Some of the problems faced by the researchers to solve the detection of plant diseases are[5-7],

- Leaf image quality should be high
- Dataset must be available publicly
- Leaf samples with noisy data
- Subsequent training and testing of the diseased samples by the process of segmentation
- Leaf diseases after detection needs a proper classification
- Environment condition also affect the color of the leaves

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♦ Since more number of diseases are affection the plants parts, the detection becomes difficult

Plant diseases are a major concern in agriculture as they can significantly impact crop yields, quality, and food security. Early detection and accurate diagnosis of these diseases play a crucial role in implementing effective disease management strategies. Traditional methods of disease detection in plants often involve visual inspection, which can be subjective and time-consuming. In recent years, there has been a growing interest in utilizing advanced technologies, such as image processing techniques, for automated and non-invasive disease detection in plants.Among the various image processing techniques, thermal imaging has gained considerable attention for its potential in detecting plant diseases. Thermal cameras capture infrared radiation emitted by objects, including plants, and generate thermal images that represent the surface temperature distribution. Infected plants often exhibit variations in temperature due to physiological and metabolic changes induced by diseases. By analyzing thermal images, it is possible to detect these temperature anomalies and identify diseased areas in plant leaves.

This review focuses on exploring the application of image processing techniques based on thermal cameras for disease detection in leaves. It aims to provide a comprehensive overview of the principles, methodologies, challenges, and potential applications associated with this approach. By analyzing thermal signatures and utilizing advanced image processing algorithms, researchers have made significant progress in automating the disease detection process and improving the accuracy of diagnosis. The use of thermal imaging for disease detection offers several advantages. First, it enables non-destructive and non-contact assessment of plant health, allowing for repeated measurements without causing harm to the plants. Second, it provides a holistic view of the entire leaf surface, capturing spatial variations in temperature that may correspond to specific disease symptoms. Third, thermal imaging can potentially detect diseases even before visible symptoms appear, enabling early intervention and preventive measures.

However, the application of thermal imaging for disease detection in leaves also poses challenges. Factors such as environmental conditions, variations in leaf characteristics, and the complexity of disease symptoms can affect the accuracy and reliability of the detection process. Furthermore, the development of robust image processing algorithms and the integration of thermal imaging with other sensing technologies are areas that require further research and development.Understanding the potential of thermal imaging-based disease detection in leaves is crucial for advancing precision agriculture and sustainable crop management. The ability to detect diseases early and accurately can facilitate targeted interventions, reduce the use of agrochemicals, and minimize crop losses. By reviewing the current state of image processing techniques utilizing thermal cameras for disease detection, this study aims to provide insights into the advancements, challenges, and future prospects in this field.

In the following sections, we will delve into the principles of thermal imaging, data acquisition methods, image processing techniques, challenges, and limitations associated with disease detection, as well as potential applications and future directions in thermal imaging-based plant disease detection.

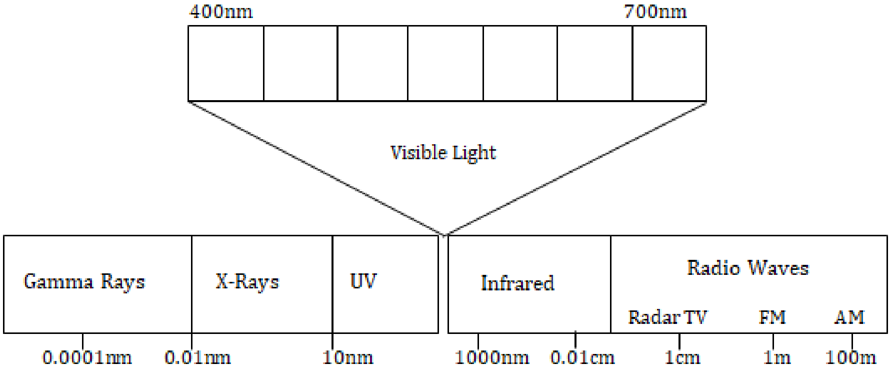

Fig 1 Electromagnetic spectrum

Figure 1 represents the electromagnetic spectrum. The electromagnetic (EM) spectrum is the distribution of range of electromagnetic radiation emitted or absorbed by a particular object. The EM spectrum spreads from the low frequencies used for radio communication to higher frequency that of gamma radiation casing wavelengths from thousands of kilometers down to a fraction of the size of an atom. Infrared imaging is one kind of thermography. The detection of radiation in the infrared (IR) range of the EM spectrum and creating the image of that radiation is called as thermal technology. This is because the IR radiation is produced by all objects due to the variation in their temperatures based on the black body radiation law.

2. Principles of Thermal Imaging

2.1 Basics of Thermal Imaging and its Working Principle

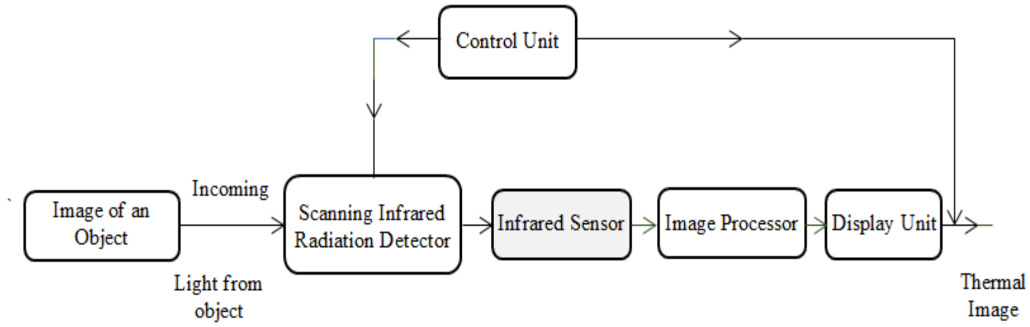

Fig 2 Thermal Imaging principle

Thermal imaging is based on the detection and measurement of infrared radiation emitted by objects. Every object with a temperature above absolute zero (-273.15°C or 0 Kelvin) emits infrared radiation. Thermal cameras, also known as infrared cameras or thermo graphic cameras, capture this radiation and convert it into a visual representation called a thermal image. The working principle of thermal imaging involves the use of a detector, typically a micro bolometer or a thermopile, which detects and measures the infrared radiation emitted by objects in its field of view. The detector converts the radiation into an electrical signal, which is then processed and translated into a thermal image. The resulting image represents the temperature distribution of the objects, with warmer areas appearing as brighter colors and cooler areas as darker colors.

The above figure 2. indicates the basics of thermal imaging camera. In which image from an object is delivered through the incoming light from the object. Then scanning of infrared radiation detector is used to detect the object, which is sensed by infrared sensor. The resultant display unit provides the thermal image from the image processor. The whole system is controlled by the control unit.

2.2 Differentiating Healthy and Diseased Leaves using Thermal Signatures

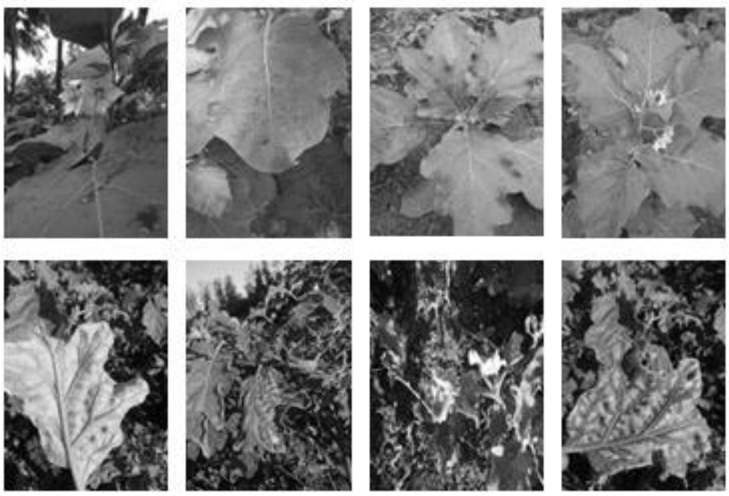

Fig 3 Healthy and Diseased Leaves

One of the key advantages of thermal imaging in disease detection is the ability to differentiate healthy and diseased leaves based on their thermal signatures. When a plant is infected by a pathogen or affected by physiological disorders, various changes occur at the cellular and tissue levels, leading to altered metabolic activities and heat dissipation patterns.

Diseased areas in plant leaves often exhibit temperature variations compared to healthy regions. These temperature anomalies can be attributed to factors such as altered transpiration rates, changes in metabolic activity, localized inflammation, or restricted water and nutrient flow. By analyzing the thermal images, these temperature variations can be identified and mapped, providing valuable insights into the presence and extent of diseases. Figure 3 portrays the image of healthy and diseased leaves.

2.3 Factors Influencing Thermal Signatures of Diseased Leaves

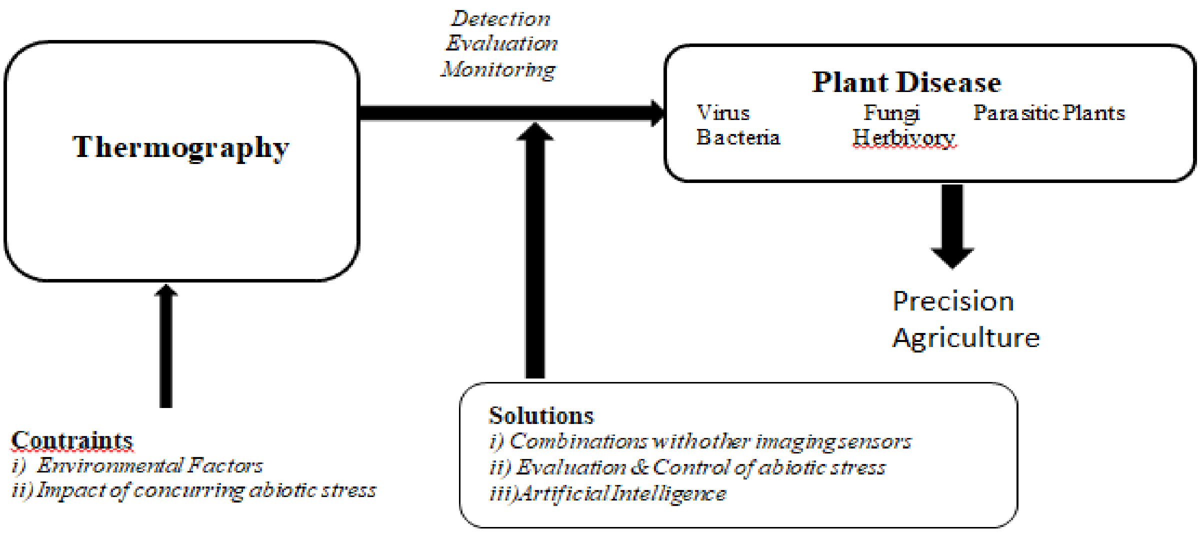

Fig 4 . Factors affecting plant leaves and its determination using thermography

Several factors can influence the thermal signatures of diseased leaves, and understanding these factors is crucial for accurate disease detection. Environmental conditions, such as ambient temperature, humidity, and wind speed, can affect the thermal patterns observed in plants. Additionally, variations in leaf properties, such as thickness, moisture content, and surface characteristics, can impact heat dissipation and the resulting thermal signatures.

The type of disease and its stage of progression can also influence the thermal patterns observed in leaves. Different diseases may exhibit distinct temperature patterns, such as localized hotspots or temperature asymmetry between healthy and diseased regions. Furthermore, the severity and extent of the disease can impact the magnitude of temperature differences between healthy and diseased areas. Figure 4 provides the factors such as constraints found in the plant leaves, plant diseases and solutions that could be achieved using thermography.

In summary, thermal imaging allows for the detection of temperature anomalies in plant leaves, providing valuable insights into the presence and extent of diseases. By considering factors such as environmental conditions, leaf properties, and disease characteristics, researchers can enhance the accuracy and reliability of disease detection using thermal imaging techniques. In the following sections, we will explore the data acquisition process for thermal imaging, as well as the various image processing techniques employed for disease detection in leaves.

3. Data Acquisition for Thermal Imaging in Disease Detection

3.1 Thermal Cameras and Sensor Considerations

The selection of an appropriate thermal camera is crucial for obtaining high-quality thermal images for disease detection. Different factors need to be considered, such as the camera's spatial resolution, thermal sensitivity, spectral range, and frame rate. Higher spatial resolution allows for capturing finer details, while greater thermal sensitivity enables the detection of subtle temperature variations.The spectral range of the thermal camera should align with the infrared wavelengths emitted by the objects of interest. Moreover, the frame rate determines the speed at which the camera captures images, which can be important when monitoring dynamic changes in leaf temperatures.

3.2 Image Acquisition Setup and Protocols

To ensure accurate and consistent data acquisition, proper setup and protocols are essential. Factors such as lighting conditions, distance between the camera and the leaves, and stability of the setup should be carefully considered.Ideally, the imaging setup should minimize external factors that could interfere with temperature measurements, such as direct sunlight, wind, or nearby heat sources. Calibration procedures, including using reference temperature sources, can further enhance the accuracy of the acquired thermal images.It is important to establish standardized protocols for image acquisition, including the positioning and orientation of the leaves, the duration of image capture, and the number of replicates. Consistency in these protocols facilitates reliable comparisons between images and ensures repeatability in subsequent experiments.

4. Image Processing Techniques for Disease Detection

4.1 Image Pre-processing

Image pre-processing techniques are employed to enhance the quality of thermal images and remove unwanted noise or artifacts. These techniques may include image filtering, image denoising, and image enhancement methods. Pre-processing plays a crucial role in improving the accuracy of subsequent disease detection algorithms.

4.2 Feature Extraction and Selection

Feature extraction involves identifying relevant characteristics or patterns from the thermal images that can discriminate between healthy and diseased leaves. Various image processing algorithms can be utilized to extract features such as temperature histograms, texture descriptors, or spatial distribution patterns of temperature variations.Feature selection techniques aim to identify the most informative features that contribute significantly to disease discrimination. This helps reduce computational complexity and enhance the performance of subsequent classification or detection algorithms.

4.3 Classification and Disease Detection

Classification algorithms are employed to classify thermal images into healthy and diseased categories based on the extracted features. Machine learning techniques, such as support vector machines (SVM), random forests, or convolutional neural networks (CNN), can be utilized for this purpose.The classification models are trained using a dataset comprising labeled thermal images of healthy and diseased leaves. The trained models can then be applied to classify new thermal images and identify the presence of diseases.

5. Challenges and Future Directions

5.1 Variability in Environmental Conditions

Environmental conditions can introduce variability in thermal patterns, making disease detection more challenging. Factors such as varying ambient temperature, humidity, or wind can influence temperature measurements and require careful consideration during data analysis.

5.2 Robustness and Generalization

Developing robust disease detection algorithms that can generalize across different plant species, disease types, and environmental conditions is a critical research challenge. The algorithms should be adaptable to varying leaf properties, disease severities, and growth stages to ensure accurate and reliable results.

5.3 Integration with Other Sensing Technologies

Combining thermal imaging with other sensing technologies, such as hyperspectral imaging or fluorescence imaging, can provide a more comprehensive assessment of plant health. Integration of multiple data modalities can enhance disease detection accuracy and improve the understanding of disease progression mechanisms.

5.4 Real-Time Monitoring and Automation

Advancements in image processing algorithms and hardware technology are enabling real-time disease monitoring and automated systems for disease detection. Developing efficient and scalable solutions that can provide immediate feedback to farmers or stakeholders is crucial for timely intervention and effective disease management.

Recent works

The tabular column provides the different imaging processing technique, the thermal imaging process utilized by different researchers and the accuracy determined by employing the techniques.

SNO	Reference	Image Processing Technique	Thermal Image Process	Accuracy
1	8	Convolutional Neural Network	Portable Thermal Camera	98.55%
2	9	Matlab programming language	Digital Thermal Camera	92.8%
3	10	CNN pretrained with VGG16 and MSVM	RGB Sensor	99.4%
4	11	CNN	RGB Sensor	90.3%
5	12	CNN and RNN	Hyper spectral Imaging	75&74.3%
6	13	VGG 16, Inception V4,ResNet,DenseNets	RGB Sensor	99.75%

7	14	SIFT Encoding and CNN pretrained with ResNet	RGB Sensor	90%
8	15	DCNN pretrained with ResNet	RGB Sensor	98.14%
9	16	CNN pretrained with AlexNet,GoogleNet Inception v3,ResNet-50,ResNet-101 and SqueezeNet	RGB sensor(Data from plant Village)	98.96%
10	17	CNN	RGB Sensor	95.82%
11	18	PD2SE-Net based on CNN and ResNet	RGB sensor (datasets from AI Challenger Global AI Contest)	99%
12	19	CNNA	smartphones	95.24%
13	20	CNN	Hyperspectral imaging	85%
14	21	CNN	RGB sensor	99.4%
15	22	GAN	Hyperspectral imaging	96.25%
16	23	GAN,VGG16	RGB sensor	90%
17	24	KNN	Thermal camera	89.4%
18	25	SVM	Thermal camera	92.75%
19	26	SVN	High resolution camera	100%
20	27	ANN	Thermal Camera	94.34%

6. Materials and Methods

The following materials and methodology are adapted for the disease detection in leaves at an early stage without affecting the entire plant. This sort of identification is also called as non-destructive testing meaning a valued technique used by many researchers to appraise the properties of a material, component, structure or system without causing any damage to the sample considered for analysis. Figure 5. Provides the block diagram of the steps involved in thermal imaging technique.

Step -1: Sample (Plant leaf image both healthy and infected leaves)

Basically the plant leaf Images were split into 10 different classes, in which one class is healthy and the other nine are unhealthy (such as early blight, mosaic virus, leaf mold, target spot, septoria leaf spot, late bright mold, two-spotted spider mite, and yellow leaf curl virus, bacterial spot), and nine unhealthy classes are categorized into five subgroups (namely- mold, viral, fungal, bacterial, and mite disease) The leaf disease sorting is a process for assigning diseases into categories based on their properties, like shape, colour and texture.

Step-2: Image generation Process

Computer- generated imagery CGI also identified as Image generation, is a collection of practices designed to make the most accurate image likely within the accessible computer hardware, along with the resources of time, skillset and funding.Image Generation is considered as a sub-class of Computer Vision engrossed on producing images by means of deep learning or complex Artificial Intelligence methods. Together these two methods rely on the usage of database of text descriptions of the images which helps as input to function.

Step-3: IR image using thermal Camera

The method of altering infrared (IR) radiation (heat) into visible images is called as Thermal imaging. This process illustrates the spatial distribution of temperature differences in a screen, which is observed by a thermal camera.Infrared or Thermal imaging technique is a process that detect systems using sensors to collect radiation in the infrared region of the electromagnetic spectrum. A thermal camera perceives the thermal heat or energy released by the sample being detected and changes it into an electronic signal. The observed signal is then sort out to deliver an image.

Simple steps to develop an innovative project using Thermal camera?

First confirm whether the Focal Length values and are properly set, then go to the menu bar, in that click Project> Next move on to image Properties Editor in which select the Camera Model then click the Edit button. Then come to the processing bar and click the Start button to start the processing.

Step-4: Information Analysis

The step involved in data analysis includes collecting all the data's, processing it, investigating the data, and applying it to determine the patterns and additional insights.

The method of Data Analysis involves the following steps namely

(i) inspecting,

(ii) cleansing,

(iii) transforming, and

(iv) modeling data

The above procedures are used for gathering with the goal of discovering valuable information along with enlightening conclusions and sustaining the decision making. It finds its application in many interdisciplinary fields such as Neural Networks, Pattern Recognition, Artificial Intelligence, etc…

Step-5: Identification of Infected portion

To identify the infected portion of the plant leaves optical techniques like multi- and hyperspectral sensors, thermography, RGB imaging have confirmed their probable in mechanized, objective, and reproducible detection systems for the determination and quantification of plant diseases at the earliest.

Step-6: Image Processing

The manipulation of digital images through the use of computer algorithms is known as Digital Image processing technique. It finds its importance in vital preprocessing step for various applications, such as object detection, image compression, and face recognition.To improve an existing image the image processing is completed and significant information's are gathered from it. These preprocessing techniques vividly enhance the performance of a model in Deep Learning-based Computer Vision applications.

Step-7: Deep learning Algorithm

Image Processing technique uses deep learning network known as CNN (Convolutional Neural Networks) to study the models that occur naturally in photos. Then this technique is capable to promote a new data to be processed by the usage of Imagenet, which is the biggest data bases among the well-known data base system consisting of labeled images. CNN is a prevailing algorithm for image processing. Hence for the automated processing images, the above algorithm is known to be the best one. Most researchers use these algorithms for the purpose of identifying the objects in an image. The images are nothing but the data of RGB combination. Various other deep learning model also exist such as restricted Boltzmann machine model, sparse model, etc. Such model are different in feature extraction but commonly similar in image recognition and classification.

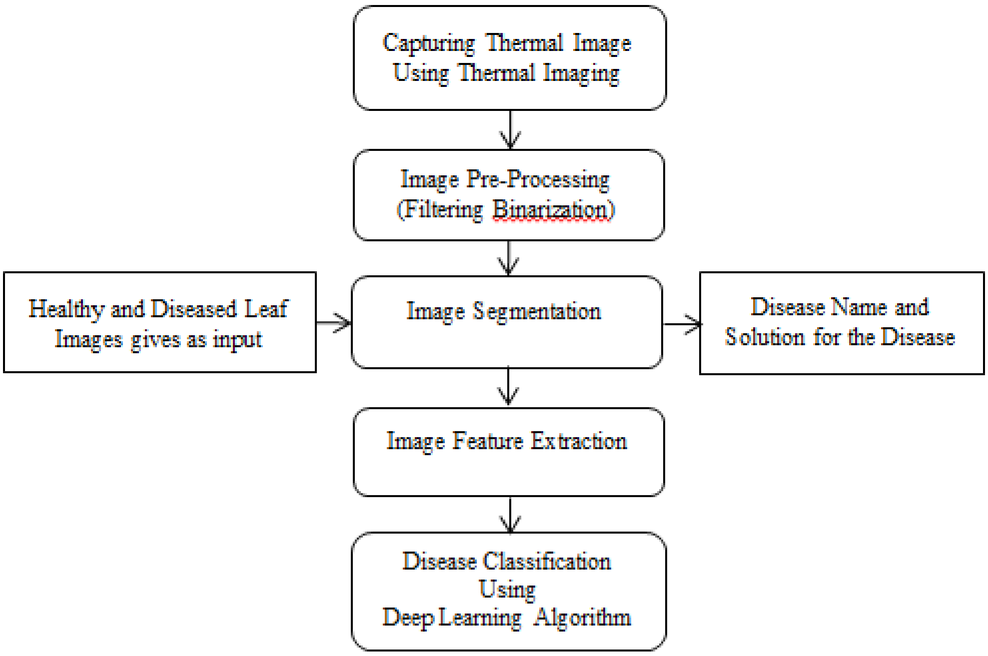

Fig 5 The Setup of thermal Imaging technique

Detection of Diseased leaves

The detection of the diseased leaves is done using image processing algorithm. These algorithms are improved to identify the plant leaf disease recognizing the colour feature of in the particular area of leaf. Certain algorithm namely K mean is utilized for colour segmentation and Gray level co-occurrence matrix (GLCM), that portrays the texture of an image by manipulating how often pairs of pixel with specific values and in a specified spatial relationship occur in an image is meant for disease classification. Vision based plant leaf disease detection displayed effective result and hopeful performance. The step by step procedure for plant leaf disease identification involves image acquisition, image pre-processing, image segmentation, feature extraction and classification.

Capturing of Thermal images and analysis

The capturing of thermal images using a digital camera and its analysis is given in fig. 1. The steps involved in the analysis are given below:

- RGB image acquisition
- Convert the input image from RGB to HSV format.
- Hiding the green-pixels
- Elimination of masked green pixels
- Segment the components
- Attain the suitable segments
- Computing the features using color-co-occurrence methodology
- Estimation of texture statistics

RGB, HSV, YIQ and Dithered Images is used for feature extraction. But the most utilized form of feature extraction is got from RGB image. The segmentation in digital photographs of plant leaves forms the new automatic method for better understanding of the disease symptoms. From this methodology, one can mention the disease for different plant species and the classification of the disease was possible in this structure. This imaging technique has helped the researchers and agriculturist to identify and detect the diseases in plants at an early stage and improve the economic level of the country.

7. Conclusion

This review paper gives a detailed study on the detection of plant leaf diseases using modern technological model and tool namely machine learning algorithm and thermal imaging process. The need of the latest technology for agriculturist is briefly discussed. The accuracy obtained from different techniques is also summarized to obtain quite good knowledge on the upgraded technology. The thermal imaging setup and the steps involved in the dataset collection and analysis of the plant diseases would help the researchers to carry out the technical processing in a simple and better way. The thermal imaging process along with the image processing technique helps the agriculturist in the earliest to detect and identify the infected plant parts and paves the way for immediate cure.

Disease detection in leaves using thermal imaging and image processing techniques holds significant potential for enhancing plant health monitoring and disease management strategies. The ability to detect temperature anomalies and identify diseased regions in leaves can aid in early intervention, enabling timely and targeted treatments and minimizing crop losses.

In this review, we have discussed the principles of thermal imaging, including the basics of thermal cameras and the differentiation of healthy and diseased leaves based on their thermal signatures. We have also explored the factors that influence thermal signatures in diseased leaves, such as environmental conditions, leaf properties, and disease characteristics.Additionally, we have highlighted the importance of data acquisition protocols for obtaining accurate and reliable thermal images. Proper selection of thermal cameras, setup considerations, and standardized protocols contribute to consistent and high-quality data for subsequent analysis.

Furthermore, we have delved into image processing techniques, including pre-processing, feature extraction and selection, and classification algorithms for disease detection. These techniques allow for the extraction of relevant features from thermal images and the classification of leaves as healthy or diseased.However, there are challenges that need to be addressed for further advancements in the field. Variability in environmental conditions, ensuring robustness and generalization of disease detection algorithms, integration with other sensing technologies, and the development of real-time monitoring and automation systems are areas that require continued research and innovation.

In conclusion, the use of thermal imaging and image processing techniques for disease detection in leaves has the potential to revolutionize plant health monitoring and disease management practices. By accurately identifying and quantifying diseases in their early stages, farmers and researchers can implement targeted interventions, optimize resource utilization, and improve overall crop productivity. Continued research and collaborations are essential to overcoming challenges and realizing the full potential of this technology, contributing to sustainable and resilient agriculture.

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