Application of thermal imaging for plant disease detection

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Abstract. The effects of plant diseases on agricultural production worldwide contribute to significant economic and post-harvest losses. To maintain the sustainability of the farming sector, the early detection of plant and pathogens is essential. Non-destructive methods for tracking the health conditions of plants in real-time applications are among the most realistic and feasible in this regard. Owing to non-destructive methods and non-contact measuring devices, thermal imaging advancement has become an essential technique in all fields. Thermal imaging operates by emitting infrared irradiation in all materials. The method, therefore, uses radiation to create an image of the thermal distribution of the body surface. This approach is useful for all areas where the difference in temperature helps in the area/object analyses. Therefore, this paper briefly explores the potential for thermal imaging to be used to detect plant disease in the control area and the field.

1. Introduction

The global production of agricultural food products is strongly influenced by plant diseases, which can be a significant cause of losses in terms of quantity, quality, and economy. Laboratory assessments and visual investigations are the most common early detection methods used to reduce losses from plant diseases. However, it is labour-intensive and time-consuming. Many researchers have adopted non-invasive methods for resolving conventional method restrictions, as reported in recent findings [1] and [2]. Furthermore, according to a study [3], the physiological parameters of plants could be measured by imaging techniques in a non-destructive way and without direct contact with the plant. Throughout plant-pathogenic infection, diseased tissue's physiological conditions, such as transpiration transformation, photosynthesis, salicylic acid (SA), stomatal conductivity and even death of the cell, are affected. This indicates the importance of early detection of plant diseases as it dramatically affects plant physiology with devastating effects [4].

Plant diseases can generally spread through three main ways: trade (migrated movement), environmental forces (weather and windborne), and vector-borne (pathogens) [5-7]. The farmers need to detect the diseases early to control its spread. The methods of prevention and treatment depend on the
type of crop and the effects of certain types of disease [8]. In order to answer fundamental issues in plant stress biology, it is necessary to analyse disease and symptoms, the severity and other relevant information. The availability of data from disease analysis can be used as a foundation for rapid management decisions. Therefore, the identification of disease will help improve the quality of a specific entity's activity to enhance and strengthen the management of plantations.

Lack of traditional methods has led to the development of modern technology. For instance, machine vision and remote sensing are utilised for plant disease detection and identification. New innovations provide the right set of circumstances for better reliability, precision, and consistency in determining plant diseases. The invisible radiation pattern on the plant leaves are turned into visible images through the method of thermal remote sensing [9], and these images are referred to as thermal images. Thermal images can be obtained through the use of a handheld camera or convenient thermal sensors that are attached to an unmanned aerial vehicle (UAV) or satellite.

Therefore, this study aimed to fill in the knowledge gaps mainly related to current thermal imaging techniques which are widely used to detect plant diseases in a control area and the field area.

2. Thermal imaging

Thermal imagery is primarily about converting images produced by the thermal wavelength radiation emitted by the cooler bodies to visible wavelength images [10]. More generally, the term thermal imaging may also refer to systems where visual images are not produced, but a thermal image is collected and processed entirely electronically to measure some defined parameters or to sense the object's presence. According to [11], the usefulness of thermal is due to four main aspects; i) It is an entirely passive technique, which does not require external sources of light to enable day and night operation and convert sensing. ii) It is suitable for detecting hot or cold places and different areas of emissivity. iii) Thermal radiation can easily penetrate fog and smoke than visible radiation, allowing the identification of visually blurred objects. iv) It is a method for remote sensing in real-time.

In the last few years, there have been rapid advances in thermal imaging. The current commercial system availability has enabled thermal imaging techniques to be applied to a wide range of fields. Thermal imaging is commonly used in a variety of areas, including agricultural, soil moisture studies, industrial, veterinary, medical, and military [12]. The surface temperature of any object can be mapped to a high resolution by using this method. Nevertheless, several variables, such as heat, wind, fog, and rain, affect the efficiency of the thermal imaging system when measuring outdoor surface temperature [13].

The principle of thermal imaging is based on the fact that infrared radiation emitted by all materials above absolute zero at a temperature of -273°C [14]. The infrared is an invisible light band in the wavelength range 0.75 to 100 µm on the electromagnetic spectrum. The infrared region comprises the near-infrared regions (0.75 to 2.5 µm), the shorter-infrared regions (1.4–3 µm), the medium-infrared regions (13 to 8 µm) and the long-wave infrared regions (higher than 8 µm) and extreme infrared regions (15 to 100 µm) [15]. This infrared subdivision is based on transmission windows where the atmosphere is mostly transparent to infrared radiation. Thermal imaging systems can detect short-wave to long-wave infrared radiation. The radiation emissions from an object depend on its temperature and emissivity. The infrared energy emitted from a measured object is transformed into an electric signal in thermal cameras through infrared detectors. It appears as a colour or monochrome thermal image in which the colour shift reflects the thermal variation of the objects [16]. The main benefit of thermal imaging is a non-invasive, contactless and straightforward tool for measuring the distribution of temperatures within a short period.

3. Thermal imaging techniques for detection of plant diseases

In agriculture, plant diseases have impacted crop development and caused significant economic losses. For instance, pathogen-related crop losses are expected to lead to the annual loss of revenue of about $33 billion in the U.S. [17]. Farmers are expected to be able to reduce the deficit about $11 million by removing 20% of soybean rust, a prevalent disease [18] in its cultivation. Research has shown that
spatial and temporal trends in crop diseases can be analysed and monitored at various stages of disease growth through thermal remote sensors (Table 1).

Various researchers have shown that thermal infrared is a useful tool for detecting pre-symptomatic diseases and pathogens in plants, [19] as well as reporting changes in local temperature due to pathogenic infections or defence mechanisms for the interaction of tobacco plant viruses. Besides, thermal infrared can be used to trace leaf spot diseases in sugar beet at the beginning of growth prior to damage occurs.

Stoll et al. [20] investigated the ability of thermal technique in pathogen detection on grapevine with sufficient irrigation or non-irrigation. Greenhouse experiments have been carried out to track leaf temperature in areas of pathogen infection and non-infection. Thermal image analysis showed that pathogen growth at the point of infection in irrigated vines increased the temperature of the leaf. In contrast, unirrigated vines showed a lower temperature at the inoculation spots. Local pathogen infections can be detected by infrared thermography before visual symptoms appear. Thermal sensing can have important applications for disease prediction models with high sensitivity towards temporal and spatial changes in the plant temperature.

**Table 1. Plant diseases detection by thermal sensors.**

| Type of plant           | Type of sensor       | Type of disease          | Geographical scale          | References |
|------------------------|----------------------|--------------------------|----------------------------|------------|
| Sugar Beet & Tobacco plants | Portable Thermal camera | Leaf spot               | Plant growth chamber        | [19]       |
| Grape                  | Portable Thermal camera | Downy mildew            | Greenhouse                  | [20]       |
| Apple                  | Portable Thermal camera | Apple scab              | Greenhouse                  | [21]       |
| Rose                   | Portable Thermal camera | Powdery mildew and gray-mold | Plant growth chamber        | [22]       |
| Cucumber               | Portable Thermal camera | Downy mildew            | Greenhouse                  | [23] - [24] |
| Plant     | Portable Thermal camera | Disease/Condition                       | Location                                      | Reference |
|-----------|--------------------------|-----------------------------------------|-----------------------------------------------|-----------|
| Sweetpotato | Sweet potato virus       | Plant growth chamber                    | [25]                                          |           |
| Winter wheat | Leaf rust                | Plant growth chamber                    | [26]                                          |           |
| Peanut     | Early leaf spot and late leaf spot | Peanut fields, Egypt                     | [27]                                          |           |
| Oil palm   | Basal Stem Rot (BSR)     | Oil palm plantation, Perak              | [28]                                          |           |
| Tea        | Leaf lesion              | Jiangsu Tea Expo Park, China            | [29]                                          |           |

Subsequently, Oerke et al. [21] utilised infrared thermography and defined the range in the temperature of infected leaves as they measured scab disease on apple leaves. The maximum temperature difference (MTD) was found to increase with the growth of scab and to be closely related to the size of infection areas. The MTD decreased in later stages due to leaf senescence. Nevertheless, the area of the leaf with increased perspiration was higher than the scab lesions, and the percentage was reduced from > 70 per cent in the early stage to < 20 per cent in mature lesions. Therefore, MTD may not just be used for the differentiation of diseased and non-diseased leaves, but also for the quantification of diseases, by all stages of scab development. The thermography method seems to be appropriate for detecting and quantifying infections of apple scab, but the method also needs to be tested on the fieldwork.

This study [22] examined the ability of thermal imaging for the pre signs of fungal diseases on rose plants (*Rosa hybrida L*). Two experiments have investigated the effects of powdery mildew and gray-mold diseases. A selection of features was performed, choosing the best extracted thermal characteristics with the highest linguistic hedge values. Results of this work showed that pre-symptomatic identification of powdery mildew and gray-mold diseases is achievable. The best prediction rates were 69% and 80% (on the second day after inoculation) for the identification of pre-symptomatic appearance of mildew and gray matter.

Berdugo et al. [23] and Oerke et al. [24] detected *Pseudoperonospora cubensis* (*P. cubensis*), which causes downy mildew in the cucumber using thermal imaging. The maximum temperature difference (MTD) in the foliage and canopy was considered adequate in controlled conditions for differentiation between infected and non-infected tissue. For healthy and infected leaves, the transpiration rate and the leaven temperature were identical in unregulated conditions, but for infected tissues, the transpiration rate was higher, depending on the symptoms of the disease. In this study, digital infrared thermography was a highly effective means of analysing the spatial effects of *P. cubensis* on the transpiration of the cucumber leaves in controlled conditions.
Wang et al. [25] conducted a study on virus diseases caused by co-infection in the production of sweet potatoes (Ipomoea batatas L). The photosynthetic output of chlorophyll fluorescence (ChlF) imaging and thermal infrared leaf thermography (TIR) imaging between sweet potatoes has been quantified by monitoring the physiological and morphological effects of infection in sweet potatoes over 29 days. The variations among treatments recorded in ChlF and TIR imagery were also correlated with virus aggregation and distribution of sweet potato. This research initially validated the application of ChlF and TIR image systems to distinguish the extent of sweet potato-related SPFMV and SPCSV virus diseases.

Based on the data obtained through this study [26], two conclusions have been drawn: (i) thermography may be used to distinguish contaminated wheat plants without a symptomatic appearance from healthy plants at 6 dpi at least four days before apparent symptoms occur and (ii) over the entire period observed, the average temperature and MTD of healthy wheat blades have not changed significantly. The average temperature, however, showed a steady downward trend, and with an increasing number of days after inoculation, the MTD of inoculated wheat slowly increased. The study shows that the early detection of wheat stripe rust is achievable by infrared thermal imaging, which is a trusted tool for fast and non-disruptive detection of wheat stripe rust. This study is, therefore, of significant importance for the early diagnosis and monitoring of plant diseases.

In this study [27], image spectroscopy and thermal imagery were used for peanut leaf spot identification. Thermal assessments were divided into two sets: one covering the entire canopy and the other one based on a single plant. In the first sets, thermal infrared tests in the diseased region revealed a higher radiance relative to the healthy area. The diminished root absorption efficiency in infected plants, which was more apparent during the hottest hours of the day when the water requirement in the plant was higher, may lead to such thermal behaviour. The second sets of assessments were carried out on single plants, which were monitored during the day for thermal activity and accurate IR responses. The data showed that the temperature of the diseased plant was 2.2°C higher than that of the healthy plants. The difference in temperature permitted discrimination between infected and healthy leaves before visible necrosis on the leaves.

This paper [28] has analysed the capability use of thermal imagery in detecting BSR-infected on an oil palm tree. Healthy and BSR-infected trees were able to be differentiated based on the result of the analysis of the thermal images by extracting features using Principal Component Analysis (PCA) method. Healthy and BSR-infected trees can be differentiated based on the trendline of the data. Results from Support Vector Machine (SVM) has better and higher accuracy compared to the k-nearest neighbour (kNN) with 89.2% accuracy during training and 84.4% during testing. It can be determined that non-infected and BSR-infected trees can be differentiated using thermal images. In future work, the method can be expended to classify different severity levels of infection.

This paper [29] researched the detection of tea diseases based on rapid thermal image classification. A grayscale canopy image dispersion curve is designed to create a classifier to quickly identify the disease image, which helps extend the working life of the UAV and significantly increases detection accurateness. Among the lesion counting algorithm and counting done by human observation, a determination coefficient R2 of 0.97 is obtained. This study offers guidance on observing the tea gardens condition with airborne thermal imaging.

4. Conclusion

This study addressed the current state of the art and the possible use of the thermal technique for the identification of plant diseases briefly in control and field area. Overall, these techniques can detect crop diseases and classify them with more than 70% accuracy with successful applications. The thermal imagery has considerable potential in future, due to its high sensitivity as a sensor technology for agricultural precision. However, it is suggested that enhancements in these techniques are required for accurate identification of plant diseases in-situ investigations.
References

[1] Aryalekshmi BN, Biradar RC, Mohammed Ahamed J. Thermal Imaging Techniques in Agricultural Applications. *International Journal of Innovative Technology and Exploring Engineering*. October 2019; 8(12):2162-68

[2] Khanal S, Fulton J, Shearer S. An overview of current and potential applications of thermal remote sensing in precision agriculture. *Computers and Electronics in Agriculture*. 2017 Jun 15;139:22-32.

[3] Xu H, Zhu S, Ying Y, Jiang H. Early detection of plant disease using infrared thermal imaging. *Optics for Natural Resources, Agriculture, and Foods* 2006 Oct 23 (Vol. 6381, p. 638110). International Society for Optics and Photonics.

[4] Omran ES. Early sensing of peanut leaf spot using spectroscopy and thermal imaging. *Archives of Agronomy and Soil Science*. 2017 Jun 7;63(7):883-96.

[5] Holl G. Climate change and extreme weather. *IOP Conference Series: Earth and Environmental Science* 2009 (Vol. 6, No. 9, p. 092007). IOP Publishing.

[6] Sankaran S, Mishra A, Elsani R, Davis C. A review of advanced techniques for detecting plant diseases. *Computers and Electronics in Agriculture*. 2010 Jun 1;72(1):1-3.

[7] Nakato GV, Beed F, Ramathani I, Rwomushana I, Opio F. Risk of banana Xanthomonas wilt spread through trade. *Journal of Crop Protection*. 2013 Jun 10;2(2):151-61.

[8] Martinelli F, Scalenghe R, Davino S, Panno S, Scuderi G, Ruisi P, Villa P, Stroppiana D, Boschetti M, Goulart LR, Davis CE. Advanced methods of plant disease detection. A review. *Agronomy for Sustainable Development*. 2015 Jan 1;35(1):1-25.

[9] Lillesand T, Kiefer RW, Chipman J. *Remote sensing and image interpretation*. John Wiley & Sons; 2015 Feb 18.

[10] Williams T. Thermal imaging cameras: characteristics and performance. CRC Press; 2009 Apr 1.

[11] Davis AP, Lettington AH. Principles of thermal imaging. Applications of thermal imaging. 1988:1-34.

[12] Vadivambal R, Jayas DS. Applications of thermal imaging in agriculture and food industry—a review. *Food and Bioprocess Technology*. 2011 Feb 1;4(2):186-99.

[13] Holst GC. Common sense approach to thermal imaging. Washington: SPIE Optical Engineering Press; 2000 Jan.

[14] Prakash A. Thermal remote sensing: concepts, issues and applications. *International Archives of Photogrammetry and Remote Sensing*. 2000;33(B1; PART 1):239-43.

[15] Tsai SR, Hamblin MR. Biological effects and medical applications of infrared radiation. *Journal of Photochemistry and Photobiology B: Biology*. 2017 May 1;170:197-207.

[16] O'Donnell CP, Fagan C, Cullen PJ, editors. Process analytical technology for the food industry—a review. *Springer*; 2014 Nov 3.

[17] Pimentel D, Hepperly P, Hanson J, Douds D, Seidel R. Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience*. 2005 Jul 1;55(7):573-82.

[18] Food FA. Agriculture Organization of the United Nations.(2017). The future of food and agriculture. Trends and challenges. Rome.

[19] Chaerle L, Hagenbeek D, De Bruyne E, Valcke R, Van Der Straeten D. Thermal and chlorophyll-fluorescence imaging distinguish plant-pathogen interactions at an early stage. *Plant and Cell Physiology*. 2004 Jul 15;45(7):887-96.

[20] Stoll M, Schultz HR, Baeccker G, Berkermann-Loehnertz B. Early pathogen detection under different water status and the assessment of spray application in vineyards through the use of thermal imagery. *Precision agriculture*. 2008 Dec 1;9(6):407-17.

[21] Oerke EC, Fröhling P, Steiner U. Thermographic assessment of scab disease on apple leaves. *Precision Agriculture*. 2011 Oct 1;12(5):699-715.

[22] Jafari M, Minaei S, Safaie N. Detection of pre-symptomatic rose powdery-mildew and gray-mold diseases based on thermal vision. *Infrared Physics & Technology*. 2017 Sep 1;85:170-83.
[23] Berdugo CA, Zito R, Paulus S, Mahlein AK. Fusion of sensor data for the detection and differentiation of plant diseases in cucumber. Plant pathology. 2014 Dec;63(6):1344-56.

[24] Oerke EC, Steiner U, Dehne HW, Lindenthal M. Thermal imaging of cucumber leaves affected by downy mildew and environmental conditions. Journal of experimental botany. 2006 Jun 1;57(9):2121-32.

[25] Wang L, Poque S, Valkonen JP. Phenotyping viral infection in sweetpotato using a high-throughput chlorophyll fluorescence and thermal imaging platform. Plant methods. 2019 Dec 1;15(1):116.

[26] Yao Z, He D, Lei Y. Thermal imaging for early non-destructive detection of wheat stripe rust. In2018 ASABE Annual International Meeting 2018 (p. 1). American Society of Agricultural and Biological Engineers.

[27] Omran ES. Early sensing of peanut leaf spot using spectroscopy and thermal imaging. Archives of Agronomy and Soil Science. 2017 Jun 7;63(7):883-96.

[28] Bejo S, Abdol Lajis G, Abd Aziz S, Seman IA, Ahamed T. Detecting Basal Stem Rot (BSR) Disease At Oil Palm Tree Using Thermal Imaging Technique. 14th Int Conf Precis Agric June. 2018;1–8.

[29] Yang N, Yuan M, Wang P, Zhang R, Sun J, Mao H. Tea diseases detection based on fast infrared thermal image processing technology. Journal of the Science of Food and Agriculture. 2019 May;99(7):3459-66.