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Remote Sensing and Its Importance in Plant Pathology

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Abstract

Detection, identification, and quantification of plant diseases by sensor techniques are expected to enable a more precise disease control, as sensors are sensitive, objective, and highly available for disease assessment. Recent progress in sensor technology and data processing is very promising; nevertheless, technical constraints and issues inherent to variability in host–pathogen interactions currently limit the use of sensors in various fields of application. The information from spectral [e.g., RGB (red, green, blue)], multispectral, and hyperspectral sensors that measure reflectance, fluorescence, and emission of radiation or from electronic noses that detect volatile organic compounds released from plants or pathogens, as well as the potential of sensors to characterize the health status of crops. Phytopathological aspects of remote sensing of plant diseases across different scales and for various purposes are discussed, including spatial disease patterns, epidemic spread of pathogens, crop characteristics, and links to disease control. Future challenges in sensor use are identified.

Keywords: Spectral imaging, detection, identification, disease control, e-nose

Introduction

The production of crop plants worldwide is limited by abiotic and biotic factors. As pests, e.g., weeds, pathogens, viruses, and arthropods and other animal pests, may be controlled to some extent by the intervention of the grower, assessment and control of crop losses due to pests are crucial, even though losses due to abiotic factors may be considerably higher. The loss potential of diseases and the actual losses have been estimated to account for 16% and 11% of the attainable crop production worldwide, respectively. It is generally agreed that plants have to be protected from damage caused by diseases and other pests. Pest management has to be effective, efficient, and sustainable and can best be realized by combining mechanical, biological, and chemical tools with other supportive technologies in integrated pest management (IPM) systems. Disease management in agricultural crops commonly assumes a homogeneous pattern of disease distribution, so crops are sprayed at uniform application rates. However, the heterogeneity of crops caused by differences in soil conditions, topographical situation, neighbouring fields, microclimatic conditions, and sources of pathogen inoculum often results in a heterogeneous distribution of diseases manifested as patches, gradients, or random patterns. As disease patterns may vary from site to site and over time within epidemics in an individual field, farmers have to extend the visual rating of disease to a representative number of samples, to decide whether or not to spray the field. The heterogeneity of disease distribution in a crop may provide an option to minimize the amount of fungicide sprayed during the growing season by applying the fungicide only where it is needed. This reduction can minimize undesirable environmental effects from pesticides as well as decrease selection for fungicide resistance in pathogens. A prerequisite for site-specific disease control is the sensing of diseases, i.e., the monitoring of as many plants as possible, ideally all plants, to determine whether any individual plant is diseased (and to what degree) as well as whether the disease needs to be controlled. Fungicide use may be significantly reduced by applying fungicides only when and where the first diseased plants occur or are likely to appear. The diagnosis and quantification of plant diseases currently rely on visual rating of plants and, in case of doubt, the use of specialized equipment for methods based on nucleic acid and serological technologies. Indirect remote-sensing approaches include thermography, fluorescence imaging, and spectral techniques, all non-invasive and non-destructive methods that allow repeated monitoring of, potentially, all plants of interest. Gas chromatography–mass spectrometry and electronic nose (e-nose) techniques are intermediate in the time required for sample preparation and measuring, as they detect volatile organic compounds (VOCs) emitted by diseased plants and pathogens infecting plant tissue. Sensors may be used for the detection of diseased plants, to decide whether to control a pathogen, and for the assessment of spatial patterns of plant diseases. The introduction of global navigation satellite systems, which can provide a link between field sites and plant characteristics, geographic information systems (GIS), and imaging sensors to discern plant status, has enabled researchers and plant growers to use technical aids for remote sensing of diseases by linking sensor data on the plant status with spatial information on the location of the plant.

Remote sensing is the acquisition of information about an object or phenomenon by a recording device not in physical or intimate contact with the object or phenomenon under study; hence, it is noninvasive and nondestructive. It is suitable for monitoring across various temporal and spatial scales as well as for time-series experiments. Proximal sensing, a subarea with sensors operating close to the target of interest, is complementary to remote sensing sensu stricto, i.e., monitoring the surface of the earth from satellite and airborne systems. The introduction of imaging sensors and the development of new methods for data processing (e.g., artificial intelligence), have considerably increased the potential of remote sensing for plant diseases. However, other issues, e.g., the impact of latent infections on the crop area to be sprayed for disease control, are still unresolved, and new questions have arisen, e.g., how to make the best use of unmanned aerial vehicles (UAVs).

Scopes of Disease Sensing

For a long time, the perception and classification of plant diseases depended on inspection by human eyes and specialized knowledge of the operator. The development of serological and DNA-based technologies has significantly improved and facilitated the identification of plant pathogens; however, these techniques are destructive and often time-consuming, and quantification is relevant to the sample only. Technical sensing of disease symptoms and otherwise detectable changes in the crop status caused by pathogens may be eligible for different purposes, under different conditions. Sensors are expected to be objective, accurate, precise, rapid, and available 24 hours a day, 7 days a week (24/7). Sensors of plant diseases may be used in quality control (e.g., by the food industry or quarantine authorities) once, or they may be integrated into autonomous systems for the continuous monitoring of crops for plant diseases, i.e., checking and keeping a continuous record of the crop health status. Systematic observation of a crop by technical sensors can allow the operator to intervene when infections are detectable or exceed action threshold levels. Ideally, sensors should be capable of (a) detecting a deviation in the crop's health status brought about by pathogens, (b) identifying the disease, and (c) quantifying the severity of the disease. The identification of a disease requires the ability to differentiate among various/all potential diseases according to disease-specific symptoms. The quantification of typical disease symptoms (disease severity) and assessment of leaves infected by several pathogens are simple for imaging systems but a challenge for non-imaging sensors and sensors with inadequate spatial resolution. In some applications, disease detection is the perception of a deviation from a healthy crop/fruit. In these cases, neither identification nor quantification of disease is required. In the context of quarantine regulations, the detection of diseases and identification of the responsible pathogens are crucial to prevent the entry of invasive species and eradicate primary sources of inoculum. Protocols of the International Plant Protection Convention for the detection of plant pathogens integrate phenotypic, serological, and molecular techniques; these methods provide complementary information. Physical sensors provide the opportunity to use autonomous systems for quarantine inspections, which may be a first step applied to bulk material to identify suspicious material that can be further tested and validated using molecular techniques for pathogen identification.

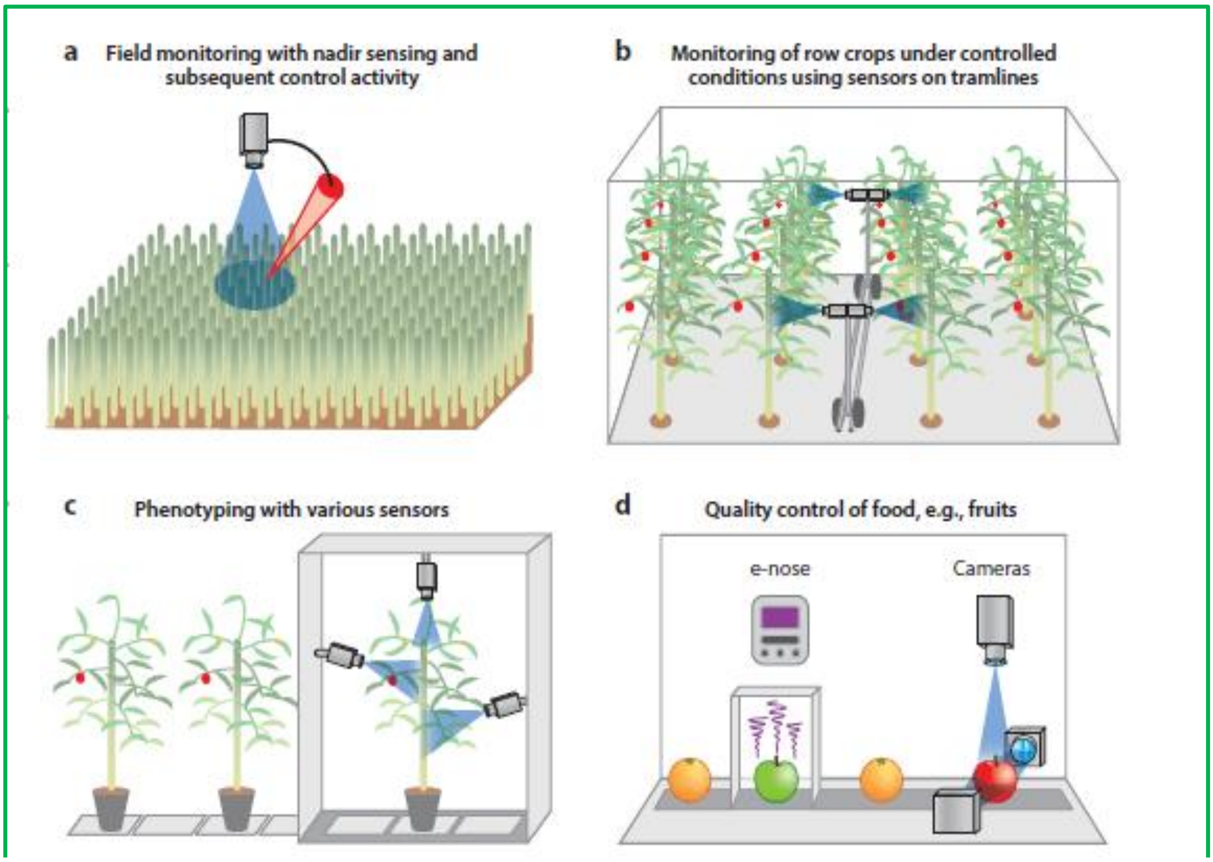

Fig.1 Application areas of remote disease sensing

Sensors for Plant Diseases

Sensors may be classified according to (a) the range of the electromagnetic spectrum, e.g., visible (VIS), near-infrared (NIR), short-wave infrared, thermal infrared, and radar; (b) the scale/platform used, e.g., remote sensu stricto, airborne and space borne, UAV, ground-based/proximal, and microscopic; (c) the recording principle, e.g., passive sensors record radiation emitted by an object (thermography) or the reflectance of solar radiation (RGB, spectral cameras)—active sensors [SAR (specific absorption rate), LIDAR (light detecting and ranging), fluorescence] emit special measuring radiation and record its modification due to interactions with the object of interest and (d) the type of data recording, i.e., imaging or non-imaging. The lower the distance between sensor, object, and radiation source, the stronger is the influence of the geometry between them. Active sensors are less affected by varying environmental factors but strongly depend on the geometry between the emitter/detector and object, and the runtime of the electromagnetic radiation is twice that of a passive sensor. In addition to optical systems, sensors for VOCs are also non-invasive, non-destructive, and passive.

Spectral Information

Spectral information ranging from 350 to 2,500 nm is recorded by radiation-sensitive detector systems that typically split the incoming radiation into its spectral components. Nonimaging spectrometers often have a high spectral resolution (measuring hundreds of narrow wavebands separately) in the full range, but the spectral information results from the average of the sensor's field of view. Imaging systems varying in spatial resolution from some hundreds to millions of pixels per image may record (a) one waveband or the sum over the 400 – 700-nm spectrum (panchromatic); (b) the three basic color components red, green, and blue (typical bandwidth 60 – 80 nm, e.g., smartphone RGB cameras); (c) additional (NIR) bands (multispectral, discrete, and somewhat narrow wavebands); or (d) narrow spectral bands over a continuous spectral range (hyperspectral, spectral resolution <1 nm). Hyperspectral data contain more spectral information than RGB, as each pixel is a vector with the dimensionality of the number of wavebands recorded (typically several hundreds).

Electronic Nose

Plants emit VOCs when affected by diseases and arthropod pests. VOCs are also emitted by healthy plants and play a role in growth, communication, defense, and survival. As abiotic stress factors also modify VOC emission, a multitude of chemicals may be released under normal atmospheric conditions and the composition of this cocktail is changed, sometimes with characteristic successions. E-noses are able to detect these VOCs; gas chromatographic headspace analytics or customized commercial e-noses (e-sensing) are available for special applications. Although often unspecific because plants may emit similar VOCs upon induction by different diseases and different plant species may emit similar VOCs, plant-emitted volatiles may be used for the detection and differentiation of plant diseases (and other pests and physical damage). The blend of VOCs may be specific for plant – parasite interactions.

Sensor Fusion

The combination of information from various sensors may improve disease sensing; however, it often suffers from differences in, e.g., spatial resolution and viewing angle. The combination of infrared thermography, chlorophyll fluorescence, and HSI in sensing Fusarium head blight of wheat ears improved the differentiation of non-inoculated and infected. The addition of leaf spectroscopy of needles to intra-canopy distribution of LIDAR returns increased the accuracy of detecting red-band needle blight. The benefit from additional relevant information has to be balanced with higher operating expenditures and extra time. The combination of several simple sensors is likely to be more successful than the combination of a system producing a high amount of information with one or two sensors delivering a single piece of information each.

Conclusions

Remote-sensing techniques differ in their potential to identify plant diseases. Chlorophyll fluorescence and thermography, although highly sensitive to changes in plant metabolism incited by pathogens, lack the potential to identify diseases and differentiate them from abiotic symptoms and effects from arthropod activities. Spectral information, in combination with spatial information from images and information on VOCs emitted from affected plants, seems to be suitable for disease identification or categorization. Nevertheless, thermography and fluorescence may be used in crop monitoring for anomaly detection followed by an inspection of suspected plants or areas. Additional sensor types can help increase the sensitivity and diagnostic capacity of platforms, as physical limitations, e.g., spatial resolution from airplanes and UAVs, persist.

References

1. Adao T, Hruška J, Pádua L, Bessa J, Peres E, et al. 2017. Hyperspectral imaging: a review on UAV-based sensors, data processing and applications for agriculture and forestry. Remote Sens. 9:1110.
2. Behmann J,Mahlein AK,Rumpf T, Roemer C, Pluemer L. 2015.A review of advanced machine learning methods for the detection of biotic stress in precision crop protection. Precis. Agric. 16:239–60.
3. Oerke, E. C. (2020). Remote sensing of diseases. Annual review of phytopathology, 58, 225-252.