Aerial imagery to improve disease diagnosis and management in field crops

Part 1: Introduction & Background

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Introduction

Timely crop disease management has been a continual challenge for producers. Diseases impact overall plant processes that ultimately cause yield losses of up to 90% if left unmanaged. With growing concern over cost-effective control, uncompromised crop yield and quality, and environmental sustainability; precision management has emerged as a critical need. Specifically, identifying the amount, temporal frequency, and spatial variability of plant protection input applications offers a promising new avenue of effective and affordable disease management. Conventional disease assessment techniques are inadequate, spatially inaccurate, and expensive (time and cost wise) to implement. The advent of drones and spectral imaging cameras can serve as an effective alternative. This article summarizes the concept and operating pipeline of drones and spectral imaging sensors towards high-throughput disease diagnosis and precision management. As part of this series of Extension publications, we will be publishing updates on our on-going research in this area on various crops as progress is made on this subject.

Conventional Disease Assessment Techniques

Historically, manual/visual field scouting has been the standard method for identifying disease infestations. This technique may work to some extent for airborne or foliar diseases but is lacking in accuracy and precision when considering soilborne diseases (until the visible symptoms become very apparent). Normally, biological changes occurring in crop canopy or fruit/grains are not immediately visible to naked eye. Therefore, for both disease types, appearance of symptoms is often an indication that it is already too late to avoid yield losses or a missed opportunity for deploying rescue treatments. Visible disease symptoms are often confused with other types of stressors such as soil pH, water stress, soil compaction, nutrient deficiencies, or other biotic or abiotic stressors (Coyne et al., 2007). Moreover, diseases can be confused with one another unless examined by a trained expert or pathologist. In addition, visual scouting can be very subjective, prone to prejudice, can be masked depending on environmental conditions and time of day, leading to costly errors (Barbedo, 2016).

Destructive crop sampling is the second most preferred method for accurate disease detection and identification. Crop or soil samples are collected at random from the field based on historic assessments and then analyzed in the lab through specific tests. For example, to identify nematode infestation, soil core samples are collected from the field, cleaned using eludriator, and then specimens are prepared using sugar solutions. These specimens are visually observed under a microscope to identify and count nematode types. Destructive and/or intensive sampling and analysis can be extremely tedious and time-consuming. For this reason, it may not be possible to collect and analyze the minimum number of samples needed to represent spatial occurrence of crop diseases within a field. Furthermore, shortage of trained nematologists with taxonomic experience further intensifies the manual assessment and delays obtaining results during peak seasons. Such delay can result in poor management decisions, future crop failures, and economic losses. Clearly, this triggers the need for high-throughput techniques for crop disease diagnosis.

Emergence of Drones

Drones are unmanned aerial vehicles that have seen significant advancements in the past two decades for agricultural operations, especially mapping and spraying. Crucial mapping applications include detection and assessments of biotic and abiotic stresses. Drones equipped with spectral/imaging cameras can provide detailed (up to mm of resolution) and high-throughput data, and thereby the potential for prompt crop protection. Aerial imaging enables understanding and management of spatial variations within the fields, which is not quite often possible with manual scouting or intensive plant/soil analysis. Most importantly, drone imaging campaigns can be conducted on-demand and quickly when crop health assessments are deemed critical.

Spectral imaging for crop disease diagnosis

Imaging for agricultural crops has evolved over time and typically includes visible or RGB, Hyperspectral, Multispectral, Fluorescence, and Thermal-range imaging among others (Figures 1 and 2). RGB imaging is similar to what the naked eyes can observe while fluorescence, hyperspectral, multispectral, and thermal imagers capture signatures or profiles of plants in terms of light, reflectance, and emissivity beyond visible-range imaging. Hyperspectral cameras comprise of 100s and 1000s of wavelengths (or sensors) while multispectral cameras comprise of 3 to 10 wavelengths within RGB and Near-infrared ranges shown in figures 1 and 2. These cameras are quite widely used for plant disease diagnosis as those can capture signatures pertaining to biological changes in crops (Figure 3), even prior to appearance of visible symptoms. Reflectance, which is the ratio of light/energy reflected from the crop surface to the light/energy incident on the crop surface is captured by the spectral cameras in these wavelengths. Figure 4 illustrates hyperspectral reflectance signatures for soybeans infected with varying severity of Asian rust. It can be observed that within 400-700 nm (i.e., Visible range) the reflectance is distinctly higher for higher levels of disease severity. This trend reverses within the Near-infrared spectrum where reflectance for a healthier crop is higher. Such signatures can potentially be utilized to identify crop types as well as the levels of disease incidence and/or severity.

Figure 1. Examples of market-available drone mountable RGB, Multispectral, and Hyperspectral cameras.
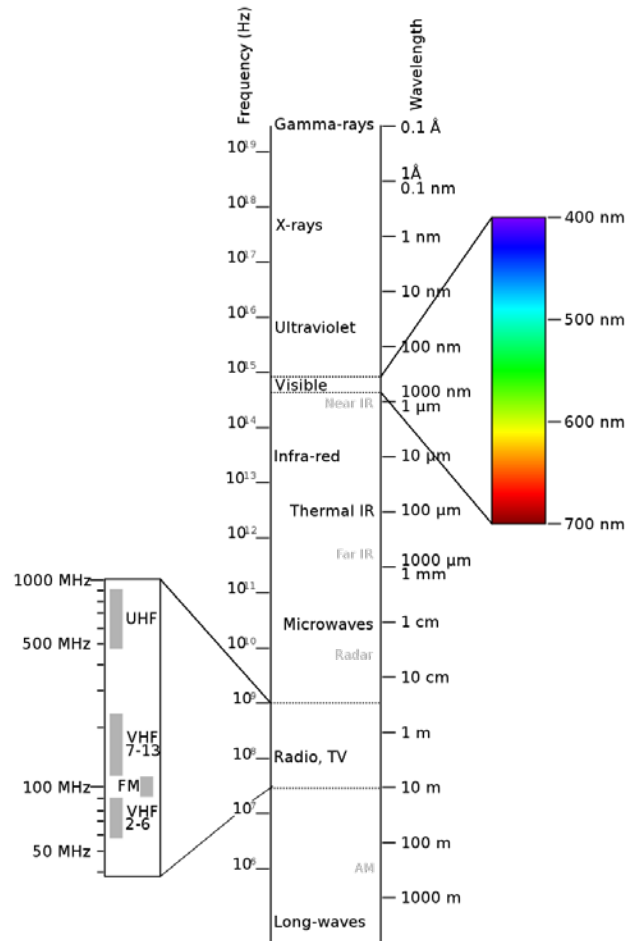

Figure 2. Illustration of electromagnetic spectrum utilized in spectral imaging. (Original: Penubag Vector: Victor Blacus, via Wikimedia Commons).
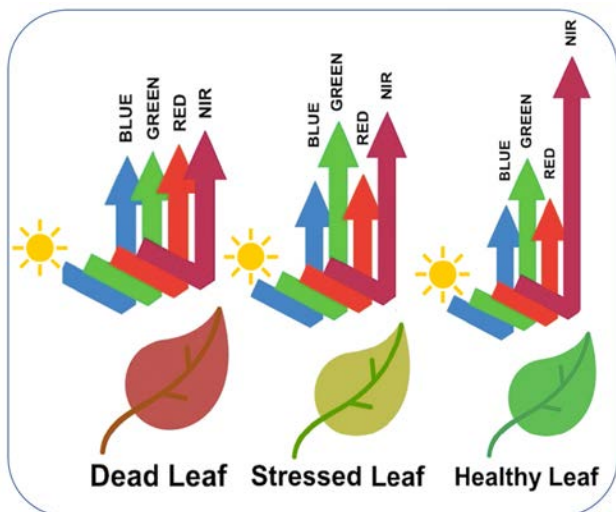
Figure 3. Illustration of light reflectance profiles from the dead, stressed, and healthy leaves.
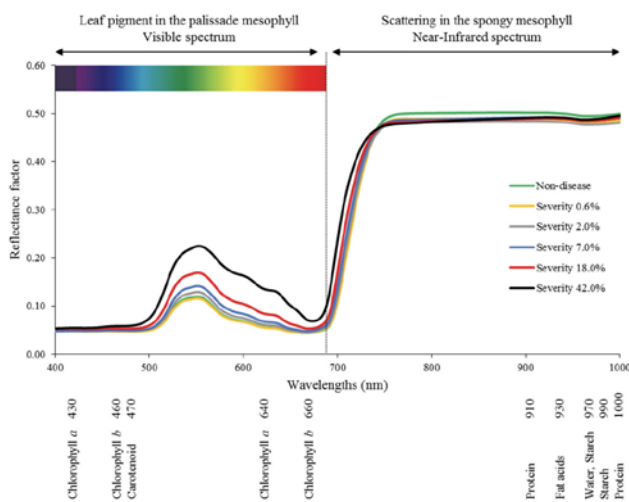

Figure 4. Illustration of spectral signatures for Asian rust in soybeans (Source: Furlanetto et al., 2021).

Spectral vegetation indices for mapping crop diseases

Vegetation indices are the most widely used features of spectral imagery to detect crop problems. These are derived using computer-driven mathematical normalization (calculation) of reflectance signatures measured in different wavelengths of the spectral sensors/cameras. Some of the popular indices include but are not limited to Normalized Difference Vegetation Index (NDVI), Green-NDVI, Normalized Difference Red-Edge Index (Ranjan et al., 2019; Chandel et al., 2021a). Typically, the higher the magnitudes of such vegetation indices, the healthier that the plants are (and vice versa for stressed plants). Different vegetation indices have demonstrated potentials for detecting different crop-

problem combinations (Singh et al., 2020; Chandel et al., 2021b) as also summarized in table 1.

Table 1. Example case studies on aerial imagery derived spectral vegetation indices for crop disease diagnosis. These are part of the on-going research at the Tidewater Agricultural Research and Extension Center in Suffolk, VA.

Crop	Problem	Vegetation Indices Used
Soybean	Cyst nematodes	GOSAVI[a], NDRE[b], GNDVI[c], GCI[d], GRVI[e]
Peanuts	Sclerotinia Blight	GLI[f], NLI[g], OSAVI[h], IPVI[i], NDVI[j]
Corn	Leaf spot	GOSAVI[a], GNDVI[c], GCI[d], GRVI[e]

[a]Green Optimized Soil-Adjusted Vegetation Index
[b]Normalized Difference Red-Edge Index
[c]Green Normalized Difference Vegetation Index
[d]Green Chlorophyll Index
[e]Green-Red Vegetation Index
[f]Green Leaf Index; [g]Non-Linear Index
[h]Optimized Soil-Adjusted Vegetation Index
[i]Infrared Percentage Vegetation Index
[e]Normalized Difference Vegetation Index

Diagnosis to management: the precision way forward

Leveraging high-throughput spectral imagery from drones and deploying vegetation indices or artificial intelligence algorithms can help derive early projections of disease occurrences. These derivations can be converted to zone-based prescription maps using GIS tools. Once obtained, these GIS-based "shapefiles" are feedable to modern-day tractor retrofits and drone-based sprayers to calibrate variable application rates of plant protection products. Research has been on-going to make this process seamless (Figure 5). Ultimately, this will enable producers to apply control measures only when needed, where needed, and in the amounts needed for uncompromised yield and production sustainability.
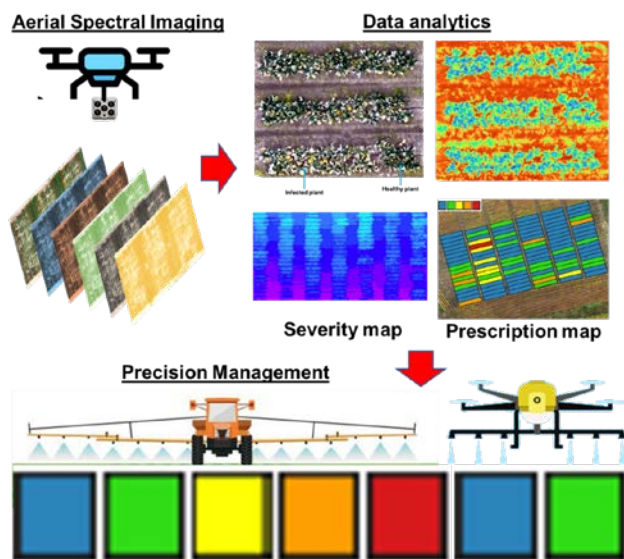
Figure 5. Illustration of operating pipeline from high-throughput spectral imaging to precision management of crop diseases.

References

Barbedo, J.G.A. 2016. "A review on the main challenges in automatic plant disease identification based on visible range images." *Biosystems Engineering* 144: 52-60

Chandel, A.K., L.R. Khot, and L.X. Yu. 2021a. "Alfalfa (Medicago sativa L.) crop vigor and yield characterization using high-resolution aerial multispectral and thermal infrared imaging technique." *Computers and Electronics in Agriculture* 182, p.105999

Chandel, A.K., L.R. Khot, and B. Sallato. 2021b. "Apple powdery mildew infestation detection and mapping using high-resolution visible and multispectral aerial imaging technique." *Scientia Horticulturae* 287, p.110228

Coyne, D., L. Nicol, and B. Claudius-Cole. 2007. "Nematologia pratica: Um guia de campo e de laboratorio. West Africa: International Institute of Tropical Agriculture (IITA)"

Furlanetto, R.H., M.R. Nanni, M.S. Mizuno, L.G.T. Crusiol, and C.R. da Silva. 2021. "Identification and classification of Asian soybean rust using leaf-based hyperspectral reflectance." *International Journal of Remote Sensing* 42(11): 4177-4198

Ranjan, R., A.K. Chandel, L.R. Khot, H.Y. Bahlol, J. Zhou, R.A. Boydston, and P.N. Miklas. 2019. "Irrigated pinto bean crop stress and yield assessment using ground based low altitude remote sensing technology." *Information Processing in Agriculture* 6(4): 502-514

Singh, V., N. Sharma, and S. Singh. 2020. "A review of imaging techniques for plant disease detection." *Artificial Intelligence in Agriculture* 4: 229-242

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