SPECTRAL REMOTE SENSING IN AGRICULTURE

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Spectral remote sensing in row crop agriculture incorporates a set of tools and techniques used to identify disruptions in plant tissue based on spectral analysis of leaf canopy reflectance. Leaf canopy reflectance information is collected through images captured by sensors carried by unmanned aerial vehicles (UAVs), manned aircraft and/or satellites.

Reflectance measurements serve as an indicator of plant tissue physical characteristics such as cell structure, water content, pigment, biomass and nitrogen content. These characteristics are changed due to the occurrence of plant pathogens, insects, nutrient deficiency and water stress.

Occurrence of stress and/or pests in plants often produce visible symptoms. However, before plants express visible changes to the naked eye, changes on the leaf can be observed through reflectance analysis, enabling the diagnosis and potential mitigation of injuries before symptom expression.

Remote sensing studies encompass an interdisciplinary approach, combining two major areas: biology and physics. Biology is used to understand the interaction between plant, pests and the environment while physics explain the changes of the plant reflectance caused by those agents.

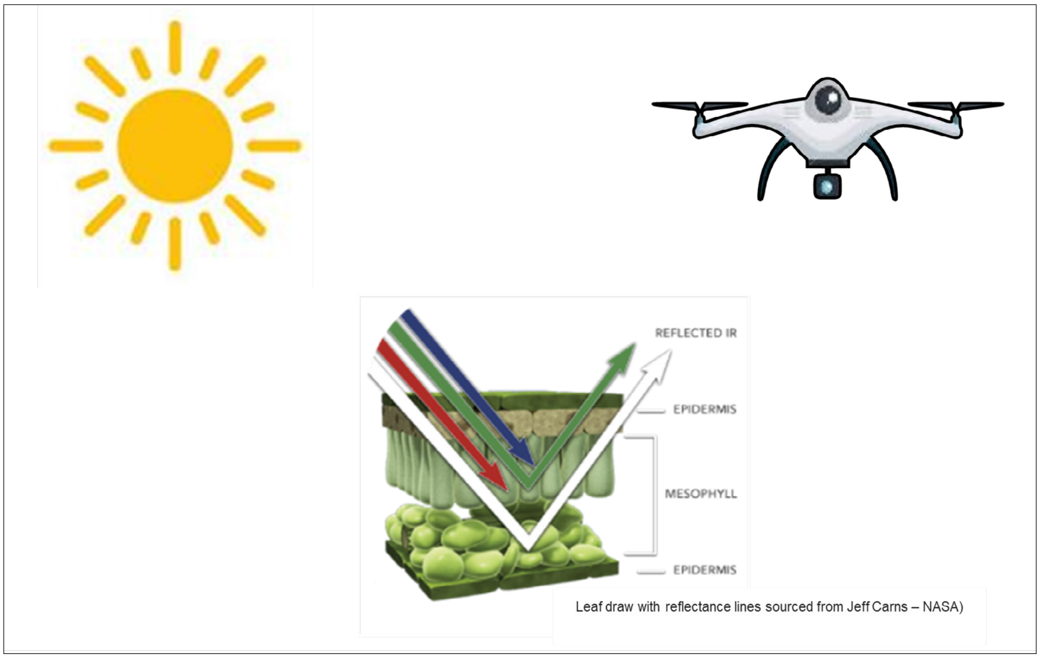

Figure 1. *Scheme with sunlight emitted onto leaf, reflected by leaf and analyzed by a sensor in the drone.*

In general, all physical objects have the ability to absorb and reflect light. One practical example is the various colors that we can see with our eyes; when a leaf is green, it is reflecting green light, whereas when it is yellow due to an injury, the leaf is reflecting yellow light. However, there are many more "colors" in the spectra that our eyes cannot see but can be analyzed using sensors and cameras. It is in these areas that remote sensing is utilized to observe plant health.

The light reflected by the plant is defined as electromagnetic radiation, which consists of electric and magnetic waves traveling through space. These waves are characterized according to their frequency and length. Waves with different lengths and frequencies make up the electromagnetic spectrum, as shown in Figure 2. Gamma waves have a higher frequency and lower length, and as the wavelength increases, the frequency decreases.

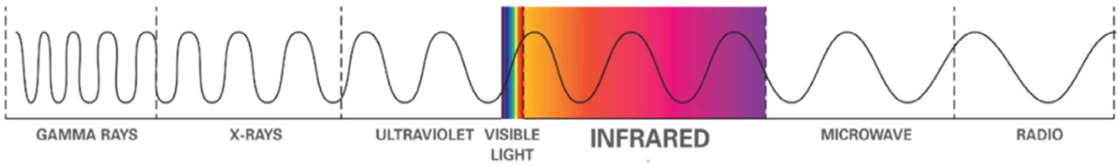

Figure 2. *Representation of the eletromagnetic spectrum with its segments starting at the gamma rays (higher frequency and lower length) until radio (lower frequency and higher length). Source:* flir.com/suas/delta/delta-solution-series-part-1-infra-red-fundamentals/

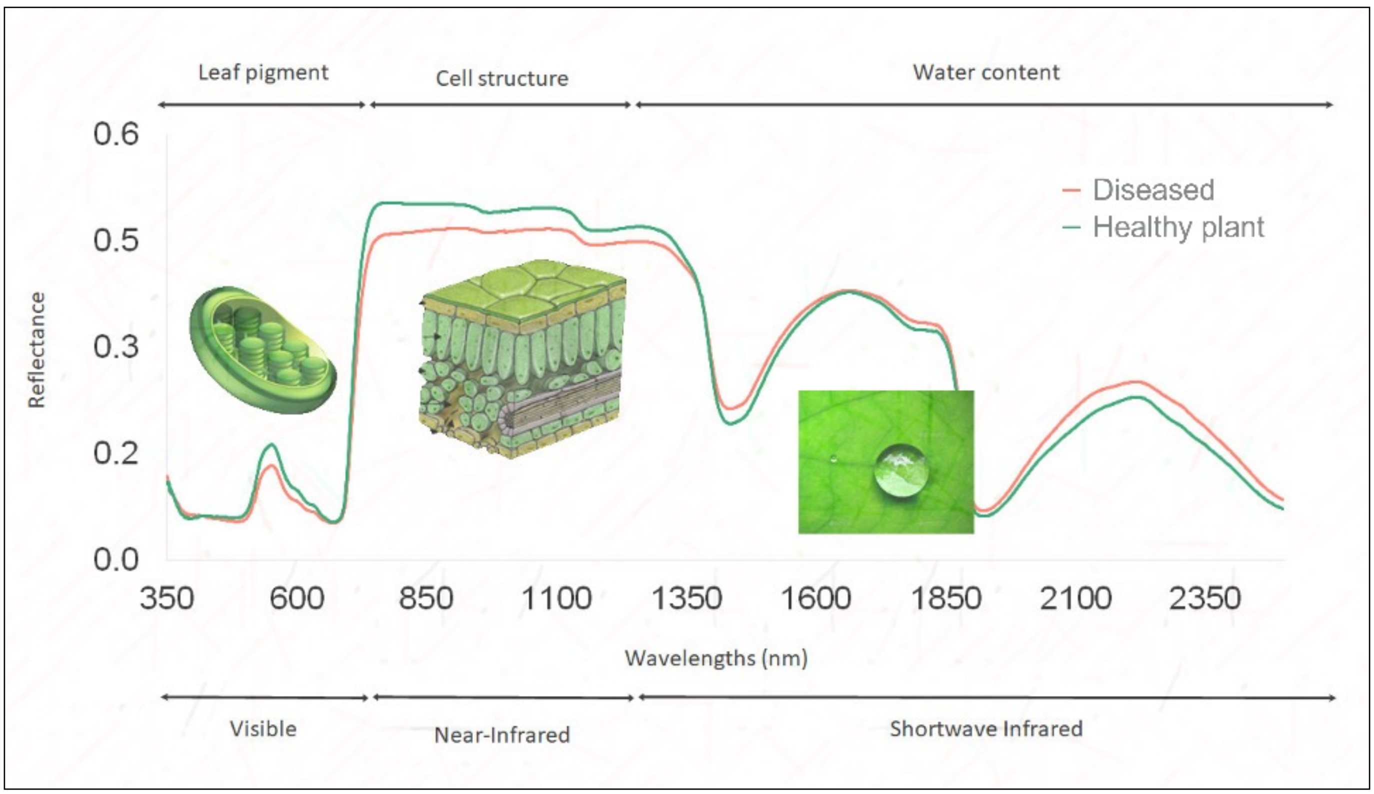

Figure 3. *Specrtal diferences bewtween a plant innoculated with* Phakopsora pachyrizi *and a non-innoculate plant. Source: Zuchelli & Fornari, 2019.*

The electromagnetic spectrum is grouped into regions. The regions most commonly used in spectral remote sensing are the following:

The **visible** portion of the spectrum ranges from violet (380 nm) to red (750nm), including all of the colors that can be seen by the naked eye. The larger wavelengths that are beyond the colors that we can see, include near infrared (700 to 1100 nm), **shortwave infrared** (1100 to 2500 nm), and **thermal** (7000 to 12000 nm) (Mahlein, 2016).

Differences in the visible region of the spectra are captured using RGB (red, green and blue) images, and the analysis in this area enables the identification of disturbances that affect the chlorophyll and other pigments in the plant. Therefore, these analyses help us estimate the field/plant biomass, identify weeds, lesions caused by disease, nitrogen deficiency and plant lodging.

The **near-infrared** region of the spectra is influenced by leaf structure, therefore changes in the cell wall, protein and starch can reduce its reflectance. The **shortwave infrared** area of the spectra is influenced by the structural nitrogen, sugar, and water content of the plant.

These areas can be assessed using multispectral and hyperspectral cameras. Multispectral cameras capture information from specific intervals between the wavelength bands (depending on the camera model), providing data for assessing nutrient status and predicting yield.

Hyperspectral cameras capture a larger area of the spectra with narrow intervals between wavelengths, which enables the identification of disease infection as shown in Figure 3, where a soybean plant is infected with soybean rust (*Phakopsora pachyrhizi*) represented by the orange line and compared with a healthy soybean plant in the green line.

The **thermal region** of the spectra assesses the plant temperature, which is an indicator of plant transpiration. This in turn helps in the identification of plant drought stress as well as plant disease infections.

Sensors are deployed using different platforms, such as satellites and unmanned aerial vehicles (UAVs), that take many pictures as they move over a field. The result of compiling/stitching all these images together to create a map is called an orthomosaic.

Each image is made up of picture elements, also known as pixels, which is the smallest element that can be manipulated through software. An image with a higher number of pixels provides greater resolution and more accurate representation of the field. The resolution is determined by multiple factors including the camera and flight parameters used to capture the image. More samples typically provide more accurate representations.

Figure 4. *Example of a platform for image collection, including the UAV Matrice 600 with a gimbal holding an RGB and a thermal camera, along with its controller.*

The use of cameras on UAVs for mapping fields is becoming a normal practice in agriculture. The system is made up of the camera, the gimbal (this attaches and stabilizes the camera), the UAV, UAV controller, GPS and a screen device (smartphone or tablet). All these parts are synchronized and work together during flight. The operation begins by first **setting up a flight plan**. This plan specifies the area to be flown, altitude, speed, image overlap and other relevant actions the UAV must perform during the flight. There are various kinds of software available that help perform these tasks, including DroneDeploy, Pix4Dcapture, DJI GS Pro, Mission Planner and OpenDroneMap.

The best choice on flight parameters and software depends on the specific capabilities of your UAV platform and the end goal of your operation. Below there are further details on the flight parameters:

- **Overlap** is the area captured in multiple images. This means the same target area will be photographed more than once due to the UAV's overlapping flight paths. There are two types of overlap: frontal (longitudinal) and side (lateral), and these percentages can be adjusted based on your flight objective and camera specifications. Multispectral cameras usually need 80% overlap, whereas infrared thermal cameras need about 90 percent.
- The **GPS (Global Positioning System)** plays a vital role in positioning the UAV and capturing images in space. The camera can either use the GPS from the UAV or have its own independent system. The coordinates embedded in the images are used during the creation of the orthomosaic. However, the GPS signal may contain errors that can be corrected in real-time with the use of RTK GPS and/or for post-processing with ground control points (GCPs).
- The **speed** of your UAV is a crucial factor because it impacts how your camera captures images. Cameras can be set to take pictures based on timed intervals (e.g., every second) or distance flown (e.g., every meter). However, it's important to ensure your UAV speed is slower than your camera's shutter speed to avoid blurry images.
- **Grid pattern** divides the entire flight area into smaller squares. These squares consider factors like flight height, speed and image overlap to guarantee the camera captures the entire area within its field of view during each flight path. Once the grid is established, the specific flight path the UAV will follow is determined.

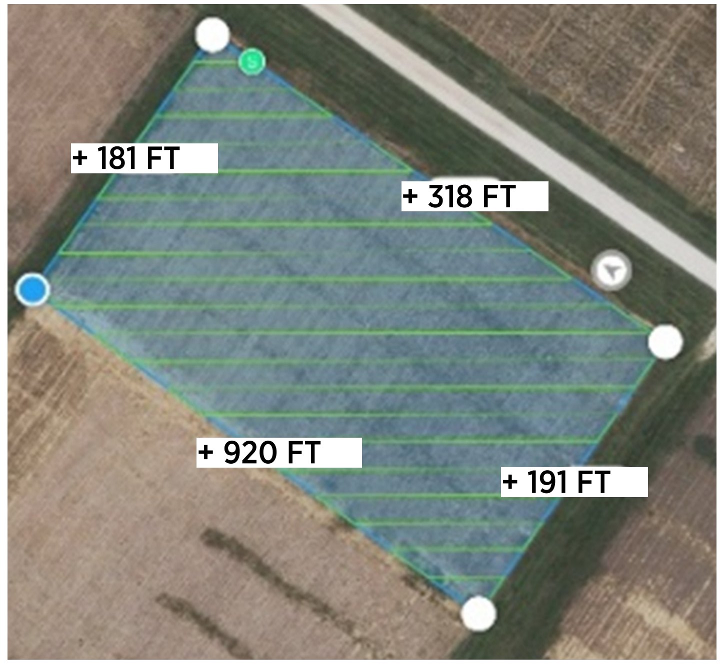

Figure 5. *Representation from the flight from the software DJI GIS Pro using a diagonal grid pattern.*

- **Flight height**, the distance between the UAV and the ground, significantly impacts the pixel size in your images. Lower flight heights capture a smaller area of ground per pixel, resulting in higher resolution and greater detail. The ideal pixel size depends on your observation target. For example, analyzing plant chlorophyll content or estimating growth stages might require a lower pixel resolution (larger ground area per pixel) compared to identifying specific plant pests or diseases, which benefits from higher resolution (smaller ground area per pixel).
- **Battery life** (i.e. how battery usage will result in amount of time UAV can fly) is not directly set during flight planning, but it is crucial to ensure completion of the operation. The battery consumption usually depends upon the payload weight, wind speed, air temperature and other flight parameters.

Speed, altitude and image overlap can be adjusted to optimize battery usage. Using higher overlap or lower flight altitude increases the number of flight paths needed to cover the same area which increases image quality, although it requires more battery power. Therefore, it is necessary to know if your operational capability matches the parameters chosen for the flight.

After setting up your flight plan, consider **making a checklist** and verifying all the equipment that needs to be brought to the field.

Before starting the flight operation, it is necessary to prepare the UAV and sensors according to the manufacturer's user guide. The field is set up with reference points such as (**GCPs**) or other reference points. These points help locate specific areas in captured images during post-processing, enabling the creation of high-quality orthomosaics and comparison between maps from different cameras and dates. The locations of the points are georeferenced and collected with the use of stationary GPS RTK. GCPs can have different shapes and formats, and when using a thermal camera, materials that contrast different temperatures are needed. Different colors, such as white and black, can work for multispectral and RGB images. The only requirement for GCPs is that they have a mark in the center of them and be made from materials that can withstand field exposure, as it is best to leave them in the field for the entire season in the exact same spot. The number of GCPs distributed throughout the field varies according to its size.

CHECKLIST

- UAV
- BATTERIES
- STORAGE UNIT
- CAMERA
- CABLES
- REMOTE CONTROL

For a field of 5,000 square meters, one can use about six, but reducing to four in smaller fields distributed throughout the area of interest is recommended. The use of GCPs is not required if your equipment has RTK GPS capabilities.

The flight operation will proceed according to the flight plan that was created in the software. Most software will communicate with the UAV's autopilot, which will take care of the UAV's takeoff and landing. Ensure that the UAV is in a safe area and that the flight complies with the current legislation for UAVs. For more information, please visit the Federal Aviation Administration website.

Preface: This publication aims to provide foundational knowledge for those beginning a spectral remote sensing program. With a focus on guiding users through best practices, it offers insights to streamline and improve data collection processes, ultimately supporting more informed and effective decision-making. Safe flights!

REFERENCES

Mahlein, A.-K. (2016). Plant disease detection by imaging sensors–parallels and specific demands for precision agriculture and plant phenotyping. Plant disease, 100(2), 241-251.

Zuchelli, E., & Fornari, M. (2019, October). Phakopsora pachyrizi monitoring by spectral reflectance. In PHYTOPATHOLOGY (Vol. 109, No. 10, pp. 190-190). 3340 PILOT KNOB ROAD, ST PAUL, MN 55121 USA: AMER PHYTOPATHOLOGICAL SOC.

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Federal Aviation Administration Drone Information: www.faa.gov/uas

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