Seeing the Invisible

Multispectral Image Analysis in Arable Farming

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Introduction

The worldwide agricultural industry will undergo substantial changes in the next few years. The protection of the environment and the fight against species extinction will lead to new technologies, stringent laws, and more sustainability in our work processes and human behavior. At the same time, we expect an increase in the worldwide human population of up to 11 billion by 2100, with most people living in cities.

One answer to the challenge of the resulting higher food production needs, while minimizing the environmental footprint in arable farming, is the concept of variable rate applications. A detailed understanding of the growth state, stress factors, diseases and pests for parts of a field or even individual crops will allow specific and “smart” applications of water, fertilizers, and pesticides according to the actual needs (see [8]).

In this paper, we outline the state of the art process of variable rate applications. We give an outlook into the future of multispectral and hyperspectral sensing technology in arable farming and how this technology can contribute valuable information for crop analytics in plant protection and crop production processes.

Foundations

When electromagnetic radiation emitted by the Sun hits Earth’s surface, a part of the radiation is reflected, and another part absorbed. Since reflectivity is a material property, the spectrally resolved reflection forms a “footprint”, which helps to identify and to classify the material. For example, healthy plants absorb, especially in the Red and Blue part of the visible light spectrum, which is partially related to the chlorophyll for photosynthesis. At the same time, they reflect much more in the Near-Infrared. Stressed plants change their spectral reflectance signature, and they reflect more in the visual range and less in the Near-Infrared, and the slope in the transition from low values in the visual to higher values in the Near-Infrared (the so-called Red Edge) becomes less steep. Soils typically have a flatter spectrum without a pronounced transition between visual and Near Infrared (see figure 1).

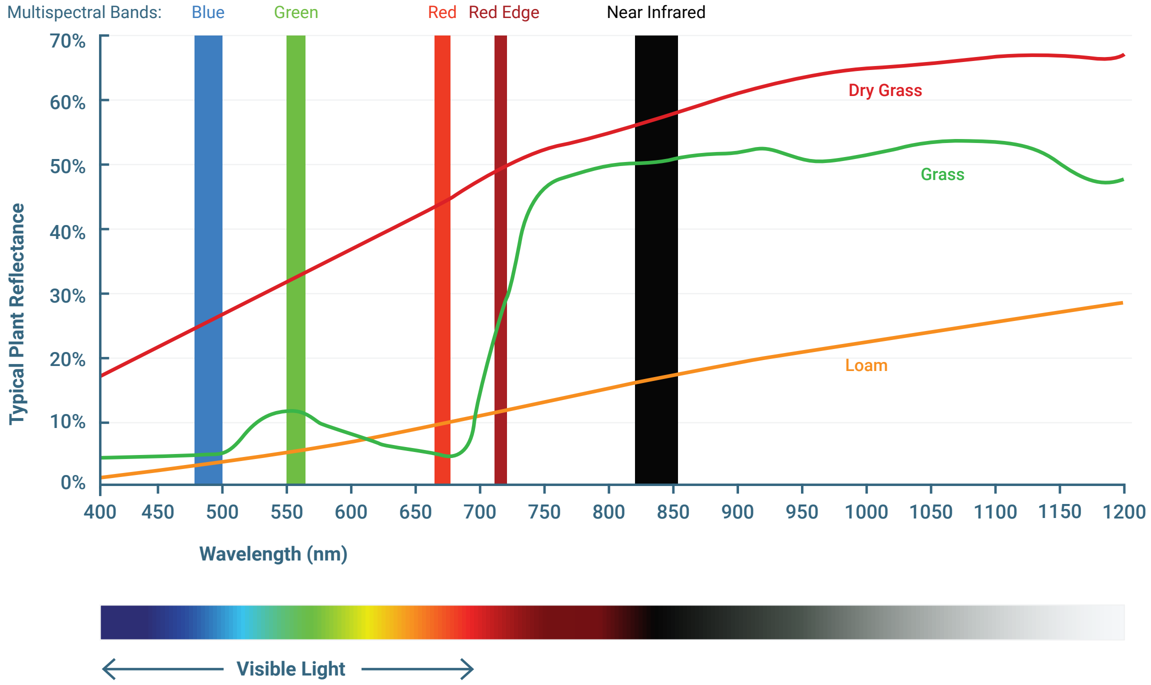

Figure 1: Multispectral cameras capture only some selected wavelength bands within the electromagnetic spectrum. Hyperspectral cameras capture a quasi-continuous range of small wavelength bands across a part of the spectrum. Beyond 1000 nm, the quantum efficiency of CMOS sensors converges quickly to zero and limits the sensible spectrum.

Multispectral and hyperspectral sensing technology is available today and has multiple application areas in agriculture:

1. Scientific agricultural research, consulting, breeding, and field tests of agrochemicals use hyperspectral sensing widely. It allows an analytical assessment of the health state and stress factors of crops. Recent research indicates that specific crop diseases come with characteristic reflectance spectrums (see, e.g. [7], [9]).
2. Multispectral imagery is used today to plan variable rate applications in arable farming [6].

General workflow of multispectral image acquisition and analytics

Multispectral sensing starts with imagery acquired by satellites, airplanes, or drones. Many images of the cameras are stitched together to create precise geolocated orthomosaics of reflectance values for each band, called reflectance maps. In the next step, reflectance maps of different bands are combined to an index map. Many specialized indices exist to obtain information regarding specific aspects of the mapped area, e.g., LCI, to visualize chlorophyll or NDVI for biomass quantification. Depending on the use case, reflectance maps and index maps serve as a base map layer to compute zonation maps or for further statistical or machine learning-based analytics

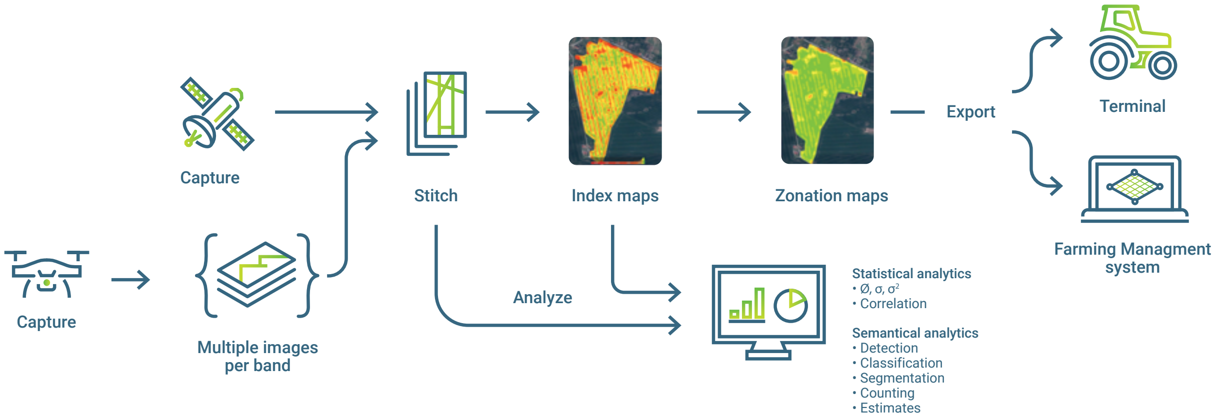

Figure 2: Workflow from image acquisition to analytics and applications

Timely and good quality data are essential for correct decisions and application maps. Computing correct reflectance from drone-based cameras is a complex and challenging task. Bias in the reflectance computation can lead to misinterpretation and incorrect treatments, with severe consequences. Therefore, sound reflectance values are paramount.

Recently, multispectral cameras with a “sky sensor”, which captures the downwelling irradiance have become commercially available. With the correct calibration, such sensors can be used to derive reflectance without an empirical calibration procedure for every acquisition. However, this requires the accurate processing of the raw data. For the same at-ground reflectance, the captured raw value changes with illumination conditions, camera settings, and camera and sky sensor orientation. For example, if the auto-exposure in the firmware of the camera decreases the exposure time, the numeric value in the raw image will decrease. This is not related to any physical change in the imaged object, but rather to a change in the sensing system. Therefore, having an accurate model of the sensor in order to back-compute physical properties from measured raw values is essential.

Pix4D is actively involved in the research. We have successfully developed and tested a new method to estimate at-ground hemispherical-directional reflectance factors (HDRF) from such cameras in both clear sky and overcast sky conditions. The findings were published in a peer-reviewed research article in a high-impact journal [1].

Case studies

The following two use cases illustrate the workflow and applications of multispectral images in arable farming.

Optimal harvest time for corn

For silage corn, there is an optimal maturity of the plants. The maturity is measured with an index, where 30% to 35% is ideal. Below 30%, the corn contains too little starch, while above 35%, higher losses during storage are likely. The traditional approach is to sample randomly selected plants in the field and estimate their dry substance. However, due to differences in the soil properties, plants at places with lower water holding capacity mature faster than at better places.

Remote sensing, in combination with ground sampling, can solve this problem. In the first step, an index map helps to select the plants for probing with a data-driven approach. These specific locations in the field are representative of the different similar zones. In the second step, samples and an index map are combined to derive the spatially resolved dry substance map (figure 3). This approach allows selective harvesting, thereby optimizing the quality of the harvest and quality control of the optimal harvest time.

Growth regulator

Especially after a mild winter, growth regulators can help to ensure quality and yield in cereal production. Flat laying wheat causes less nitrogen absorption with a negative environmental impact and commercially can lead easily to a loss of 200 EUR / ha for a farmer.

Due to spatial differences in soil types, relief, and soil moisture, crops grow differently at different places. With a flat rate application of growth regulators, certain areas of a field can be oversupplied or undersupplied. Too much growth regulator shortens the roots and can reduce the yield when it is dry.

Multispectral sensing can help to apply the right dose of growth regulators. The previous N uptake of the plants is computed from an index map. This value is the data basis for the area-specific application for growth regulators (figure 4). If the value is high, there is a lot of chlorophyll, i.e. biomass. The amount of growth regulator must then be increased.

Long-term tests by Agrarpohl [10] confirm an average increase in the yield of 40 EUR / ha for winter wheat leveraging variable applications of growth regulators compared to non-variable applications.

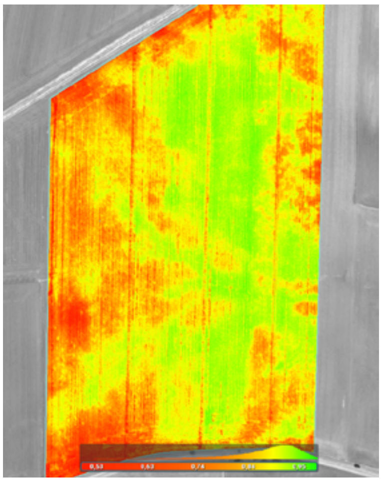

Figure 3: Dry substance map derived from multispectral data in order to estimate the best possible harvest time.

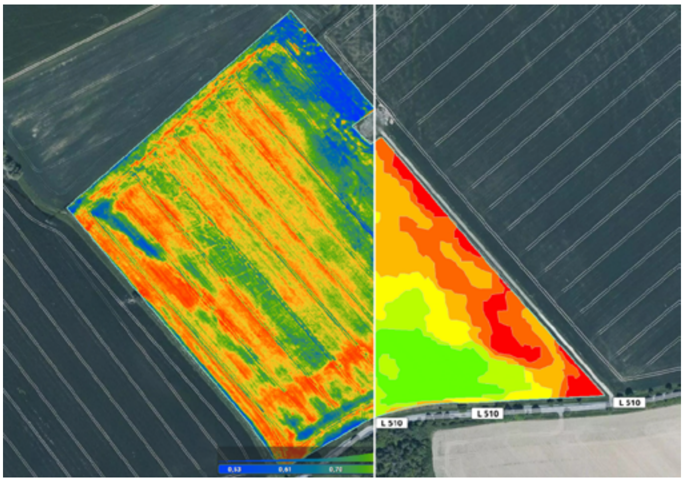

Figure 4: An NDVI indicating the biomass distribution over a field. On the right side, a computed zonation map for growth regulator applications.

Agrarpohl, Wolfenbüttel [10] provided fig. 3 and 4.

Outlook

1. With improved connectivity, processing power, and reliable communication standards in the agricultural industry, we expect a substantial improvement in the user experience when dealing with multispectral and hyperspectral sensing, processing, and planning software. Within the next ten years, we assume seamless workflows from advanced sensing technology to variable-rate sprayers as established standards in crop production processes without the need for manual interactions of farmers and field workers.

2. Driven by the need to protect our resources and environment we assume that variable-rate fertilization and crop production techniques will replace conventional crop production processes with the next generation of machines within the next 15 years (see [8] for quantitative predictions).

3. With the evolution of sensing technology and algorithms, the qualitative planning for variable rate applications will evolve into quantitative analytics. It means that farmers will not only know that they should apply less or more in certain regions but also exactly how much, i.e., algorithms will partially replace the human judgment of the agronomist.

4. The fusion of data from multiple sensors, phenological databases, weather, and soil information, and advanced analytics with the help of machine learning, can allow an automatic spatially resolved detection of crop diseases. In combination with databases for agrochemicals agents, it could, for example, suggest the correct application and the respective doses to cure the detected disease.

About Pix4D

Pix4D is the world-wide market leader in professional drone mapping and photogrammetric software solutions. Based in Switzerland, with offices in San Francisco, Denver, Shanghai, Berlin, Madrid, Tokyo, the company's end-to-end solutions empower individuals to capture their maps of changing environments instantly. Images taken by hand, by drone or by plane are automatically converted into georeferenced 2D mosaics, index and zonation maps, 3D surface models, and point clouds.

Pix4D's site in Berlin develops vertical applications for agriculture and public safety. Pix4D continuously enhances its industry-leading position in image processing, computer vision and photogrammetry, radiometry, and machine learning (see [1–5]).

Being part of Parrot Group Holdings, Pix4D can cooperate closely and leverage unique solutions from both senseFly and MicaSense. senseFly is the leader in the fixed-wing drone market, while MicaSense is a leading manufacturer of high-resolution multispectral cameras. With hardware and software development closely aligned, the Parrot group of companies provides world-leading drone-based sensing technology with powerful analytics specifically developed for the global agriculture market.

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