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Infrared Imaging for Plant Protection

Fungi infections, which cause variations in plant surface temperatures, can be recognised by infrared cameras within the thermal range (MIR) under laboratory conditions. In the field, pronounced natural temperature variations of several Kelvin within the crop canopy prevent the recognition of infected plants through commercial thermal vision systems as stand-alone solutions. NIR cameras fitted with band-pass filters show different intensity distributions of the reflected radiation. Assessing the spectral intensity relations improves the differentiation. Through NIR the surface tissue cell ingredients are measured, and thermography determines the plant transpiration rate.

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Keywords

Thermography, NIR spectra, infrared imagery, plant discrimination, powdery mildew, stripe rust

Literature

Literature references can be called up under LT 05310 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm. .

Machine vision developed to a powerful tool for many applications within the last decades. Whereas the recognition of single plants, and so the differentiation between crops and weeds, is solved principally by means of grey image processing („monospectral" processing) [e.g. 1-19], usually this method fails for high density crops. Only multi-spectral image processing has the potential to identify weed distributions in fields and to analyse areas with infested plants.

Discrimination of plants

There are numerous papers [e.g. 7, 20-28], which show the applicability of VIS and NIR spectroscopic methods for the detection of plant infections and weed. Because the structure of surface tissue cells and their soluble contents influence the NIR reflection, differences in the NIR reflectance are expected. Thermography is the temperature visualisation of self-radiation of the object under consideration. Plants with different transpiration rates have different surface temperatures due to the latent heat necessary for water evaporation. If a pathogen infection affects the transpiration rate of plants, thermography should enable to recognise this infection.

Measurements by thermography

In laboratory experiments, studies were performed on the development of infestation of wheat plants (*Triticum aestivum*, variety „Kanzler"), which were infected by powdery mildew (*Blumeria* [syn. *Erysiphe*] *graminis* DC. f. sp. *tritici* March.) and by stripe rust (*Puccinia striiformis* West.). Whereas the temperature differences between healthy and infested plants, infected by stripe rust, did not exceed ± 0.1 K usually, temperature differences of up to 0.9 K were observed at plant parts infected by powdery mildew. Normally, the temperature of the infected plant leaves decreased in the course of infection. In some trials, the temperature of leaves of infected plants, which looked healthy, increased later on and reached higher values, relative to healthy plants. As a result, this largely complicates the recognition of plant

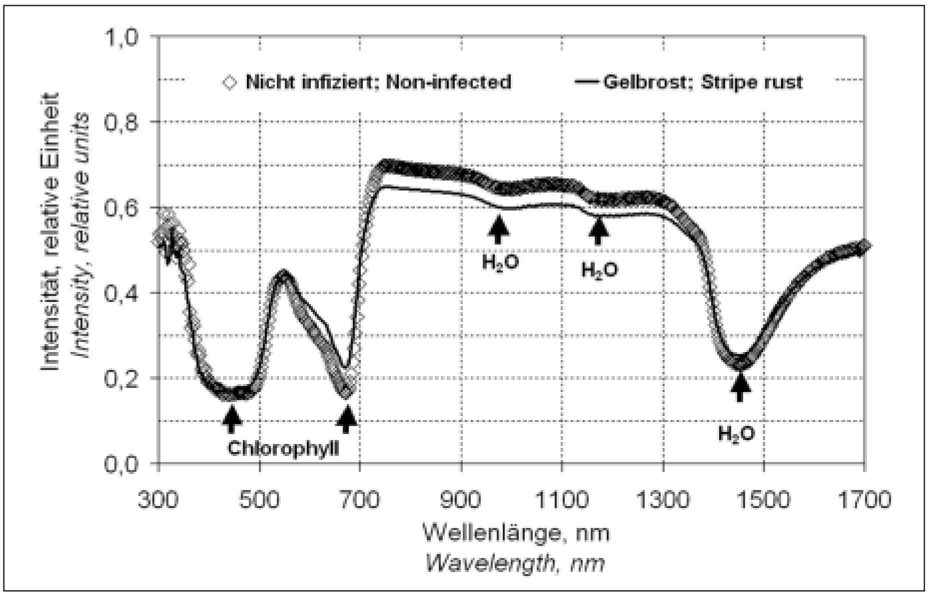

Fig. 1: VIS and NIR reflection spectra of healthy wheat plants (Triticum aestivum, variety „Kanzler") and leafs of plants, infected by stripe rust (Puccinia striiformis West.). Each given spectrum is the mean of 20 individual spectra. Arrows indicate characteristic wavelengths (chlorophyll and H_2O).

infections, as different effects occur at different states of infection. The field trials indicated a second difficulty for the application of thermal vision. The crop stand has a natural temperature variation of several Kelvin. Although infected plants can be recognised by thermography, information for plant protection cannot be achieved by commercial thermal vision systems as stand-alone solution.

Measurements in the NIR range

Spectral bands with and without water absorption are in the NIR range (*Fig. 1*). Infection by fungi and other microorganisms can affect the surface structure, e.g. drying and different kinds of changes caused by cuticula decomposing enzymes or formation of mycelia. Therefore, spectra of healthy and infected leaves were investigated and infrared images of healthy and infected plants were taken by band-pass filters with transmission ranges inside and outside the water absorption band (around 1.4 μm). With this approach, the water content of the surface tissue can be obtained [29, 30], whereas thermography determines the transpiration rate of the plants.

Outside the water absorption band, the NIR reflection of infected plants leaves slightly decreased compared to that of healthy plants. In contrast, a slight increase was measured in the water absorption band for the infected leaves. The differences between healthy and infected plants are marginal and the standard deviations of the means overlap nearly total. Discrimination due to these small differences is not possible. Since the intensity changes are opposite inside and outside the water absorption band, the ratio of intensities improves the chances for differentiation. Healthy plant leaves show a ratio of 5.78 ($\sigma = 0.35$ with 240 data) for the relationship of spectral lines in the range 1070-1100 nm to the range 1435-1465 nm. Plant leaves, infected by stripe rust, have a ratio of 4.68 ($\sigma = 0.83$ with 240 data).

The NIR images at wavelengths of 1075 nm and 1420 nm differ from each other. In the water absorption band (1420 nm), plant parts are darker then with the band-pass filter of 1075 nm (*Fig. 2*). The differences between infected and healthy plants depend on the angle of image taking and changes in the course of infection. Thus suitable information for plant protection cannot be derived by simple methods like threshold evaluation. A pixel processing of two or more identical NIR images with different wavelength ranges may provide a better solution for successful analyses because intensity ratios improve the discrimination potential in the NIR range.

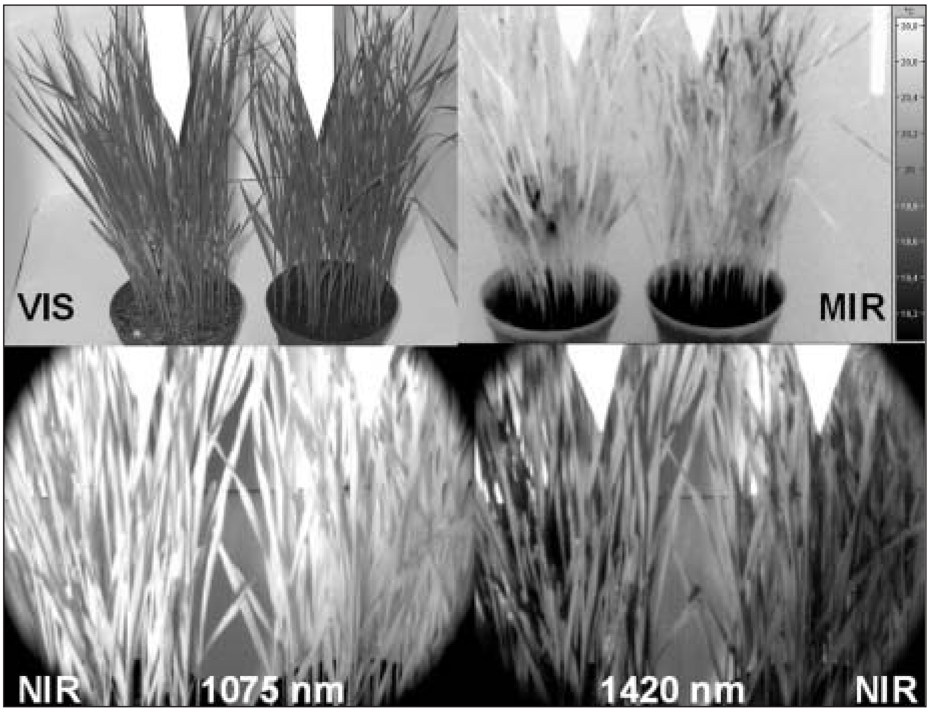

Fig. 2: NIR Images of wheat plants (Triticum aestivum, variety „Kanzler“) infected by powdery mildew (Blumeria [syn. Erysiphe] graminis DC. f. sp. tritici March.; left pot) and of healthy wheat plants (right pot). Air temperature 24.1°C, relative humidity 52 %
VIS: Digital camera image
MIR: Thermal image
NIR 1075: Image of NIR camera and band-pass filter 1075 ± 75 nm
NIR 1420: Image of NIR camera and band-pass filter 1420 ± 75 nm

Perspective

Multi-spectral images in the VIS/NIR range are not a serious technological obstacle nowadays. This wave range can be tackled with appropriate objectives and ray dividers. Weed mapping by means of the combination of VIS and NIR image processing [31-35] can serve as an example. Suitable conditions must be chosen for synchronic online imaging in the thermal and NIR range, in order to obtain comparable measuring spots for both wave bands. Since different materials are utilised for the optical part (NIR: glass and MIR: Germanium), joint objective and joint ray dividers are not available at present. If NIR and MIR cameras should be combined for online detection of infestation, only the intensity of overlapping image parts can be used. Additionally, the NIR image should be represented by images, processed of several wave bands, because the directly measured NIR intensity distribution has lower potential for plant discrimination.