Application of Thermal Imaging in Agriculture and Forestry

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Abstract
Thermal imaging visualizes differences in surface temperature by detecting infrared radiation emitted by objects. Thermography has been used for scheduling irrigation, soil salinity detection, detection of diseases and pathogens, estimating yield, maturity evaluation and vegetative damage detection. This paper briefly reviews various studies conducted on application of thermal imaging in agriculture and forestry.

Keywords: agriculture thermal imaging, forestry thermal imaging

1. Introduction

Noninvasive indicators are very useful in obtaining reliable data without directly affecting organisms, thus avoiding undue stress reactions. Among these indicators, infrared thermography is a suitable tool to obtain such goals.

Ludwig (2013) states that “Thermal imaging allows the visualization of differences in surface temperature by detecting infrared radiation emitted by any body in two spectral atmospheric windows at 3-5 and 8-14 μm. Thought specific algorithm these radiation data can be transformed into images in scalar grey levels. Gray levels images finally can be converted in false color scale in which a color reference scale is used to put in evidence thermal anomalies. In the field of biological applications infrared thermography (IRT) is used for visualizing stress induced changes in leaf transpiration”. Thermography has been used for scheduling irrigation, assessing soil salinity, disease and pathogen detection, yield estimation, maturity evaluation and bruise detection (Ishimwe et al., 2014). This paper briefly reviews several studies that apply thermal imaging in agriculture and forestry.

2. Thermography in Agriculture and Horticulture

Thermal profile of seeds can be used to detect subtle changes in temperature (Kranner et al., 2010). Classification and separation of seeds using the remote sensing technique has been reported by Zhang et al. (2012). In particular, hyperspectral imaging in the visible and near infrared (VIS-NIR) region was used for discriminating between different varieties of commercial maize seeds. In this research, 330 hyperspectral images representing six varieties of maize seeds were evaluated.

Principal component analysis (PCA) and kernel principal component analysis (KPCA) were used to explore the internal structure of the spectral data. Also, four textural variables including contrast, homogeneity, energy, and correlation were extracted from the gray level co-occurrence matrix (GLCM) of each monochromatic image based on optimal wavelengths (Zhang et al., 2012). For maize seed identification, several models were established by least squares-support vector machine (LS-SVM) and back propagation neural network (BPNN) using four different combinations of principal components (PCs). In conclusion, Zhang et al. (2012) stated that “The recognition accuracy achieved in the PCA-GLCM-LS-SVM model (98.89%) was the most satisfactory one. We conclude that hyperspectral imaging combined with texture analysis can be implemented for fast classification of different varieties of maize seeds.”

Ishimwe et al. (2014) indicated that, according to Hellebrand et al. (2002) and Ljungberg & Jonsson (2002), significant positive correlations were found between seedling temperature and damage degree. Thus, IR thermography can be used to detect seed and seedling viability, physical damage, physiological disorders, and to evaluate seed growth processes and plants grown in nurseries and greenhouses.
Numerous researchers using IR thermography to schedule irrigation have focused on plant indicators such as temperature, evapotranspiration rate (Jones et al., 2009; Ballester et al., 2013), stomatal conductance, or stomata closure (Bajons et al., 2005; Blonquist et al., 2009; Granta et al., 2012). Canopy temperature monitoring by infrared techniques to reveal both abiotic and biotic stresses (e.g., related to water deficit before irrigation) has been the subject of several research publications (Jones et al., 2009; Ballester et al., 2013). Ballester et al. (2013) compared sap flow and canopy temperatures to predict the effect of water deficit before irrigation on fresh fruit weight at harvest. Yields from individual trees were weighed to obtain average fruit weight. Images were taken weekly at solar midday from the sunny side of trees and were analyzed automatically. Data were analyzed using analysis of variance procedures for mean separation and contrasts between treatment pairs. This experiment showed a good correlation between canopy temperature measured by thermal imaging and harvest fruit weight. The authors concluded that canopy monitoring by thermal imaging was a useful tool that avoided excessive water stress in citrus orchards managed under deficit irrigation. Jones et al. (2004) reviewed various methods used for irrigation scheduling. They contrasted traditional water-balance and soil moisture-based approaches with those based on the direct monitoring of plant responses to water deficit. Special attention was given to more recent advances such as the use of infrared thermometry and thermography to detect changes in canopy stomatal conductance. Monitoring stomatal conductance (rather than water potential) may be a better indicator of plant response to drying soil since reductions in conductance can occur before major changes in plant water status that would result in fruit bruising (Ishimwe et al., 2014).

Excessive use of pesticides for plant disease treatment increases the danger of toxic residue levels on agricultural products. In the study (Moshou et al., 2004), the difference in spectral reflectance between healthy and diseased wheat plants was investigated at an early stage in the development of the “yellow rust” disease. For disease detection several algorithms were developed, based on neural networks. Oerke et al. (2006) researched leaves of cucumber in relation with influence of downy mildew using thermal imaging. Under controlled conditions, changes in temperature of infected leaves allowed to find difference between healthy and infected areas in thermograms, even before visible symptoms of downy mildew appeared. Thus, digital infrared thermography permitted a non-invasive monitoring and an indirect visualization of downy mildew development (Oerke et al., 2006).

The effect of spatial variability of the leaf temperature of inoculating grapevine leaves (Vitis vinifera L. cv. Riesling) with a fungal pathogen (Plasmopara viticola) was studied with thermal imagery (Lindenthal et al., 2005). It is shown that early and remote detection using thermal imagery has the potential for pre symptomatic diagnosis of biotic stress.

In another publication (Stoll et al., 2008) several experiments were conducted under greenhouse conditions to monitor leaf temperature of Plasmopara viticola pathogen-infected and non-infected areas. Analysis of the spatial and temporal sensitivity of the temperature profile shown, that there is difference between healthy and infected areas on the leaf irrespective of the plant water status.
Thermography is useful tool for assessment of scab disease on apple leaves (Oerke et al., 2011). Infrared thermography for sensing and quantifying apple scab was assessed by investigation of the water balance of apple leaves in relation to the disease stage and the severity of scab. Oerke et al. (2011) found that leaf transpiration was increased by all stages of scab development. The maximum temperature difference may be used in screening systems for monitoring in precision agriculture.

A theoretical basis for study of the relationship between crop yield and one time-of-day measurements of the temperature difference between foliage and ambient was developed (Smith et al., 1985).

A publication of Scotford & Miller (2004) is reported about experiment, in which a radiometer system and ultrasonic sensor were attached to a tractor mounted boom and used in parallel to measure the normalized difference vegetation index (NDVI) of three varieties of winter wheat. Each variety was planted at three seed. The experiment shown that the radiometer system is useful for monitoring the crop.

Hyperspectral imaging (HSI) is an emerging platform technology that integrates conventional imaging and spectroscopy to attain both spatial and spectral information from an object. Although HSI was originally developed for remote sensing, it has recently emerged as a powerful process analytical tool for non-destructive food analysis.

The paper (Gowen et al., 2007) provides an introduction to hyperspectral imaging application to food safety, quality assessment, and defect identification.

3. Thermography in Forestry

In forestry, the detection of seedling stress helps nursery managers reduce the risk of financial loss (Jackson, 1986). Active ground optical remote sensing (AGORS) devices mounted on overhead irrigation booms in nursery operations could help improve seedling quality by automatically monitoring for seedling stress (Eitel et al., 2010). In this experiment measurements were conducted before full canopy closure. The soil moisture level was constant between samples. The AGORS equipped with a ACS-470 device (Holland Scientific, Inc., Lincoln, NE, USA) was mounted 0.85 m above containers which allowed approximately 7 trees [Scotch pine (Pinus sylvestris)] to be measured at a time. Experimental results suggested that red-edge waveband reflectance information improves the ability of AGORS to monitor plant stress, particularly at early stages of ontogenesis (Eitel et al., 2010).

The use of infrared thermal imaging of almond trees under water-stress conditions was studied by García-Tejero et al. (2012). A method that estimated water stress of young almond trees from thermal images was developed. In this research, daily canopy temperature at midday was measured with an infrared camera along with standard measurements of stem-water potential and stomatal conductance. Note that stem water potential and stomatal conductance measurements have been widely used in citrus orchards (managed with deficit water irrigation techniques) to determine the
plant water status (Ballester et al., 2013). Over the course of this study, these parameters showed highly significant correlations among the differentials of canopy-air temperature, stem-water potential and stomatal conductance. They concluded that infrared thermography was a suitable technique for assessing crop-water status and could be important for automated plant-water stress management in almond orchards.

Sankaran et al., 2013, 2011, 2011a; Mishra et al., 2012). Experiments were conducted under controlled laboratory and field conditions. Field studies involved acquiring spectral data from citrus leaves (healthy and HLB-infected symptomatic leaves) from the sides of the tree canopy. In conclusion, Sankaran et al. (2013) emphasized that thermal imaging of visible-near infrared can be an important remote sensing technology for frequent monitoring of diseases in citrus orchards.

Estimation of Number and Diameter of Apple Fruits in an Orchard during the Growing Season by Thermal Imaging has been studied by Stajnko et al. (2004). A thermal camera captured images of apple trees five times during the vegetation period June–September 2001. A temperature gradient between fruits and their background has been measured. Correlation coefficient for the fruit’s diameter varied between 0.68 and 0.70.

Wen, & Tao (2000) considered the technology of automated machine vision apple defect sorting. They suggested to use a near-infrared (NIR) camera and a mid-infrared (MIR) camera for simultaneous imaging of the fruit being inspected. Wen, & Tao (2000) noted that the NIR camera is sensitive to both the stem-end/calyx and true defects; whereas the MIR camera is only sensitive to the stem-end and calyx.

The paper of Bulanon et al. (2008) presents a study of the thermal temporal variation in citrus canopy as a potential approach for improving fruit detection for harvesting orange. Surface temperature of the fruit, ambient temperature and relative humidity were measured. Fruit and canopy temperature profile demonstrated a relatively large temperature gradient.

**Conclusion**

The use of thermal imaging is a fast growing and potentially important tool in various fields of agriculture and forestry. We have provided several examples regarding the application of thermal imaging to scheduling irrigation, soil salinity detection, detection of diseases and pathogens, yield estimation, maturity evaluation, and detection of injury.

However, thermal imaging may have potential applications for other fields of agriculture and forestry. In the area of epigenetic and ecological genetics, its application may aid in the development of methods or instruments that can be used by plant breeders. For example, identification of genotypes by their phenotypes in segregated generations, selection of parents for predicting and receiving transgressions (or heterosis) in the breeding process in both self- and cross-pollinated plants. Thermal imaging may play an important role for the fast identification of valuable individual genotypes; that is, the bearers of economically significant hardiness genes for disease and drought
resistance. Application of this technique may also have relevance in segregating crop breeding generations or in the study of native plant populations.
References


