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Research Paper

Optimising configuration of a hyperspectral imager for on-line field measurement of wheat canopy

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There is a lack of information on optimal measurement configuration of hyperspectral imagers for on-line measurement of a wheat canopy. This paper aims at identifying this configuration using a passive sensor (400–750 nm). The individual and interaction effects of camera height and angle, sensor integration time and light source distance and height on the spectra's signal-to-noise ratio (SNR) were evaluated under laboratory scanning conditions, from which an optimal configuration was defined and tested under on-line field measurement conditions. The influences of soil total nitrogen (TN) and moisture content (MC) measured with an on-line visible and near infrared (vis-NIR) spectroscopy sensor on SNR were also studied. Analysis of variance and principal component analysis (PCA) were applied to understand the effects of the laboratory considered factors and to identify the most influencing components on SNR.

Results showed that integration time and camera height and angle are highly influential factors affecting SNR. Among integration times of 10, 20 and 50 ms, the highest SNR was obtained with 1.2 m, 1.2 m and 10° values of light height, light distance and camera angle, respectively. The optimum integration time for on-line field measurement was 50 ms, obtained at an optimal camera height of 0.3 m. On-line measured soil TN and MC were found to have significant effects on the SNR with Kappa values of 0.56 and 0.75, respectively. In conclusion, an optimal configuration for a tractor mounted hyperspectral imager was established for the best quality of on-line spectra collected for wheat canopy.

1. Introduction

Advanced methods for early disease detection in crops is vital for improving the efficacy of treatment, reducing infection and minimising the losses to yield and quality. Traditionally, disease detection is carried out manually, which is costly, time consuming and requires special expertise (Bock, Graham, Gottwald, Cook, & Parker, 2010; Schmale & Bergstrom, 2003). Developments in agricultural technology have led to demands for a non-destructive, automated approach for crop disease detection that should be ideally rapid, disease specific, and sensitive to early symptoms (López et al., 2003). Optical sensing methods are non-destructive, allowing repeated data

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acquisition throughout the growing season without inhibiting crop growth. Spectroscopy and imaging techniques have been used in disease and stress monitoring (Hahn, 2009). However, their *in-situ* application although established in other industries (e.g. health services, pharmacology and food safety) is still rather limited. Both Lenk et al. (2007) and Sankaran, Mishra, Ehsani, and Davis (2010) reviewed studies on implementing the technology in the field, for mapping crop disease. Yuan, Pu, Zhang, Wang, and Yang (2016) have used high spatial satellite imagery in the detection of powdery mildew. Remote spectral sensing for identification of weeds in wheat fields has been tested by means of ground collected data (Gómez-Casero et al., 2010). Herrmann, Shapira, Kinast, Karnieli, and Bonfil (2013) have applied proximal hyperspectral imagery in the field for weed detection (e.g., both broadleaf and grass weeds), reporting 85% accuracy. Okamoto and Lee (2009) collected *in-situ* hyperspectral images for the detection of green citrus fruits, reporting promising results for identification of citrus fruits from background objects. In contrast, laboratory methods for disease classification and plant growing conditions have been studied and demonstrated (Roggo, Duponchel, & Huvenne, 2003; Wu, Feng, Zhang, & He, 2008). Hahn (2009) claims that spectroscopic and imaging techniques could be integrated with agricultural vehicles, providing non-invasive and reliable systems for the monitoring and mapping of crop diseases, with further potential for early disease detection. Moshou et al. (2005) have shown that hyperspectral imaging for the recognition of *in-situ* disease can provide identification with a high degree of accuracy. Depending on the method of analysis and data fusion, an error between 1 and 16.5% was reported.

Spectral reflectance in vegetation canopies is dependent on several factors including the illumination angle, the canopy architecture and the radiative properties of the plants. The reflectance of crop canopies is non-lambertian scattering, varying with the sun position, view positions and meteorological conditions including cloud cover (Asner, 1998; Pinter & Jackson, 1985). Plant species, maturity, phenology, level of foliage and nutrient status are plant properties affecting reflectance (Asner, 1998; Coops, Smith, Martin, & Ollinger, 2003; Gnyp et al., 2014). Geometrical arrangement of objects can affect the spectral reflectance such as leaf orientation, which cannot be controlled during on-line measurements (Asner, 1998; Coops et al., 2003). This creates problems associated with reduced reflection from light scattering. Shadows at small scale can be reduced by additional light sources and that opposing lighting can help reduce shadows (Barbedo, Tibola, & Fernandes, 2015). Oberti et al. (2014) argued that the angle between the canopy and camera in the range between 0° and 60° affects the sensitivity of a mounted sensor due to light backscattering, suggesting the potential of an oblique camera angle, to reduce the impact on signal-to-noise ratio (SNR) variation.

A tractor mounted hyperspectral imager allows for on-line field crop canopy sensing and mapping, however, an optimal configuration of the camera, light source and integration time needs to be established for optimal quality of imagery and spectra to be collected. Spectral quality is predominantly affected by sensor integration time, camera orientation, and light height and angle from the object (leaf or canopy). Integration time is the period over which the detector collects photons of light. The greater the integration time and light intensity, the more reflected light is expected to be captured by the detector, providing a higher SNR and pronunciation of the spectral peaks. Though when relying on sunlight the intensity can be variable. When applying a spectral technique to a forward moving platform (on-line measurement) longer integration times result in an average spectrum over a larger area, reducing the sensitivity. Furthermore, the greater the distance between the camera and its subject, the larger the area observed and captured by a single pixel, reducing spatial resolution. Therefore, optimising the measurement configuration is essential before on-line field measurements can be successfully carried out. Furthermore, background soil influences canopy spectra, and efforts have been made to remove this influence (Huete, 1988). Based on remote sensing data of the surface soil, Demetriades-Shah, Steven, and Clark (1990) suggested using a second order derivative to remove deviations caused by the soil background. However, none of these studies have investigated the influences of on-line measured (at a depth of 15–20 cm) soil properties [e.g., moisture content (MC) and total nitrogen (TN)] on the quality of crop canopy spectra.

This paper evaluates, under laboratory conditions, the individual and interaction effects of camera height and angle, integration time and light distance and height on the spectral SNR of a wheat plant canopy captured with a hyperspectral line imager. Furthermore, the influence of measured soil MC and TN on SNR of plant spectra collected on-line in the field is also assessed. This was essential to inform optimal configuration and operational conditions for on-line field measurement of crop canopy and diseases.

2. Materials and methods

2.1. *Hyperspectral configuration in the laboratory*

Winter wheat *Triticum sativum* (Solstice variety) was grown outdoors in 600 × 400 mm trays (depth of 120 mm) with 100 seeds evenly sown and spaced in 5 parallel lines. After seeding the trays were predominantly rain fed, to reduce input of excess salts from treated tap water. A push broom hyperspectral imager (spectrograph) (HS spectral camera model from Gilden Photonics Ltd., UK) was used to capture high-resolution line images with a resolution of 1608 pixels over 1 s, using a diode array detector. It is a 12 bit Basler piA 1600-35 gm camera, with Schneider-Kreuznach XNP1.4/23 lens and has a pixel pitch of 7.4 μm interpolated/averaged to 0.6 nm readings with a spectral range of 400–750 nm. The reflected light from the target travels through the lens, past an entrance slit through a series of inspector optics in the spectrograph and then split by the prism dispersing element into different wavelengths. This sensor was chosen for its potential for being applied to crop canopy measurements, and was of low price compared to comparable sensors, commercially available in the market.

The data captured is in the form of a line array, with each pixel containing a spectrum and one detector per pixel across the swath. In order to compile a full image, every line across a