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Temperature-stabilized laser-based sensors for accurate plant discrimination

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ABSTRACT

We propose the use of temperature-stabilized lasers to improve the accuracy of a spectral-reflectance-based plant discrimination sensor for use in selective herbicide spraying systems. The discrimination of Canola from Wild-radish is based on Normalized Difference Vegetation Index (NDVI) measurements at two different laser wavelengths. Indoor experimental results show that the relative discrimination accuracy for a temperature non-stabilized sensor drops to 12.5% when the laser temperature varies between 16 °C and 34 °C. Experimental results also show that by controlling the temperature of the laser diodes, canola crops can be discriminated from wild radish weeds with accuracy as high as 90%.

1. Introduction

The most widely used practice in the agricultural industry for weed control is still the spraying of an entire field with selective herbicides at different times in the cultivation cycle. Significant concerns have been raised over threats to consumer health and the environmental damage that results from widespread agricultural use of herbicides (Kettles et al., 1997; Gorell et al., 1998). Furthermore, the growing phenomenon of weed resistance to herbicides and the increasing costs of weed management continue to place increasing pressure on the farmers' ability to maintain and improve profitability. Despite the implementation of alternative weed control methods, such as physical removal, crop rotation and mechanical separation, herbicide application remains the most widely used form of weed control, and this is unlikely to change in the short to medium term. An automatic real-time weed detection system, where weed detection and treatment are performed at the same time, can yield considerable reduction in the amount of herbicide used for weed control (Brown and Noble, 2005; Sinden et al., 2004).

A commercially available device which uses Light Emitting Diodes (LED) of two wavelengths in the red and near-infrared bands to illuminate the field has been used for plant detection (NTech, 2009). While this LED-based plant sensor system can discriminate plants from soil, it cannot discriminate weeds from crops (green-from-green), thus limiting its application in precision agriculture. The authors have reported a three-laser-based weed detection sensor capable of performing limited green-from-green discrimination (Askraba et al., 2016; Askraba et al., 2013). However, a major drawback of the above-mentioned LED- and three-laser-based sensors is their vulnerability to temperature changes.

In this paper, we propose and demonstrate the operation a new temperature-stabilized 3-laser spectral-reflectance-based plant discrimination sensor that comprises temperature controllers with thermoelectric (Peltier) devices and thermistors, as temperature sensors, which maintain the temperature of all used laser sources at 25 °C over an operating temperature range 16–34 °C. The rationale for this work is that the treatment of weeds is most effective when applied at 21–30 °C (Zollinger, 2012), and therefore, it is advantageous to investigate the effect of temperature on the discrimination accuracy of the developed weed sensor, and to provide a viable solution that maintains adequate performance of the sensor over a practical operating temperature range.

The discrimination approach used in this work is based on measuring the intensities of the specular and diffuse laser light beams reflected off a leaf structure (Mauseth, 2003) to calculate the two Normalized Difference Vegetation Indices (NDVI) of the investigated crop and weed species. Comprehensive spectral reflectance measurements show that the physiological differences between plant species are evident in the spectral region from 500 nm to 800 nm. Typical measured average reflectance spectra in the

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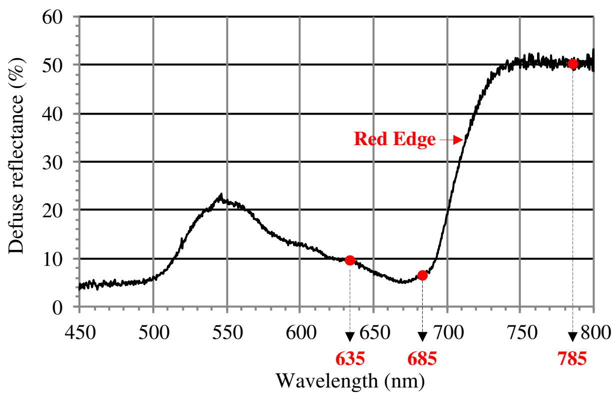

Fig. 1. Typical measured diffuse reflectance spectrum in visible and NIR regions for wild radish leaves. In general, the variations in reflectance in the spectral range from 500 nm to 800 nm can be used to discriminate between different plants.

visible and Near Infra-Red (NIR) region for wild radish (*Raphanus raphanistrum*) leaves, a dominant weed in a canola field, is shown in Fig. 1.

For plant illumination, the sensor employs commercially available 635 nm, 685 nm and 785 nm laser sources to achieve limited discrimination between a crop and several dominant weeds ("green-from-green"). By using more wavelengths at points in the spectrum where plants show different optical characteristics, higher plant discrimination accuracy can be achieved.

2. Review of the state of the art

The first commercial system, Detectspray, was reported by Felton et al. (1987). This system was based on Weed Activated Spraying Processing (WASP). However, its dependence on ambient lighting made impractical and subsequently it was discontinued (Rizzardi, 2007). Currently, there are three main commercially-available products for weed detection and spot spraying, namely, (i) Rees Equipment, (ii) Weedseeker, and (iii) H-Sensor.

Rees Equipment is based on using a hood and an artificial light source for vegetation illumination in conjunction with video image processing that extracts the colour and basic shape and size properties of target weeds (Rees et al., 1999). The product was designed to spray weeds in fallow situations, and hence, had limited applicability to cropped areas.

The "Weedseeker", an automatic spot spray system developed by Patchen Inc., employs two sets of Light Emitting Diodes (LEDs), operating at two wavelengths in the red and near-infrared bands, for vegetation illumination (NTech, 2009). While this LED-based plant sensor system can discriminate plants from soil (green-from-brown), it cannot discriminate weeds from crops (green-from-green), thus limiting its application mainly in orchards, vineyards or fallow fields.

The H-Sensor is a machine vision-based real-time crop/weed discrimination and herbicide spot spraying sensor capable of recognizing crops, grass weeds and herbs (Leithold, 2013). Two Light Emitting Diode (LED) arrays, in the red and NIR wavelength bands, are used to illuminate plants. The software program analyzes the images collected with frame rate of 10 fps (at 12 km/h) and classifies them in real time using a plant classification data base (Society of Precision Agriculture Australia, 2015). The classification database can be modified and fine-tuned to improve the sensor performance through a "training" technique. Four or more H-sensors (one H-Sensor/6 m of boom length) can be mounted on a farming vehicle spray boom at height of 875 mm. The accuracy of the H-Sensor is relatively low, and it is currently being trialed at different farms to maximize its weed detection accuracy.

3. Material & methods

3.1. System description

The developed temperature-stabilized spectral-reflectance-based plant discrimination sensor is shown in Fig. 2. It comprises two 3-laser-diode combination modules driven by constant current laser drivers, two optical cavities for multi-spot laser beam generation, a high-speed line scan image sensor, a central processing unit, a laser temperature sensor, a farming vehicle speed sensor and laser temperature control units.

Fig. 3(a) shows a schematic diagram of the sensor architecture where vegetation is sequentially illuminated by laser beams of three different wavelengths (Paap et al., 2008). Note that sequentially driving the lasers typically limits the speed of the farming vehicles. However, the line scan sensor used in the experiments has an exposure time of 100 μs and a scan rate of 2.5 kHz, enabling plant discrimination at farming vehicle speeds of about 7.5 km/h (Askraba et al., 2016). With advances in high-speed electronics and algorithms, a plant discrimination speed of approximately 18 km/h can be attained. Weed/crop discrimination is achieved by recording and processing plant reflectance data for each laser

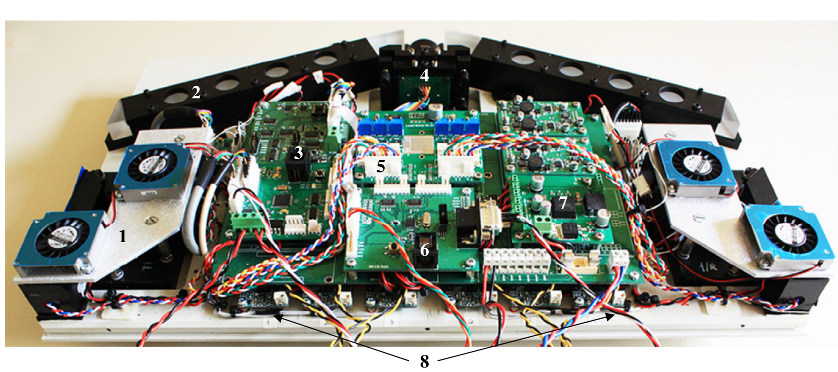

Fig. 2. Stand-alone temperature stabilized laser spectral-reflectance-based plant discrimination sensor. It integrates: (1) two 3-laser diode modules with hot plates and fans; (2) two optical cavities for multi-spot laser beam generators; (3) laser temperature and speed sensor monitoring unit; (4) high-speed linear photo-detector array; (5) drivers for six lasers; (6) central processing unit; (7) main power supplies; (8) six lasers temperature controller units.