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Research paper

Development of an automation system for greenhouse seedling production management using radio-frequency-identification and local remote sensing techniques

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ABSTRACT

More and more crops are grown in greenhouses, and crop growth status monitoring is equally important as field-grown crops. An automation system based-on multi-spectral imaging and mobile environmental factor sensing has been developed and operated. To obtain necessary spectral image information of seedling growth status on greenhouse benches, a series of image processing procedures was developed. The study also explored the applications of the radio frequency identification (RFID) system to construct a traceability system for seedling production in greenhouse. Days of seedlings growth can be calculated estimating the PLAI of the plant-oriented multi-spectral images with $R^2 = 0.989$. Appropriate irrigation level could be estimated using different indices with environmental factors. Greenhouse cultivation is a site-specific management illustrated by precision integration.

1. Introduction

In order to meet the increasing demands for high quality and safe vegetable products, it is critical to effectively manage the growth of vegetables, especially during the seedling stage. In the last two decades, the majority of seedling growth has been moved into greenhouses, where the seedlings can grow in regular trays under automatically controlled environments (Chen et al., 2002, 2004, 2006, 2007, 2011; Yang et al., 2008). Although the macro-environment in a greenhouse remains relatively constant, the micro-environment around each tray could differ drastically. Not only are the outside factors such as cloudy and rainy weather known to affect the micro-environment of the seedlings, but the inside factors such as the shade from the greenhouse architecture and temperature gradients also play an important role (Kittas et al., 2003). Moreover, uniform operation of automatic devices, e.g. the spraying system, is key to providing the same irrigation to the different crops or the different days of growth of seedlings in the same greenhouse (Johnson et al., 1982). Therefore, the development of a reliable and traceable system capable of sensing the whole environment while monitoring factors critical to plant growth will be crucial to greenhouse operation.

Spectral imaging, an essential technology to remote sensing, as well as remote sensing by satellites, has led the development of precision agriculture for field crops (Han et al., 2001). Such precision agriculture (PA) approaches have been shown to increase crop quality and yield, as well as decrease adverse environmental impacts by improving cultivation and management control on the farm (Marino et al., 1999). PA is site-specific cultivation, and the position information acquired from a global positioning system (GPS) needs to be combined with the plant sensing data (Hache, 2003). Several vegetation indices were developed to analyze the spectra or spectral imaging information, amongst which the projected leaf area index (PLAI) (Running et al., 1986; Grace, 1987; Gong et al., 1992; Barclay, 1998; Kacira et al., 2002) and normalized difference vegetation index (NDVI) (Plant et al., 2000; Lizaso et al., 2002) were commonly used. While remote sensing data is typically acquired by aircraft or satellites, such techniques are less feasible in areas such as Taiwan where segmented fields were developed against steep slopes. The PA technology hence needs to be modified to be suitable for such applications.

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Nevertheless, more and more crops such as vegetables and ornamental plants are now grown in greenhouses, and growth status monitoring of these crops is equally important as that for field-grown crops (Chen et al., 2002, 2004). Consequently, ground-based multi-spectral remote imaging (Yao et al., 2001; Kostrzewski et al., 2002) and plant-oriented remote-sensing algorithms (Chen and Li, 2001) based on monitoring of plant physiological status need to be developed for greenhouse production. In addition to remote sensing information, environmental controls for temperature, relative humidity, and lighting are also vital to the cultivation of crops in greenhouses (Chen et al., 2006). For these purposes, radio frequency identification (RFID) technology is ideal for indoor greenhouse applications to link all the information from the spectral image sensing information, environment factors, and seedling positions (Yang et al., 2008). Therefore, the objectives of this work were (1) to design and develop a RFID-integrated multi-functional remote sensing system for both monitoring and managing purposes, and (2) to establish the RFID information system for greenhouse operations by linking the environmental and the management information to construct a production traceability system.

2. Materials and methods

2.1. Hardware system

The multi-functional remote sensing system (Fig. 1) includes carrier, imaging sub-system, environmental sensing sub-system, and RFID information system (Chen et al., 2006), and the system was mounted on the boom of the variable-rate spraying system to cruise the greenhouse. The boom carrier can be controlled manually or automatically, and can cruise along the length of the benches in the greenhouse, thereby obtaining multi-spectral images of the plants on the benches as well as environmental measurements of temperature, relative humidity, and lighting condition throughout the greenhouse. The images and environmental measurements are linked using the RFID information system. In contrast to current greenhouse practices, in which environmental measurements are made at only a few specific locations, the environmental sensing sub-system developed in this study provides environmental data over a map of the greenhouse area. Thus, the contour profiles of temperature, relative humidity, and lighting conditions can be used to improve the degree of uniformity of these environmental conditions. The multi-spectral images, when correlated to physiological status of the plants, provide information essential for the development of plant-oriented remote-sensing algorithms by which site-specific needs of plants, such as irrigation and nutrient management, could be managed.

2.1.1. Imaging sub-system

The imaging sub-system was developed based on a Barebone SG31G2 computer (Shuttle Co., Taiwan) and a P1394V frame grabber (Billionton Co., Taiwan) was employed with the CCD cameras. The multi-spectral remote imaging system was constructed using both color and B/W IEEE-1394 CCD cameras (AVT Marlin F145-C2, F145-B2; Allied Vision Technologies GMBH, Germany). The electronic shutter speed and gain value were controlled for automatic and correct exposures using software developed in this study with LabVIEW (National Instrument Co., USA) and Matlab (Mathworks Co., USA). A band filter with peak wavelength at 780 nm (NIR) was used for the F145-B2 B/W CCD camera to obtain near infrared images. Red, green, and blue band images (R, G, and B) were obtained from the F145-C2 color CCD camera. The projected leaf area index (PLAI) for the plant canopy was calculated by the following formula:

$$\mathrm{PLAI} = \frac{P_{\mathrm{Canopy}}}{P_{\mathrm{Tray}}} \tag{1}$$

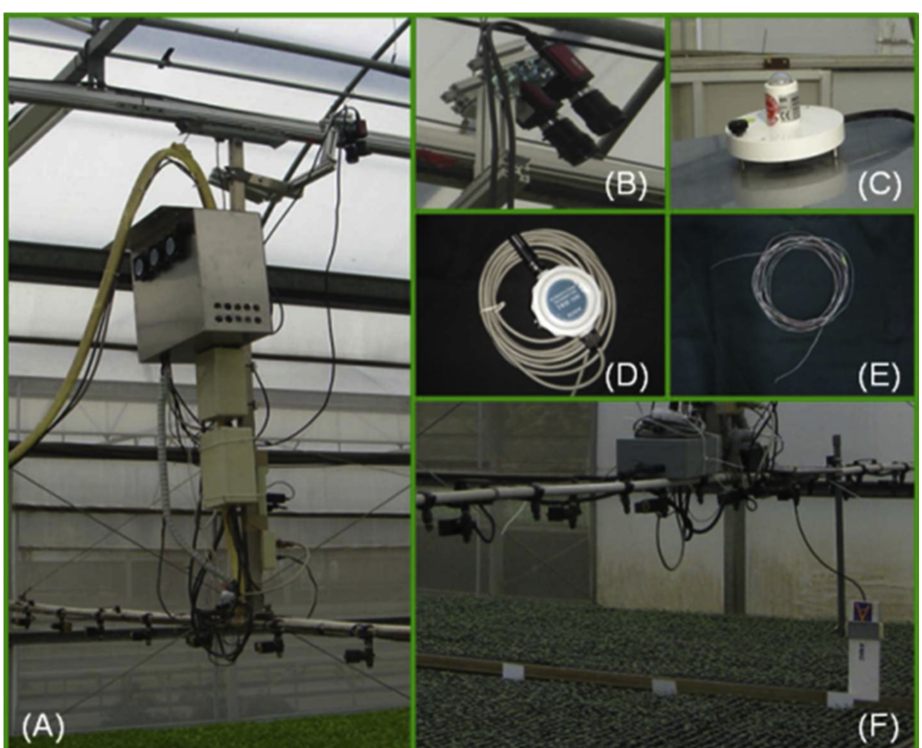

Fig. 1. (A): Multi-functional remote sensing system, (B): the dual band CCD camera for the multi-spectral image acquisition, (C): the quantum sensor, (D): the temperature and the relative humidity sensor, (E): thermocouples, (F): RFID information system with RFID reader, antenna, and RFID tags.