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Sensing systems for precision agriculture in Florida

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ABSTRACT

Many sensing systems have been developed for use in precision agriculture in Florida over the past decade. These systems have been designed for specialty crops such as citrus and blueberry. Systems include those for fruit recognition for yield mapping as well as those for disease detection systems using ground- and aerial-based platforms. Other systems discussed are used in soil phosphorus detection using near-infrared (NIR) and Raman spectroscopy, debris detection generated from citrus mechanical harvesting, detection of citrus fruit dropped on the ground due to disease, citrus leaf nitrogen detection, silage yield mapping, soil nutrients and grain insect detection using NIR spectroscopy. A summary of past efforts is presented in this paper, applications of these different sensing systems are discussed, and future directions are described.

1. Introduction

Precision technologies have been developed mostly for traditional crops since the advent of precision agriculture in the early 1990s. The concept of precision agriculture involves the assessment of in-field spatial variability of different factors such as fertility, soil type and characteristics, and water content in a field and the subsequent management of each crop production input in a more precise and site-specific manner according to the variability. However, in Florida, specialty crops such as citrus and blueberry are mainly grown, rather than traditional row crops, and therefore, alternative technologies are needed in order for precision agriculture to be applied. Over the past decade, much effort has been made to develop sensing technologies for site-specific crop management in Florida, and they were evaluated in actual crop production so that growers can increase yield and profit and maintain the quality of the environment to assure sustainability.

The United States is the second largest citrus producer in the world. Sixty-five percent of its citrus industry is in Florida, which corresponds to more than 450,000 acres of citrus groves. The Florida citrus industry has an estimated economic impact of $8.9 billion (Hodges and Spreen, 2012). In recent years, citrus production has been seriously affected by the emergence of exotic diseases such as citrus greening or Huanglongbing (HLB), citrus canker, and citrus black spot. Citrus production costs have increased from $800 per acre in 2004 to $1800 per acre in 2012. This $1000 increase in production cost in less than ten years is mainly due to additional costs of managing HLB disease. It has been estimated that citrus greening alone has cost about $3.63 billion in lost revenues. With globalization and expansion in the trade of agricultural commodities, this disease is feared to quickly spread from one area to another. Disease management is quickly become one of the most serious challenges in agriculture. In managing plant disease, detection is one of the most important steps. Detecting disease at an early stage, especially at the asymptomatic stage, could be the most cost-effective method of disease control. Currently, human scouting is most commonly used technique for disease detection in the majority of crops. However, human scouting is costly, time-consuming, and limited to human senses for the detection of disease. In recent years, progress in the area of low-cost, low-altitude satellites and unmanned aerial systems have provided an opportunity for continuous monitoring of plants. Such a crop monitoring system consists of a sensor system and a platform that carries the sensor. As shown in Fig. 1, the sensor could be hand-held, ground vehicle-based, or aerial-based. Changes in the spectral characteristics of the plant canopy in the visible, near-infrared (NIR), and mid-infrared (MIR) parts of electromagnetic spectrum are the basis for most commonly used sensors in detecting plant disease and stresses.

The objectives of this study are (1) to provide an overview of sensing systems for precision agriculture developed in Florida, which are different than those developed for traditional grain crops, and (2) to discuss and present future directions.

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2. Various sensing systems for fruit and tree crops

2.1. Fruit recognition

This section presents different sensing systems developed for identifying fruit and tree crops which are used in the development of fruit yield mapping systems. The yield mapping systems are considered as a first step in implementing precision agriculture.

2.1.1. Citrus yield mapping by detecting immature green and mature citrus

Various methods were developed to detect immature green and mature citrus fruit for the purpose of yield mapping. In the early 2000s, Annamalai and Lee (2003) developed an image processing algorithm to detect citrus fruit in an image using hue and saturation thresholds of citrus fruit, leaves, and background classes. They reported an R^2 of 0.76 between the number of fruit by the machine vision algorithm and the number by manual counting. The total processing time for an image was 283 ms with a 750 MHz Pentium processor excluding image acquisition time. Further, Annamalai and Lee (2004) investigated spectral signatures of immature green citrus fruit and leaves for the purpose of developing spectral-based fruit identification and an early yield mapping system. Diffuse reflectance of fruit and leaf samples were measured in the range of 400–2500 nm, and two important wavelengths, 815 nm and 1190 nm, were identified as shown in Fig. 2. A ratio of these two wavelengths was used to distinguish immature green fruit from leaves.

Zaman and Schumann (2005) utilized an ultrasonic system to measure citrus tree volumes in Florida and compared the results with manual measurements. They also investigated relationships between tree volumes measurements and row spacings as well between tree volumes and tree ages. Their measurements produced good results with manual measurements (R^2 = 0.95–0.99). They found out that the ultrasonic measurements were more accurate for young trees with narrower row spacing and that more frequent measurements would be needed for groves with wider spacing and old trees. Further Zaman et al. (2006) extended the ultrasonic measurement of tree volumes to fruit yield estimation. Their results from a 17 ha Valencia grove in Florida yielded an average fruit yield prediction accuracy of 90.6% with a root mean square error (RMSE) of 4.2 Mg/ha. They reported that the relationship between ultrasonic tree size and fruit yield was significant with an R^2 of 0.80. In another citrus fruit recognition study, Bulanon et al. (2009) implemented image fusion of a visible image and a thermal infrared image to increase fruit identification. They performed image registration, Laplacian pyramid transform, and fuzzy logic to detect fruit and reported that fuzzy logic was better for identifying fruit due to its robust inference engine.

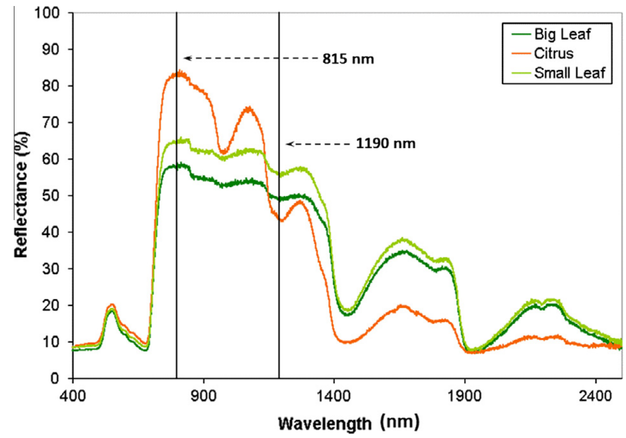
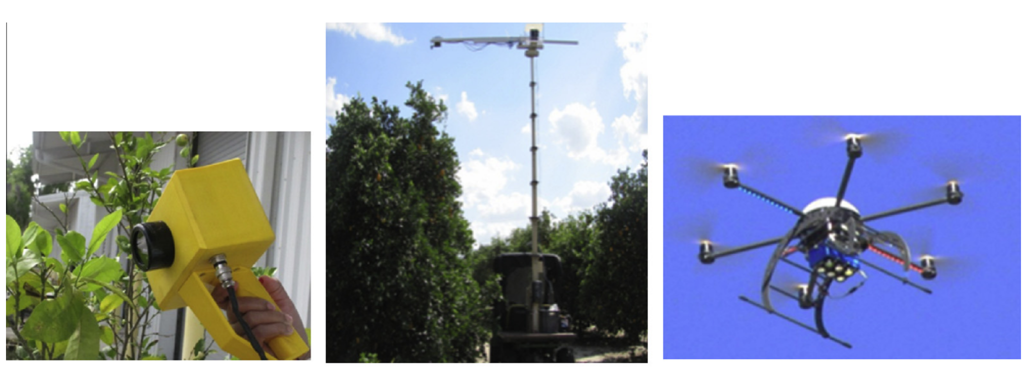


Fig. 2. Reflectance spectra of immature green citrus and leaves (adapted from Annamalai and Lee (2004)).

Employing an outdoor hyperspectral imaging system, Okamoto and Lee (2009) developed algorithms to detect green immature citrus for three different varieties using the range of 369–1042 nm. A linear discriminant analysis for pixels was used to identify fruit objects and spatial image processing steps were used to detect green citrus. They reported detection accuracies of 70–85% depending on citrus varieties and 80–89% accuracy for the fruit in the foreground. For a combined set of three varieties, a 75.8% success rate was reported for the validation set images. Young leaves were the main obstacle for correction identification since they were spectrally very similar to green citrus.

Since hyperspectral imaging systems are usually expensive, attempts were made to utilize a typical consumer-grade digital camera to detect immature green citrus fruit. Kurtulmus et al. (2011) developed a machine vision algorithm to distinguish immature green citrus fruit from other objects in natural outdoor color digital images using color, circular Gabor texture, and a novel 'eigenfruit' method. They reported a correct identification of 75.3% for immature green citrus for a validation set. In Bansal et al. (2013), a percent leakage of the fast Fourier transform was used to distinguish fruit from other objects in natural outdoor color digital images, and 82% of fruit were correctly identified from a set of 60 validation images. Also, Sengupta and Lee (2014) developed a method for identifying immature green citrus from digital color images and reported a detection accuracy of 80.4% in a validation set. A Hough circle detection and texture classification by a support vector machine (SVM) were used to find all potential citrus fruit.



(a) (b) (c)

Fig. 1. Types of sensor on a crop monitoring system: (a) hand-held, (b) ground vehicle-based, and (c) aerial-based.