YOUNG LEAF DETECTION FOR SPOT SPRAY TREATMENT OF CITRUS CANOPIES TO CONTROL PSYLLIDS

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ABSTRACT

Huanglongbing (HLB) is an important disease of citrus that is spread mainly through a vector, psyllid (*Diaphorina citri*), that feeds predominantly on young leaves. Given the selective feeding of the insect, treating only the young flush, instead of spraying the entire tree canopy, may be a prudent and economical way to control psyllids. A young leaf detection module, intended for a spot sprayer system, was developed and tested in the lab under both static and dynamic conditions. It consisted of a four-band active optic sensor (570, 670, 750, and 870 nm), a control box, a data logger, and a Java program on a portable laptop computer. The Java program contains commands to operate the sensor and solenoid-controlled spray nozzles, as well as the classification algorithm to detect young leaves. The algorithm was based on either Euclidean Distance (ED) or Matching Measures (MM) methods of classification (for comparison) using different vegetation indices derived from the spectral reflectance data obtained with the four-band active sensor. A light-emitting diode (LED) in the control box comes on/off, with clicking sounds, to indicate the presence/absence of young leaves. When young leaves are detected, the nozzles of a spot sprayer should simultaneously open to apply spray. A laboratory arrangement (where the spot-sprayer component was left out) was set up and the module tested to characterize its potential utility. The static test was done to determine the repeatability error, $\%e_{Rmax}$, of each of the four bands at four different target distances (TD) based on reflectance of young leaves. Overall, 570>870>750>670 nm, in decreasing order of $\%e_{Rmax}$, and the 670 nm band was least influenced by TD. The dynamic test was performed to determine young leaf detection efficiency, η_{YLD}, and leaf discrimination efficiency, η_{LD}, of the system as a basis for comparing: 1) a subset of four vegetation indices (VI) against all nine originally considered; and 2) Euclidean Distance Method against Matching Measures. The treatments thus consisted of three classification methods (ED, MM80 (MM with cutoff = 80%), and MM70) and two sets of VIs (All and Sub).The results established that using the subset of VIs (η_{LD} > 50%) was better than using all nine (η_{LD} < 50%) and ED classification method was better than MM in discriminating young leaves. Also, sensor travel direction was not found to be significant. With respect to $\eta_{YLD,}$ no significant difference was found between ED_Sub and MM70_Sub at the 95% confidence level. However, MM80_Sub was significantly lower than both but not significantly different from MM80_All . Based on η_{LD}, apart from ED_Sub that was significantly greater than ED_All , all other treatments were not significantly different. At the end, ED_Sub (η_{YLD} = 90.6%, η_{LD} = 62.5%) was better than MM70_Sub (η_{YLD} = 86.9%, η_{LD} = 58.1%) although this difference was not significant. Overall, these results show a good potential for discriminating young and old leaves; however, η_{LD} of 62.5% was not considered adequate and the system thus requires further testing and improvement.

Keywords: active optic sensor, spectral reflectance, vegetation index, leaf classification

INTRODUCTION

Huanglongbing (HLB or citrus greening disease) is considered as one of the most important diseases of citrus due to its highly destructive nature (Manjunath et al., 2005). It was discovered in Florida in 2005 (Halbert, 2005). The disease is transmitted primarily by the Asian Citrus psyllid (*Diaphorina citri*), the only known vector for the disease. Psyllids predominantly feed on young (immature) citrus leaves (Halbert and Manjunath, 2004; APHIS, 2007).

To manage the disease, psyllids are controlled by regular foliar pesticide applications and the HLB infested trees removed and destroyed to prevent the disease from spreading to healthy neighboring trees (APHIS, 2007). The Citrus Health Management Areas (CHMA) initiative, a program spearheaded by the University of Florida (UF) in partnership with the citrus industry and the Florida Department of Agriculture and Consumer Services (FDACS) promotes the coordination of efforts to control and minimize the movement of the psyllid. However, the typical current spraying of whole canopies is wasteful since usually the proportion of young leaves in a tree canopy is very small, especially in summer, and the excess pesticide loading on the canopy is unnecessary burden. Isolating young leaves for treatment will not only cut production cost but is also environmentally viable. Developing a spot sprayer system that can discriminate young leaves from mature ones can significantly reduce application rate, and hence, the need to develop a system that would be able to achieve this separation automatically.

Spectral reflectance properties can be used to identify different objects or to determine various conditions of vegetation. Examples of application include: identifying disease or stress conditions in sugarcane (Apan et al., 2003); identifying weeds in mint and vineyards (Gumz and Weller, 2005; Weedseeker, 2012); predicting crop canopy measurements (Muller et al., 2008); and detection of fruit quality (Camps and Christen, 2009). Thenkabail et al., (2002) found four narrow bands to be effective in estimating a good number of vegetation characteristics. These bands are centered around the red absorption maxima (675 nm), the near-infrared peak (905 nm), the mid section of the red-edge (720 nm), and the green reflectance maxima (550 nm), respectively in order of significance. Various spectral indices derived from these bands, and used in different applications have been documented (Apan et al., 2003; Zarco-Tejada et al., 2005; Sankaran et al., 2011).

For citrus application, there have been ongoing efforts towards HLB detection (Hawkins et al., 2010; Sankaran et al., 2010; Sankaran et al., 2011). However, little has been done to identify young leaves for precision pesticide treatment. A preliminary study on the reflectance characteristics of citrus indicated that there was dissimilarity between young and mature leaves, which is consistent with the work of Ye et al. (2008).

The objectives of this study were to: 1) develop a sensing system that can detect young citrus leaves for spot pesticide treatment as a more economical and environmentally sustainable option for the control of psyllids (*Diaphorina citri*) in HLB management; 2) characterize its young leaf detection component based on static and dynamic tests under controlled laboratory conditions; and 3) establish its potential for use under field conditions.

MATERIALS AND METHODS

Laboratory Setup

The laboratory setup consisted of a four-band active optic sensor mounted (facing downwards at an adjustable height (target distance, TD) from the floor) on a metal frame, a control box, a data logger, and a portable laptop computer with a Java program. The four-band sensor (Fig. 1) was custom built (Applied Technologies LLC, Stillwater, OK), having four light sources operating at different wavelengths. Two of the bands (570 and 670 nm) are in the visible range (Red) whereas the other two (750 and 870 nm) are in the near infrared (NIR) region. Mishra et al. (2011) gives more details on its construction. The sensor could be moved in two directions (A (near-infrared bands leading) and B (visible bands leading)) by a variable speed motor and a sprocket-chain arrangement. Based on earlier work by Maja et al. (2009), orienting the sensor perpendicularly to the target was considered optimum. A piece of cardboard was coated on one side with flat black paint and placed on the floor as target background (painted side facing upwards). Flat black paint was chosen to absorb light waves from the sensor and allow only the waves reflected by targets on the background to reach the sensor's detector.

When the four-band sensor is activated, light waves emit from the light sources unto the target and a light receiver (CCD, charge-coupled device) detects the reflectance from the target. This information is sent to the control box and received on the laptop through the data logger. The Java program on the laptop computes vegetation indices (VI) from the reflectance values and uses those to detect the presence or absence of young citrus leaves. When young leaves are detected, one of the light-emitting diodes (LED) in the control box comes on, and then off again when no young leaves are being detected. This on/off is accompanied by clicking sounds that simulate opening/closing of a solenoid-controlled nozzle to apply spray.

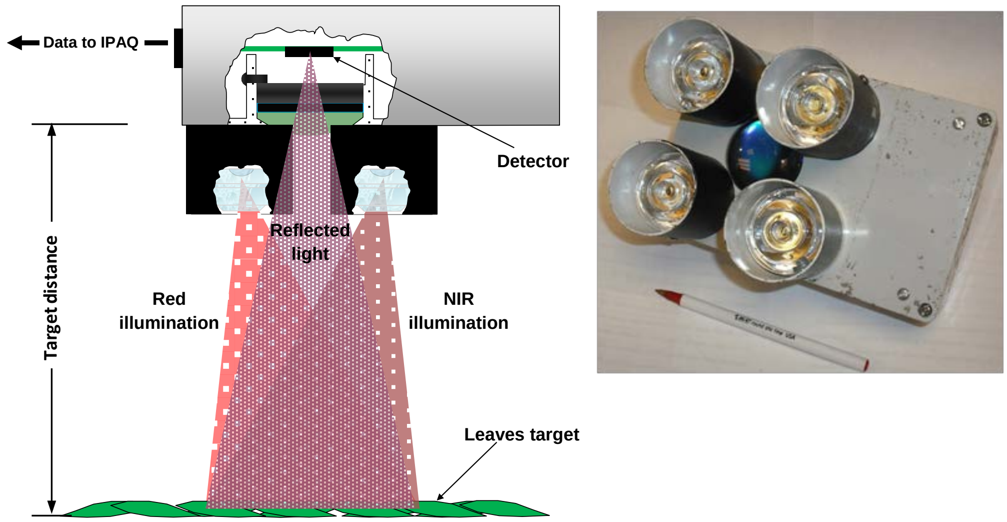

Fig. 1. Four-band sensor: Schematic profile (left) and photograph (right).

The developed Java program runs in real-time in Netbeans Integrated Development Environment (IDE), continuously receiving spectral reflectance data from the sensor. The algorithm used to differentiate young from mature leaves was based on either the Euclidean Distance (ED) or the Matching Measures (MM) Method of classification (Lattin et al., 2003) using vegetation indices (VI) derived from the spectral reflectance data. Nine VIs (Table 1) originally used in the program could be selected or deselected on the graphical user interface (GUI) for use in classification.

Table 1. Vegetation indices used in leaf classification algorithm.

Name	Equation	Reference
Simple Ratio 1 (SR_1)	$R870/R570$	Zarco-Tejada et al. (2005)
Simple Ratio 2 (SR_2)	$R870/R750$	
Simple Ratio 3 (SR_3)	$R750/R570$	Apan et al.(2003); Zarco-Tejada et al. (2005)
Normalized Difference 1 (ND_1)	$(R750-R570)/(R750+R570)$	Zarco-Tejada et al. (2005)
Normalized Difference 2 (ND_2)	$(R870-R750)/(R870+R750)$	Zarco-Tejada et al. (2005)
Normalized Sum 1 (NS_1)	$(R750+R570)/(R670-R570)$	(This study)
Normalized Sum 2 (NS_2)	$(R870+R570)/(R670-R570)$	(This study)
Normalized Sum 3 (NS_3)	$(R870+R670)/(R570-R670)$	(This study)

Simple Ratio 4 (SR_4)	$R570/R670$	Zarco-Tejada et al. (2005)

Implementation of the ED method in the program was as follows. While in operation, the system takes ten sample readings for each target area sensed. Then using the computed VI values, the program calculates the following distance measures:

$$d_{YL} = \left[\sum_{i=1}^{n} \left(\bar{x}_i - \bar{x}_{i,YL} \right)^2 \right]^{1/2} \quad (1)$$

$$d_{ML} = \left[\sum_{i=1}^{n} \left(\bar{x}_i - \bar{x}_{i,ML} \right)^2 \right]^{1/2} \quad (2)$$

where, $\bar{x}_i$ is the mean value of a selected VI for the area being sensed, n is the number of VIs selected, $\bar{x}_{i,YL}$ is the mean value of the VI for young leaves calibration data, and $\bar{x}_{i,ML}$ is the mean value of the VI for mature (old) leaves calibration data. The system indicates young leaf detection if $d_{YL} \le d_{ML}$; otherwise, it indicates other target (including mature leaves).

Implementation of the MM method in the program was also accomplished by calculating, for each target area sensed, the following measures:

$$d_{i,YL} = \left(\left| x_{ij} - \bar{x}_{i,YL} \right| \right) \quad (3)$$

$$d_{i,ML} = \left(\left| x_{ij} - \bar{x}_{i,ML} \right| \right) \quad (4)$$

where, x_{ij} is the value of a selected VI for a sample reading. If the number of readings over all selected VIs for which $d_{i,YL} < d_{i,ML}$ is greater than or equal to a set critical percentage (CP) of the overall number of readings (i.e., the number of VIs selected times 10 sample readings), the system indicates young leaf detection; otherwise, it indicates other target.

Repeatability of the Four-Band Sensor

A test was performed to establish the intrinsic repeatability of the four-band active optic sensor based on reflectance data from young leaves. Young leaf samples from a Valencia orange orchard were arranged on the black background in the scanning path of the sensor (Fig. 2). With the sensor directly above each sample, twenty reflectance readings were taken from seven leaf samples (replicates) at four TDs (55, 65, 75, and 85 cm) in a split plot design. For each band, repeatability error, $\%e_{R\max}$, was computed as reported in Figliola and Beasley (2005):

$$\%e_{R\max} = \frac{2S_x}{r_o} \times 100 \quad (5)$$

where, S_x is the output standard deviation and r_o is the full scale output range.

Fig. 2. Leaf samples on flat black background: Young leaves (left) and old leaves (right).

Leaf Detection Test

A test was carried out to evaluate the performance of the leaf detection system and to compare the performance of the classification methods (ED; MM80 – MM with CP = 80%; and MM70 – MM with CP = 70%) used for leaf detection at TD = 78 cm. In earlier tests (Maja et al., 2009), 78 cm TD was used as optimal. Young and mature leaf samples from a Valencia orange orchard were split into five parts each for replication (Fig. 3) and placed on the background for reading. One sample was used for calibrating (training) the system in static mode while the remaining four were used for testing in dynamic mode. Twenty readings were taken from the sample of each leaf type for calibration. For each replication of the test, one sample of each leaf type was placed apart on the background in the scanning path of the sensor. The sensor was moved twenty times in both directions (A and B) at a speed of about 0.3 m/s, and leaf detection tallied. Young leaf detection was tallied as 'correct detection' (CD) and mature leaf detection as 'wrong detection' (WD). On the other hand, young leaf non-detection was considered 'wrong non-detection' (WND) and mature leaf non-detection as 'correct non-detection' (CND). Based on some preliminary data, only SR4, NS1, NS2, and NS3 were used as an optimal set as against using all nine VIs.

Two measures of performance (η_{YLD} – Young Leaf Detection Efficiency; and η_{LD} – Leaf Discrimination Efficiency) were established and used for comparisons. They are defined as in Equations 6 and 7.

$$\eta_{YLD} = \frac{N_{YLD}}{N_{YLS}} \times 100 \quad (6)$$

$$\eta_{LD} = \frac{N_{YLD} + (N_{MLS} - N_{MLD})}{N_{YLS} + N_{MLS}} \times 100 \quad (7)$$

where, N_{YLS} is the number of young leaf scans, N_{MLS} is the number of mature leaf scans, N_{YLD} is the number of young leaf detections, and N_{MLD} is the number of mature leaf detections. Equation 6 is a simple percentage and greater values indicate better performance. However, Equation 7 is more complex and a summary of explanations to possible values are presented in Table 2. Based on Table 2, η_{LD} should be >75% to be considered good performance.

Fig. 3. Example of leaf samples used as replicates in tests: young leaves (top) and old leaves (bottom).

Table 2. Summary of explanations to possible values of η_{LD} .[1]

N_{YLD}	N_{MLD}	η_{LD} , %	Explanation
N_{YLS}	0	100	Complete CD and perfect discrimination.
N_{YLS}	N_{MLS}	50	No discrimination.
0	N_{MLS}	0	Negative discrimination – No CD but perfect WD.
0	0	50	No leaf detection.
a	*a*	50	No discrimination.

[1] η_{YLD} is young leaf detection efficiency; η_{LD} is leaf discrimination efficiency; N_{YLS} is the number of young leaf scans; N_{MLS} is the number of mature leaf scans; N_{YLD} is the number of young leaf detections; N_{MLD} is the number of mature leaf detections; and *a* is an arbitrary integer < N_{YLs} (where $N_{YLS} = N_{MLS}$) .

RESULTS AND DISCUSSION

Results of the repeatability test (Fig. 4) show that TD affects the performance of the four-band sensor; repeatability varied with TD. Overall, the 570 nm band ($\%e_{R\max}$ = 19.3±4.5%) had the highest repeatability error, followed by the 870 nm band ($\%e_{R\max}$ = 14.5±4.0%), then 750 nm band ($\%e_{R\max}$ = 10.1±6.9%), and then the 670 nm band ($\%e_{R\max}$ = 7.2±1.1%). The 670 nm band was least affected by TD. Inferring from these results, it is evident that TD will affect the overall performance of the leaf detection system.

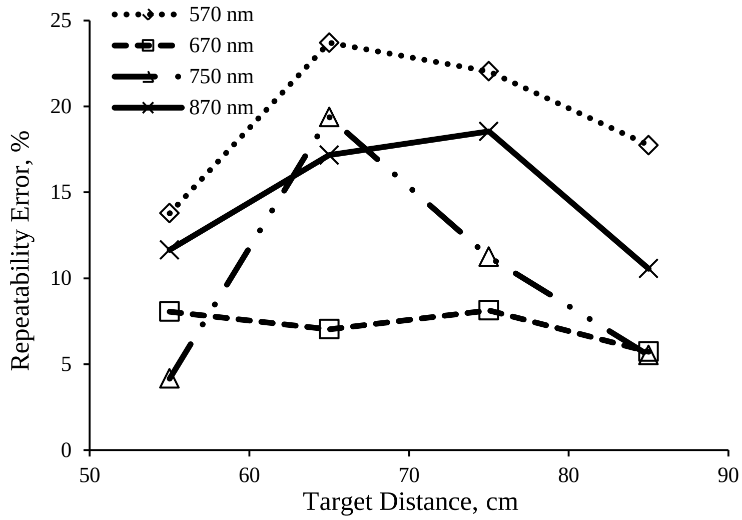

Fig. 4. Repeatability error of four-band sensor based on static tests.

The leaf detection test results are summarized in Fig. 5. Overall, using the subset of VIs (only SR4, NS1, NS2, and NS3) was better than using all nine VIs and there was no significant difference between sensor directions A and B. For young leaf detection, there was no significant difference between ED_Sub and MM70_Sub (p=.9996) at the 95% confidence level, but MM80_Sub was significantly lower than both (p=.0005 and p=.0012, respectively) and not significantly different from MM80_All (p=.6054). This could be attributed to the fact that using CP=80% gives less accommodation for detecting young leaves as against CP=70%. For leaf discrimination, there was generally no significant difference between the treatments, but ED_Sub was significantly higher than ED_All (p=.0268). It is worth noting that WD was higher than CD when using all VIs (η_{LD} < 50%), indicating very poor performance. Finally, ED_Sub (η_{YLD} = 90.6%, η_{LD} = 62.5%) seemed to be better than MM70_Sub (η_{YLD} = 86.9%, η_{LD} = 58.1%) although this difference was not significant. However, η_{LD} of 62.5% was not considered good enough; thus, requiring further testing.

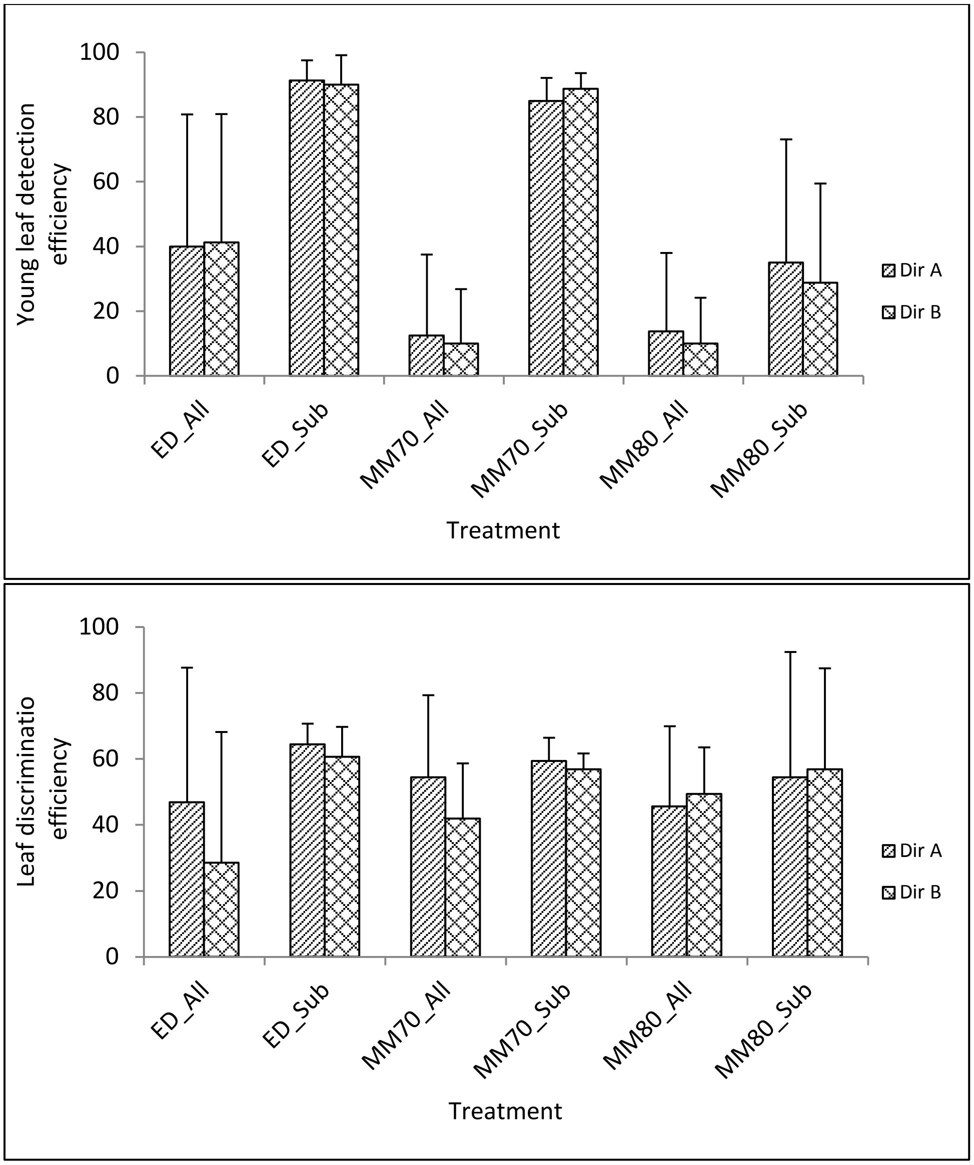

Fig. 5. Comparison of classification treatment for leaf detection: Young leaf detection efficiency (Top) and Leaf discrimination efficiency (Bottom).

CONCLUSION

The overall results of this study have demonstrated that the four-band optic sensor has the potential of obtaining useful data for detecting young leaves for spot sprayer application in citrus. It established that the intrinsic repeatability of the sensor is influenced by its distance from the target. The 670 nm band gave the most repeatable data in static mode, followed by the 750 nm, then 870 nm, and lastly the 570 nm band. Young leaf isolation was possible using Euclidean Distance and Matching Measures methods of classification, but the former gave superior results. Moreover, we discovered that not all vegetation indices are useful for this purpose. Given the magnitude of the potential uncertainty in leaf discrimination further testing would be required to establish the overall performance as related to different setup parameters, especially target distance from the sensor. This information would be necessary in the design of a spot sprayer system to precisely treat young citrus leaves.

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