THE INTERNATIONAL SOCIETY OF
PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

DEVELOPMENT OF A MULTIBAND SENSOR FOR CITRUS BLACK SPOT DISEASE DETECTION

Alireza Pourreza[1], Wonsuk Lee[2], Jun Lu[3], Pamela Roberts[4]

[1] Kearney Agricultural Center, University of California Cooperative Extension, Parlier, California, USA

[2] Department of Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, USA

[3] College of Science, Huazhong Agricultural University Wuhan, Hubei, China

[4] Department of Plant Pathology, University of Florida, Immokalee, Florida, USA

A paper from the Proceedings of the
13th International Conference on Precision Agriculture
July 31 – August 4, 2016
St. Louis, Missouri, USA

Abstract. *Citrus black spot (CBS), or Guignardia citricarpa, is known as the most destroying citrus fungal disease worldwide. CBS causes yield loss as a result of early fruit drop, and it leaves severely blemished and unmarketable fruit. While leaves usually remain symptomless, CBS generates various forms of lesions on citrus fruits including hard spot, cracked spot, and virulent spot. CBS lesions often appear on maturing fruit, starting two months before maturity. Warm temperature and sunlight exposure increase the number of lesions. Two main sources of inoculum are infected leaves decomposing on citrus orchard floor and lesions on infected branches, fruits, and leaves. Wind and water splash can spread the disease to healthy trees. In order to better control the CBS disease, the infected trees should be identified and located preferably at the early stages of infection for an efficient site-specific treatment. In this paper, an affordable vision based sensing method was introduced that was able to detect the citrus fruit with CBS lesions under the field condition. It was shown in a previous study that CBS lesions could be identified with a 100% accuracy in a laboratory using only the color information in regular RGB images. Two DSLR cameras were modified to capture images in two NIR bands as well as red, green, and blue channels. Images of citrus trees*

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 13th International Conference on Precision Agriculture. EXAMPLE: Lastname, A. B. & Coauthor, C. D. (2016). Title of paper. In Proceedings of the 13th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

were acquired in a grove near Immokalee, Florida, USA. An image analysis algorithm was developed to segment the potential spots on the citrus fruit and confirm if they are CBS lesions. Morphological features were extracted from the potential spots in all color components of the images. The algorithm was able to determine if a fruit is CBS positive or CBS negative. The results showed that acceptable accuracies using images that were obtained by the proposed sensing system. The proposed imaging method is an affordable diagnosis method for CBS detection under the field condition.

Keywords. Camera Conversion, Citrus Black Spot, Disease, Image analysis, Near Infrared

Introduction

Citrus black spot (CBS) is a recently found disease of citrus in Florida, USA (caused by fungus *Guignardia citricarpa*) that reduces both fruit quality and yield. It was first seen in spring of 2010 in South Florida near Immokalee (Schubert et al., 2013). CBS generates some fruit lesions on citrus fruit peel that makes it inappropriate for fresh market. Also, it causes early fruit drop (Junior et al., 2016) that extremely affects crop yield (Choi et al., 2015). Transportation of nursery stock or leaf debris from infected trees can increase the spread of the disease (Pourreza et al., 2015a).

Machine vision systems have been employed in many aspects of citrus production. Choi et al. (2014) developed a machine vision system to find premature citrus fruit drop at different locations in a grove and to estimate the dropping period by analyzing the visual features of fruit. Vision-based sensors have also been widely used in citrus disease detection. Pourreza et al. (2015b) developed a customized imaging sensor to detect citrus Huanglongbing (HLB) disease. Their sensor was able to acquire images at a specific wavelength of 591 nm; which was used to identify HLB accurately. In another study, they realized that their customized imaging setting was twice better than a conventional color imaging for HLB detection purpose (Pourreza et al., 2015c).

Polymerase Chain Reaction (PCR) test is the common diagnosis method for CBS (Tomlinson et al., 2013). However, PCR test requires sample collection, and it is both time and effort consuming while it is unable to provide real-time results. Bulanon et al. (2013) conducted a hyperspectral image analysis between 480 nm to 950 nm, and determined four bands of 781 nm, 713 nm, 629 nm, and 493 nm as the potential wavelengths for the development of a multispectral camera to detect CBS. Kim et al. (2014) developed a hyperspectral imaging method for identification of CBS lesions. They employed two hyperspectral analysis procedures of spectral information divergence (SID) and spectral angle mapper (SAM), and obtained up to a 97% accuracy in CBS detection. Zhao et al. (2015) acquired hyperspectral images of several CBS lesions between 396 nm and 1010 nm, and they determined 533 nm as the best wavelength for identification of CBS. Using a Kernel SVM classifier, they were able to identify 98% of CBS lesions accurately. Although some work has been done in CBS detection using optical sensing in the laboratory, there is no study on CBS diagnosis under the field condition. The main goal of this study, therefore, was to develop and evaluate a multispectral imaging solution for detection of CBS lesions under the field condition.

Materials and Methods

Sensing system

A customized Visible-Near Infrared (VIS-NIR) multispectral (MS) imaging system was developed using two modified mirrorless cameras (EOS M10, Canon Inc., Tokyo, Japan), a 2- camera mounting bracket, and a shutter controller. Any commercial digital camera is equipped with an infrared (IR) Cut Filter (ICF) that is positioned in front of the sensor to block the NIR. Otherwise, the color channels mix infrared and visible information. In order to enable the mirrorless cameras to capture light reflectance in NIR range, the internal ICFs of the mirrorless cameras were removed and the cameras were modified so that one could capture blue, green, and NIR (680-800 nm) while the other one could acquire reflectance in green, red, and NIR (800-900 nm). Therefore, a combination of the two cameras provided us with a 5-band multispectral imaging system that included three visible bands and two NIR bands (Fig. 1a).

Data Collection

In-field MS image acquisition was conducted in early March 2016, in a grove including *Valencia* orange trees near Immokalee, Florida. The imaging sensor was mounted on an unmanned ground vehicle (UGV) for field inspection (Fig. 1b). The robot drove between the rows of citrus trees, stopped in front of each tree, acquired images, and then went to the next tree. Image acquisition was conducted in two blocks of the citrus grove: first in a healthy block where no symptomatic fruit had been observed before; and second in a CBS infected block where oranges with CBS lesions were marked by red ribbons. Before the image acquisition, the cameras were calibrated using a white paper and their custom white balance capabilities. Both cameras were set on manual modes with the following settings: focal length: 15 mm; F-stop: f/8; exposure time: 1/640 sec; and ISO-speed: 800. The images were saved in a JPG format.

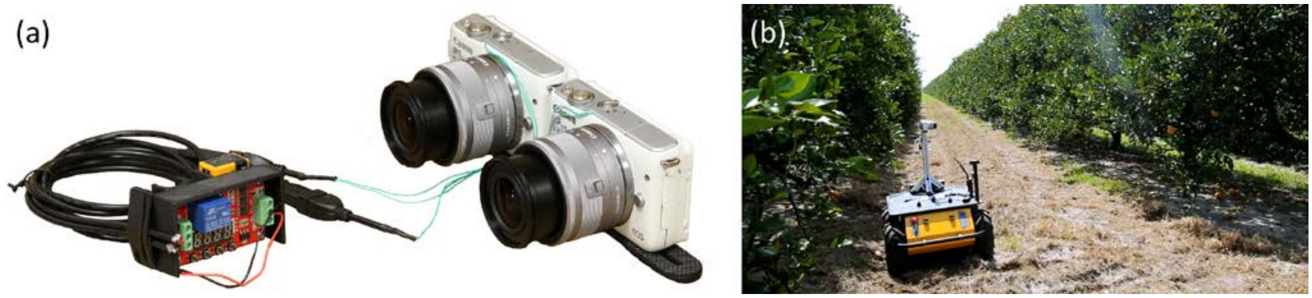

Fig 1. The imaging sensor (5-band camera); (a): two converted Canon M10 mirrorless cameras mounted on a bracket and the shutter controller; (b): the 5-band imaging system mounted on a field robot for autonomous field inspection.

Image Analysis and Classification

The overall image processing steps are shown in Fig. 2. At the first step, six color components including blue, green1, NIR-1 (700-800 nm) from camera #1, and NIR2 (800-900 nm), green2, and red from camera #2 were extracted. A total of 80 citrus fruits including 40 samples with CBS symptoms (hard spot) and 40 samples with healthy peel were segmented manually from the background. Selected sample citrus fruits were in various illumination conditions such as uniformly illuminated by direct sunlight, partially in shade, and totally in shade. A histogram analysis was conducted for each single citrus fruit to determine a customized gray value threshold for segmenting the potential CBS spots on the citrus fruit peel. Fig. 3a illustrates the detailed flowchart of histogram analysis. A customized threshold (T) for each fruit was determined and used for segmentation. The potential segmented spots were then further analyzed morphologically to determine if they are CBS lesion or not. Fig. 3b shows the shape analysis steps. Basically, any potential spot needed to meet certain criteria that were found by experience. The shape features that were used to validate that a spot is CBS included area, minor to major axis ratio, solidity, extent, and centroid. If a segmented area passed all the five criteria in Fig. 4b, it was considered as a CBS lesion, otherwise, it might be a symptom of other disease or noise, but not CBS lesion.

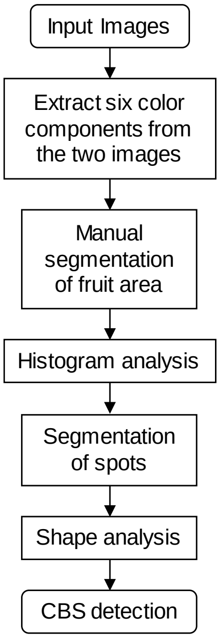

Fig 2. Flowchart of the overall image processing steps to detect CBS lesions.

The image analysis steps described in Figs. 2 and 3 were applied to all 80 samples. If at least one CBS lesion was detected on citrus fruit, it was considered as a CBS positive, otherwise, the sample was categorized in the CBS negative class. This process was repeated for all six color components.

All image processing and data analysis were conducted in MATLAB (version R2015a, MathWorks, Natick, MA).

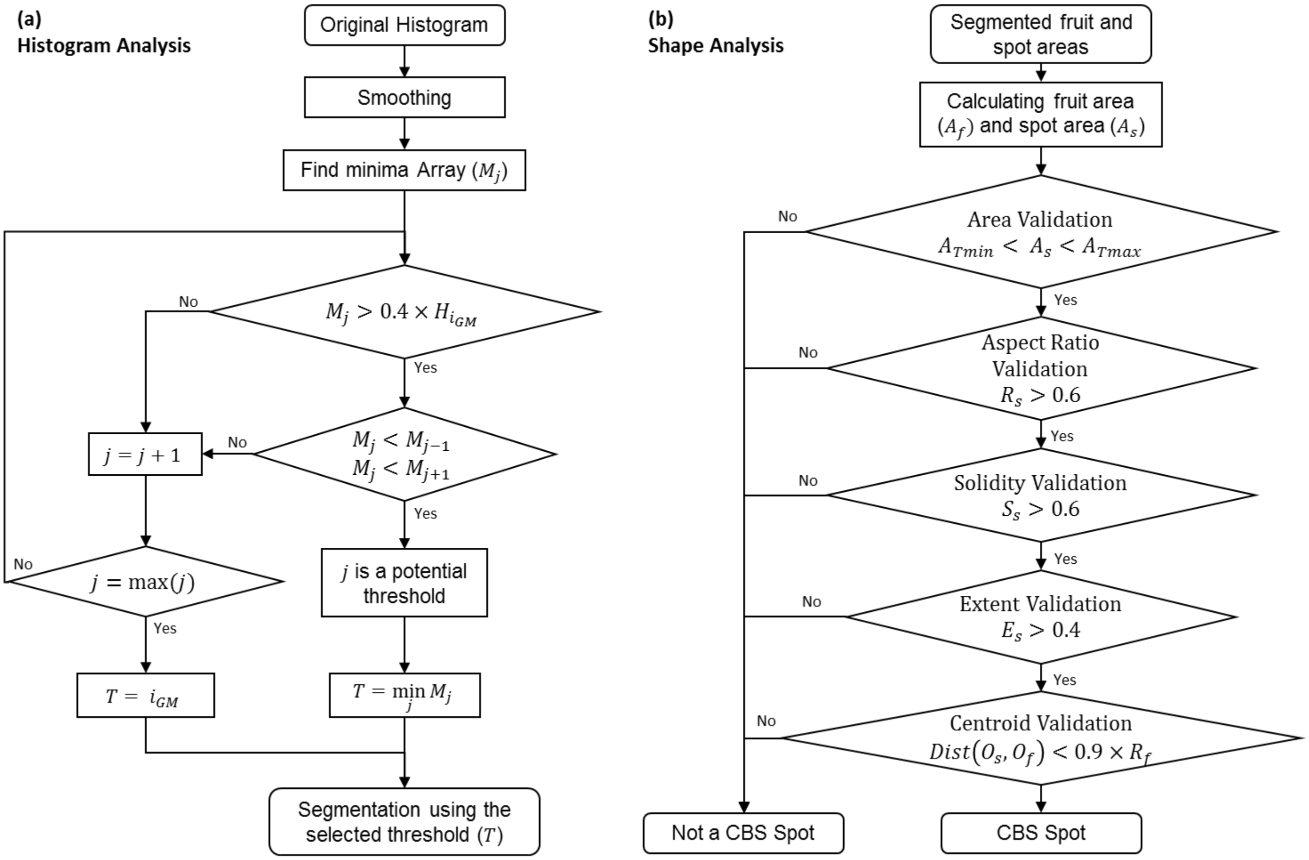

Fig 3. The flowchart of histogram and shape analysis; (a): histogram analysis to identify a threshold for segmenting the image and finding the potential CBS spots. M_j is the array of local minima, $H_{i_{GM}}$ is the general maximum value in the histogram array, and T is the selected gray value threshold for segmenting potential CBS spot; (b): shape analysis to determine if the segmented spot is actually a CBS spot. The acceptable range for the spot area was a function of the fruit area: $A_{Tmin} = 0.04 \times A_f$ and $A_{Tmax} = 0.1 \times A_f$. The aspect ratio ($R_s$) is indicating the ratio between minor and major axises. O_f and O_s are the centers of circles fitted on the fruit area and the spot area, respectively. R_f is the radius of the circle circles fitted on the fruit area.

Results and Discussion

The classification results including true positive rates (TPR) and false positive rates (FPR) for each color component as well as for three combinations of color components are shown in Table 1. The results for single color components revealed that the green channels presented the best CBS detection accuracies (TPR) with minimum error (FPR). However, the green channel in camera #1 had a slightly better accuracy. The next best accuracy was achieved when the red channel images were used for classification. The last three columns in Table 1 illustrate the results obtained by combining color components. It was determined that the best accuracy could be acheived by combining the results of the two green channels and the red channel. However, as the TPR increased using this combination, the FPR increased as well. The CBS detection using NIR color components resulted in the least TPR and highest FPR. One possible reason might be the high reflectance similarity between healthy citrus peels and CBS hard spot lesions in NIR band (700-900 nm), comparing to green and red wavebands as shown by Pourreza et al. (2015a).

Table 1. Classification accuracies (true positive and false positive rates) for CBS positive and CBS negative samples acquired for each color component separately, and also for three combinations of color components.

	Color Component								
	NIR1	Green1	Blue	Red	Green2	NIR2	Green1+Green2	Red+Green2	Green1+Red+Green2
True Positive Rate (TPR)	15%	60%	40%	45%	55%	20%	80%	75%	87.5%
False Positive Rate (FPR)	5%	2.5%	5%	2.5%	5%	12.5%	7.5%	7.5%	10%

Images of a sample citrus fruit with CBS symptom and their corresponding six color components are illustrated in Fig. 4. Although green channel was a common color component in both cameras; the two green channels did not represent similar intensities. One reason might be the lack of similarity of green components in the two cameras due to the different conversions that were applied to each of them. The images in the NIR2 channel were darker than other color components, despite the fact that citrus peel and CBS lesions have high reflectance in this band (Pourreza et al., 2015a). The original blue channel in camera #2 was replaced by the NIR2 band after conversion. Therefore, one possible reason might be less sensitivity of the blue channel (in the charge-coupled device sensor) to light in the NIR band.

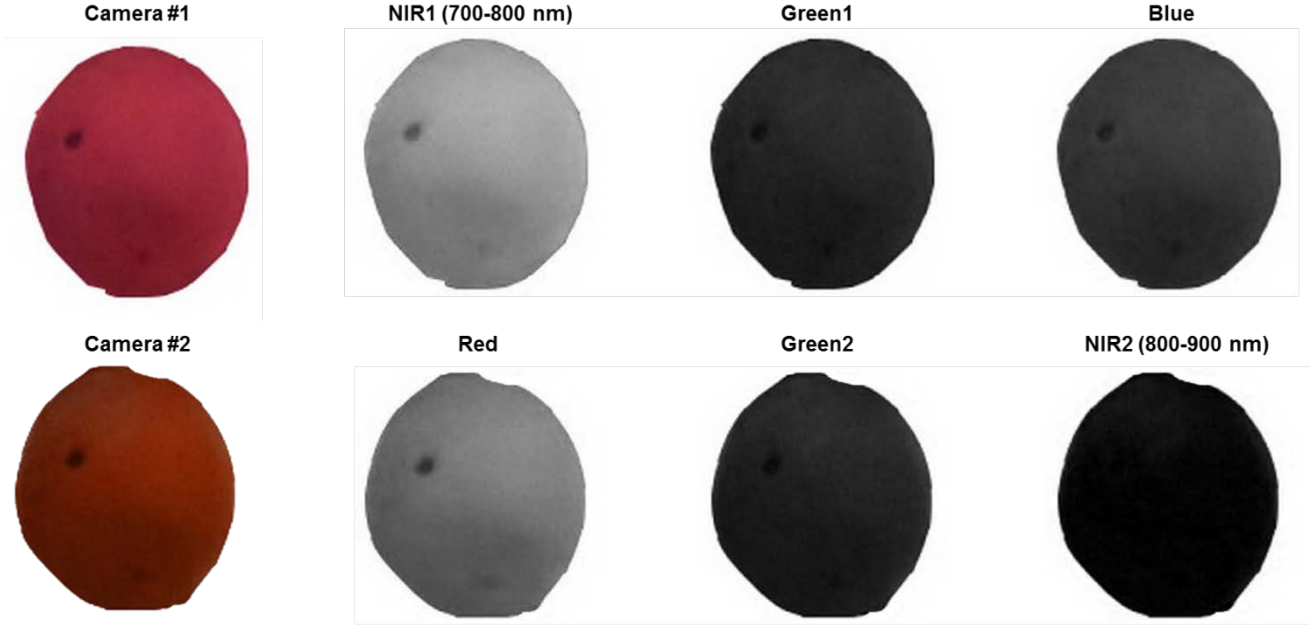

Fig 4. Images of a sample citrus fruit with one hard spot symptom as well as their corresponding six color components captured by the sensing system.

Conclusion

In this study, an affordable multispectral sensing system was developed for CBS detection under the field condition. The sensor was mounted on an UGV for field inspection. A dataset including multiband images of 80 citrus fruits (CBS positive and CBS negative) was created and used to test the proposed diagnosis method. The result showed that the green and red color components of the multispectral images had useful information that can be utilized for CBS detection under the field condition with an acceptable accuracy.

References

Bulanon, D. M., Burks, T. F., Kim, D. G., & Ritenour, M. A. (2013). Citrus black spot detection using hyperspectral image analysis. *Agricultural Engineering International: CIGR Journal, 15*(3), 171-180.

Choi, D., Lee, W. S., Ehsani, R., & Roka, F. M. Estimation of Prematurely Dropped Citrus Count on the Ground before Harvesting. In *2014 Montreal, Quebec Canada July 13–July 16, 2014, 2014* (pp. 1): American Society of Agricultural and Biological Engineers

Choi, D., Lee, W. S., Ehsani, R., & Roka, F. M. (2015). A Machine Vision System for Quantification of Citrus Fruit Dropped on the Ground under the Canopy. *Transactions of the ASABE, 58*(4), 933-946.

Junior, G. J. S., da Silva Scapin, M., Silva, F. P., Silva, A. R. P., Behlau, F., & Ramos, H. H. (2016). Spray volume and fungicide rates for citrus black spot control based on tree canopy volume. *Crop Protection, 85*, 38-45.

Kim, D., Burks, T. F., Ritenour, M. A., & Qin, J. (2014). Citrus black spot detection using hyperspectral imaging. *International Journal of Agricultural and Biological Engineering, 7*(6), 20-27.

Pourreza, A., Lee, W. S., Combs, R., Roberts, P., & Ritenour, M. A. Spectral band selection to design a low cost sensor for citrus black spot disease detection. In *2015 ASABE Annual International Meeting, 2015a*: American Society of Agricultural and Biological Engineers

Pourreza, A., Lee, W. S., Ehsani, R., Schueller, J. K., & Raveh, E. (2015b). An optimum method for real-time in-field detection of Huanglongbing disease using a vision sensor. *Computers and Electronics in Agriculture, 110*(0), 221-232, doi:http://dx.doi.org/10.1016/j.compag.2014.11.021.

Pourreza, A., Lee, W. S., Etxeberria, E., & Banerjee, A. (2015c). An evaluation of a vision-based sensor performance in Huanglongbing disease identification. *Biosystems Engineering, 130*, 13-22, doi:http://dx.doi.org/10.1016/j.biosystemseng.2014.11.013.

Schubert, T., Dewdney, M., Peres, N., Palm, M., Jeyaprakash, A., Sutton, B., et al. (2013). First report of Guignardia citricarpa associated with citrus black spot on sweet orange (Citrus sinensis) in North America. *European Journal of Plant Pathology, 137*(3), 635-647.

Tomlinson, J., Ostoja-Starzewska, S., Webb, K., Cole, J., Barnes, A., Dickinson, M., et al. (2013). A loop-mediated isothermal amplification-based method for confirmation of Guignardia citricarpa in citrus black spot lesions. *European Journal of Plant Pathology, 136*(2), 217-224.

Zhao, C., Lee, W. S., & He, D. Citrus black spot detection based on selected wavelengths using hyperspectral images. In *2015 ASABE Annual International Meeting, 2015*: American Society of Agricultural and Biological Engineers