Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2008, 4 (4), 333 - 338

A Measurement System for Quantifying Citrus Foliage Volume and Porosity

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Abstract: Accurately quantifying the variation of citrus canopy foliage parameters in an orchard has several important applications in precision management of citrus production. The major foliage parameters are considered as tree height, volume, mass, percent surface production area, and porosity. The goal of this study was to develop a measurement system that can accurately measure these parameters, particularly tree porosity and volume. A laser measurement system was developed on a small utility vehicle platform. The measurement system consisted of a laser scanner, a LabVIEW program for controlling the laser scanner, an algorithm for obtaining tree canopy volume and foliage porosity from measurements of the laser scanner, and a computer. Field and laboratory experiments were conducted to evaluate the accuracy of the system. Also, different mathematical approaches were utilized to find the relationship between the output of the laser sensor and tree density. Since it is difficult to measure true volume of the tree canopy, the performance of the system for measurement of volume, height, and width was tested on an object of known volume, height, and width. The volume of the object was calculated by summing up the area of individual slice images obtained by the laser sensor. The slice images clearly describe the surface shape of the object at each slice. The error in volume measurement was less than 1%, and the error in height and width measurement was less than 12 cm. To build a calibration equation for measurement of tree foliage porosity, three porous plates with porosities of 39.97, 47.95, and 59.96 %, were made out of paper. The distance data sets were processed using the Fourier transform and then the amplitude spectral densities were used as the porosity index. The R^2 value of the calibration equation between the porosities and measured indices was 0.987. Test results showed the promising potential of the laser scanner for measurement and mapping of tree foliage parameters in citrus orchards.

Key words: Tree canopy, laser sensor, citrus, precision agriculture

INTRODUCTION and LITERATURE REVIEW

The rapidly changing and very competitive agricultural market requires new and innovative farming strategies. Advances in technology can be applied to maximize crop profitability by optimizing the application of crop inputs, maximizing yield, and reducing the management risk factors and pollution associated with agriculture. Information-based management technology is a new concept in agriculture which is playing an increasingly important role in today's agricultural production systems, regardless of operation size or commodity type.

An information-based pest and disease management technique depends heavily on reliable and cost-effective site-specific data collection. The lack of sensors and instrumentation that can rapidly determine plant and soil characteristics in the field is a major bottleneck in the implementation of this technique.

In a citrus production system, yield variation is mainly influenced by disease, pests, weeds, soil fertility, soil moisture, variation in canopy size, and weather. Knowing plant volume and biomass at different stages of crop growth could provide valuable information on the health and needs of a crop. Plant biomass variation can cause variation in yield; therefore, knowing the crop status early in the growing season could give farmers a chance to correct the probable yield-limiting causes.

Ehsani and Lang (2002) built a laser-based system for plant volume measurement. It was able to measure plant volume and height accurately, indicating the possibility to measure the biomass and calculate the leaf area index. Tumbo (2002) et al.

compared the performance of a laser system with the performance of an ultrasonic system for tree canopy volume measurement. The laser showed better measurement accuracy especially on defoliated trees and small trees. Wei and Salyani (2004, 2005) developed a laser scanning system and corresponding algorithms for measurement of tree canopy volume. Volume measurement error of a rectangular box was 4.4%.

A laser scanner, which is also called laser radar or a laser range finder, is a non-contact optical device that measures the distance to an object in a scanning field using a pulsed laser beam. The scanner's measurement is based on the Time-of-Flight (TOF) principle. A laser source inside the scanner emits a pulsed laser beam. If this beam hits an object, part of the beam is reflected back to the scanner and hits a detector inside the scanner. The time between transmission and reception of the pulsed signal is directly proportional to the distance between the scanner and the object. The laser pulse is diverted sequentially with a specific angular interval using an internal rotating mirror. Thus, a fan-shaped two-dimensional scan is made of the surrounding area.

For agricultural and industrial applications, the distance to a target object is a valuable measurement because it can be used for determining a host of other measurements. For example, objects in an open space can be detected and counted by measuring the distances to the objects. Even the positions and shapes of the objects can be obtained. Distance measurement can be useful in generating the surface topography of a target object, such as fruit trees. The 3-D image of an object can be also reconstructed using distance measurements, obtained by moving a sensor in a 2-D plane.

Currently, laser scanners are commonly used for detecting and avoiding obstacles for use in robotics, in mapping environments for use in agricultural applications, and for measuring the surface topography of soil, plants, and objects of irregular shapes. It is expected that their applications will be extended to other areas because of their advantages over other distance-measurement devices.

The overall goal of this study was to develop a laser-based measurement system and corresponding algorithms for tree canopy height, width, volume, and porosity measurements and evaluate its accuracy. In addition, it created the tree canopy variability map of a citrus orchard.

MATERIAL and METHOD

The key component of the system was a laser scanner sensor (model LMS200, SICK Inc., Germany) which was mounted on a stand in the back of the vehicle, 1.40 m above the ground (Fig. 1). The laser scanner was turned 90° so that it scanned trees vertically. An inertial sensor (model VG440-CA, Crossbow Technology Inc., San Jose, CA) was mounted on the top portion of an antenna tower that was mounted on the rear frame of the vehicle. The inertial sensor measured the roll and pitch angles of the test vehicle to correct the laser measurement based on the measured angles. A GPS (model GPS18-5Hz, Garmin International Inc., Olathe, KS) was mounted on the top portion of the antenna tower to measure the travel speed of the vehicle. The output rate of the GPS was 5 Hz. The laser sensor, inertial sensor, and GPS communicated with a notebook computer running at a CPU speed of 2 GHz via a serial-to-USB adapter (model 2403, Sealevel Systems Inc., Libery, SC) at baud rates of 500, 38.4, and 19.2 kbps, respectively. The interface program was written using LabVIEW (ver. 8.2, National Instruments Co., Austin, TX.) to change the settings of the sensors and collect the data. The system was mounted on a John Deere gator utility vehicle (model HPX, Deere and Company, Moline, IL) to scan fruit trees in orchards. (Fig.1)

Resolutions of the laser-scanned image

The LMS200 laser scanner has two scanning range options: i) from 40° to 140° with the angular resolutions of 0.25°, 0.5°, and 1°, and ii) from 0° to 180° with the angular resolutions of 0.5° and 1°. The maximum measurement range of the LMS200 is 8 m with ± 20 mm system error in mm mode and 80 m with ± 40 mm system error in cm mode. In the system, the LMS200 vertically scanned trees in the range of 40° to 140° with an angular resolution of 0.25° and ran in the mm mode. Scanning times per cycle are 53, 26, and 13 ms at 0.25°, 0.5°, and 1° angular resolution, respectively, in both scanning ranges. The horizontal resolution of the scanned object image is based on the travel speed of the vehicle and the angular resolution of the laser sensor, and the vertical resolution is based on the distance between the laser sensor and the target trees and the angular resolution of the laser sensor (Table 1).

Algorithms for volume, width, and height measurements

Figure 2 shows the schematic view of the laser setup for tree scanning. During scanning the tree, the distance (TD) between the tree trunk and the laser, and the height (SH) of the laser from the ground were kept constant as 2.3 m and 1.4 m, respectively. The laser sensor basically measures a distance (d_k) to a spot on the tree canopy at a scanning angle (θ_k). The spot in the polar coordinator was transformed to a point in the x-y coordinator using Equations (1) and (2). As shown in Fig. 3, a new point with the negative x-value and the same y-value of the point was created because of the assumption that the laser covers only one side of the tree and the tree canopy is symmetric with respect to the vertical center line on the tree trunk. This procedure was applied to all the laser spots measured. The points adjacent to each other in the x-y coordinates were connected. This made a polygon. The area of the polygon was calculated using a function, “polygon”, which is provided by MATLAB (ver 7.1, The MathWorks Inc., Natick, MA). The volume of the slice (V_i) was obtained with the area of the polygon (A_i), the travel speed of the vehicle (S), and the laser scanning time per cycle (Δt, 53 msec) using Eq. (3). The total volume of the canopy (V) was obtained by summing up the volume of the each slice (V_i) (Eq. 4).

$$x_k=TD-d_k\cdot\sin(\theta_k) \tag{1}$$

$$y_k=SH+d_k\cdot\cos(\theta_k) \tag{2}$$

$$V_i=A_i\cdot\Delta_t\cdot S \tag{3}$$

$$V=\sum_{i=1}^{n}V_i \tag{4}$$

When the laser scan line hit the left-most edge of the tree canopy, a timer in the control program began to run. The timer stopped when the scan line reached the right-most edge. The width of the canopy (W) was calculated with the time measured by the timer ($T_{i=n}$-$T_{i=1}$) and the travel speed of the vehicle (S) using Eq. (5). In each scan, the highest y-value was recorded. The highest value among the highest y-values was selected as the height of the canopy (H) using Eq. (6).

$$W=(T_{i=n}-T_{i=1})\cdot S \tag{5}$$

$$H=\underset{i=1}{\overset{n}{Max}}\left\{\underset{k=1}{\overset{m}{Max}}(y_k)\right\} \tag{6}$$

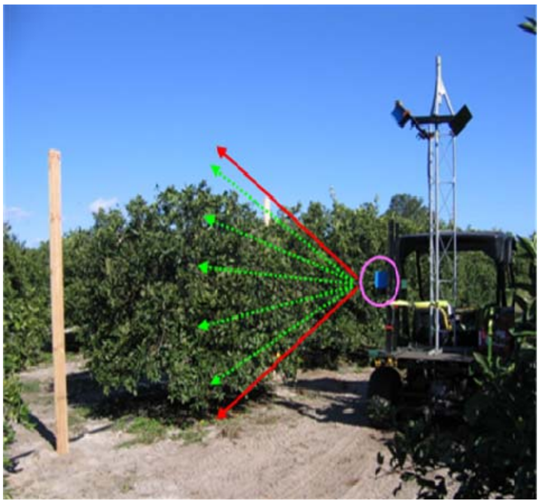


Figure 1. Test vehicle equipped with the laser scanning system.

Calibration for porosity measurement

To build a calibration equation for measurement of tree foliage porosity, three porous plates with porosities of 39.97, 47.95, and 59.96 % were made out of paper. Distance measurements by the laser scanner on each porous plate were processed using the Fourier transform. The amplitude spectral density of the transformed data was used as the index for porosity.

RESULTS

Figure 4 shows tree images scanned by the laser sensor. The scanned image clearly depicts the shapes of the trees. Even the curvature of trees can be estimated from the different image colors that indicate the distance to the tree canopy from the laser sensor.

In additional tests the performance of laser scaners was measured using a slightly different algorithm and two laser sensors instead of one. The performance of the system for measurement of volume, height, and width was tested on an object of known volume, height, and width. The volume of the object was calculated by summing up the area of individual slice images obtained by the laser sensor. Some of the slice images are shown in Fig. 5. The slice images clearly decribe the surface shape of the object at each slice. The error in volume measurement was less than 1%, and the error in height and width measurement was less than 12 cm (Table 2).

Figure 6 shows the test results of porosity measurement on three porous plates with porosities of 39.97, 47.95, and 59.96%. The R^2 value of the calibration equation between the porosities and the indexes was 0.987 as shown in Fig. 6(b). This test result shows the potential of the laser scanner for measurement of tree foliage porosity.

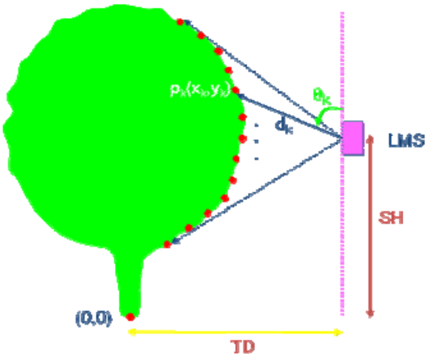


Figure 2. Schematic of the laser setup.

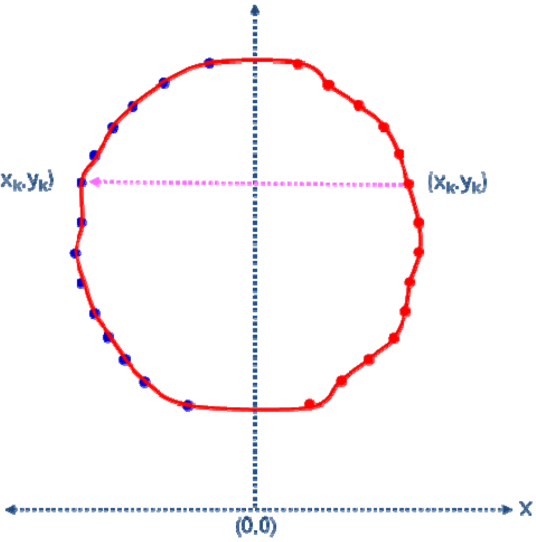


Figure 3. Laser scanning points in the x-y coordinates.

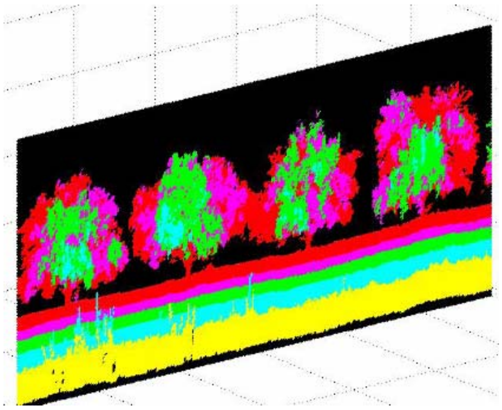


Figure 4. Tree image scanned by the laser sensor

Table 1. Horizontal and vertical scanning resolutions of LMS200 at different travel speeds and angular resolutions. The vertical resolutions were calculated under the assumption that the distance between the LMS200 and the trees is 2 m. Scanning resolutions in cm.

Travel speed (m/sec)	Sensor Orientation	Angular resolution of LMS200 (°)		
		0.25	0.5	1.0
0.5	Horizontal	**2.65**	1.30	0.65
	Vertical	**0.87**	1.75	3.49
1.0	Horizontal	5.30	2.60	1.30
	Vertical	0.87	1.75	3.49
2.0	Horizontal	**10.60**	5.20	2.60
	Vertical	**0.87**	1.75	3.49
3.0	Horizontal	15.90	7.80	3.90
	Vertical	0.87	1.75	3.49

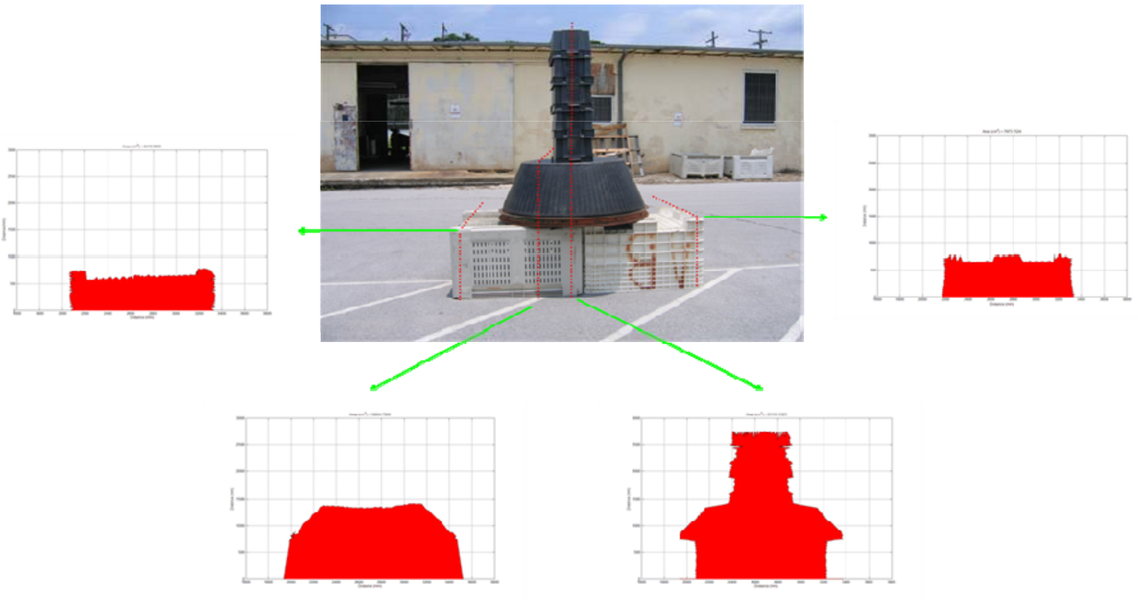
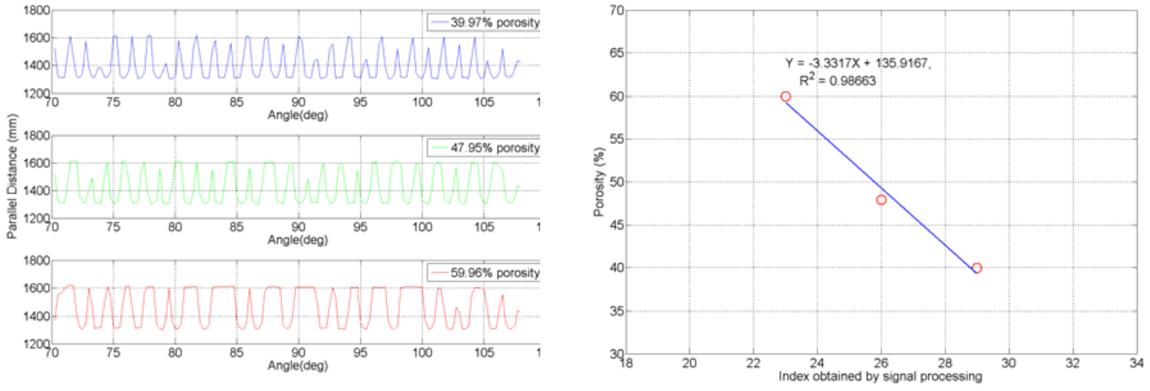


Figure 5. Object used for volume, height, and width measurement, and scanned slice images.

Table 2. Errors in volume, height, and width measurement

Parameters	True value	Measured value	|True - Measured|	Error (%)
Volume (m^3)	3.09	3.12	0.03	0.97
Height (m)	2.78	2.90	0.12	4.32
Width (m)	1.40	1.43	0.03	2.14



(a) (b)

Figure 6. Test results for porosity measurement: (a) distance measurement on each porous plate, (b) relationship between porosity and index obtained by the Fourier transform.

Figure 7 shows the the volume variability map of a citrus orchard mesured by the system developed in this study.

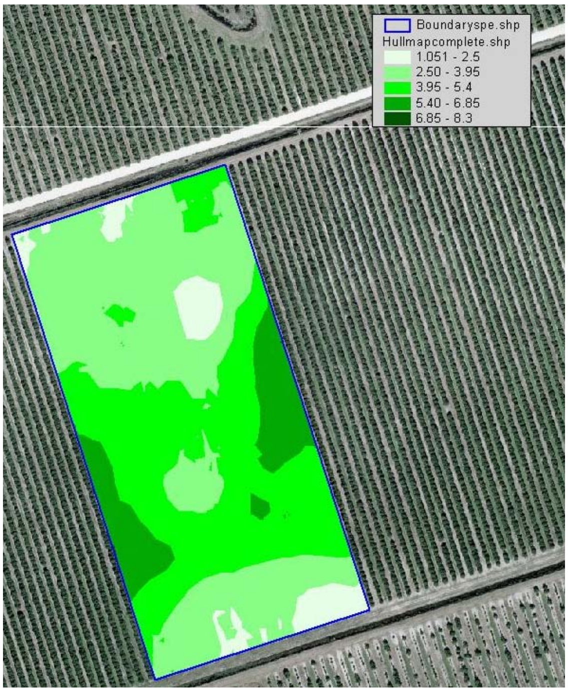


Figure 7. Contour map of tree volume (in cubic meters) in a citrus orchard at Fort Basinger, FL

CONCLUSIONS

A laser-based system for tree canopy height, width, and volume measurements was developed and tested on an object of known volume, height, and width. orchard. The error in volume measurement was less than 1%, and the error in height and width measurement was less than 12 cm. To build a calibration equation for measurement of tree foliage porosity, three porous plates with porosities of 39.97, 47.95, and 59.96 % were made out of paper. Test results showed the promising potential of the laser scanner for measurement and mapping of tree foliage parameters in citrus orchards. The field tests showed the system can accurately measure and map the canopy variability in the field.

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