Computers and Electronics in Agriculture 134 (2017) 43–50

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

# Real time canopy density validation using ultrasonic envelope signals and point quadrat analysis

Tomas Palleja *, Andrew J. Landers

*Cornell University, Barton Laboratory, Geneva, NY 14456, USA*

ARTICLE INFO

*Article history:*
Received 19 February 2016
Received in revised form 4 January 2017
Accepted 14 January 2017
Available online 21 January 2017

*Keywords:*
Density
Orchards
Vineyards
Ultrasound
Point quadrat analysis

ABSTRACT

An important goal for orchard and vineyard spraying systems is real-time adjustment of the operating parameters according to the target density, with the aim of keeping the droplets in the canopy, thus improving spray deposition and reducing spray drift. One apple orchard and two vineyards were scanned weekly using an ultrasonic system, the data provided by the sensors was correlated with the data obtained performing Point Quadrat Analysis. Results show the system has to be calibrated for each plant or variety and proved that the ultrasonic system is capable of sensing density within an average error of 4.76% during early, mid-season and full canopy, up to harvest date.



## 1. Introduction

In modern orchards and vineyards there are numerous row widths, varieties, plant spacing and variations in canopy shape and style. Canopy characteristics (height, width and density) also change as the growing season progresses. It is very important to apply the correct amount of spray to prevent over or under-dosing as this can result in inadequate plant protection; pest resistance, poor insect and disease control, increase costs and risk of chemical contamination.

An important goal for spraying systems is real-time adjustment of the operating parameters (air flow, pressure, active nozzles, etc.) according to the target density, with the aim of keeping the droplets in the canopy, improving spray deposition and reducing spray drift (Landers, 2010, 2011).

In Point Quadrat Analysis (PQA), a probe is passed through the canopy and any contact with biomass, such as leaves or fruit are identified and recorded (Smart, 1985; Smart and Robinson, 1991). The canopy is sampled at a designated height, which is usually at the fruit zone, at consistent intervals along the row. Enhanced Point Quadrat Analysis (EPQA) was developed to be more descriptive than PQA as it adds metrics which allow cluster exposure mapping and leaf exposure mapping to measure sunlight distribution (Meyers and Vanden Heuvel, 2008).

Travis et al. (1987) sprayed metal chelates on apple trees (high, moderate, and light canopy densities) and conducted mineral analysis of leaf deposits, reporting highest spray deposition and lowest variation on the trees with a light canopy. Austin et al. (2011) used EPQA to quantify the effect that canopy density exerts on the deposition of spray materials onto developing clusters, and showed that canopy density influences powdery mildew development through fungicide coverage. Using a LIDAR on apple orchards, Walklate et al. (2002) concluded that tree area/density is the best crop structure parameter to be used as a reference for pesticide dose. Diago et al. (2016) developed an image-based method to assess the percent of canopy gaps in vineyards (different conditions and varieties) and compared with PQA The determination coefficient ($R^2$) of the regressions between the percent of gaps, using both methods, exceeded 0.90 ($p < 0.05$) in each site, and $R^2$ of the global regression was 0.93 ($p < 0.05$).

Tumbo et al. (2002) proposed the use of ultrasound sensors to estimate the volume of citrus trees using the principle of time of flight to determine the distance to the target. Adopting the same system, Zaman and Salyani (2004) proved that forward speed is not as important as tree density on volume estimation and, Escolà et al. (2011) reported interferences between adjacent sensors spaced less than 60 cm apart. This method assumes constant distance from the sensor to the tree center, and small variation on this distance results in a large error on the final volume estimation (Palleja et al., 2010). Balsari et al. (2008) went one step further analyzing the Crop Identification System (CIS), developed by the 3B6 company (C.O.B.O. Divisione 3B6, Sistemi Elettronici Industriali

* Corresponding author.
*E-mail addresses:* tpc63@cornell.edu (T. Palleja), andrew.landers@cornell.edu (A.J. Landers).

http://dx.doi.org/10.1016/j.compag.2017.01.012
0168-1699/

Company, Castelletto Ticino-NO, Italy) and concluded that there is a relationship between canopy density and its ultrasonic echo signal. Balsari et al. (2009) also solved the target distance by using GPS and reported better spray deposition by adjusting the sprayer parameters (air flow and nozzles) as a function of the CIS data.

In a previous work, Palleja and Landers (2015) reported a low cost system using 4 ultrasonic sensors and a microcontroller board to estimate the canopy density as a function of the ultrasonic echoes. It was tested as the growing season progressed and the data obtained was highly correlated with the season but it was not compared to actual canopy density. The main objective of this work is to compare the ultrasonic data with a scientifically accepted method to estimate canopy density, find a correlation, and validate the ultrasonic system. The PQA was selected as it is an acceptable yet simple field method to measure key parameters of the canopy characteristics.

## 2. Materials and methods

This section describes the materials and methods used to carry out the experiments, which include a modified sprayer, ultrasound sensors, algorithms and PQA frames. The ultrasonic system is detailed in the previous work (Palleja and Landers, 2015) but, in order to assist in the reading of this paper, it is briefly described, emphasizing the improvements made.

### 2.1. Modified sprayer and ultrasound sensors

The sprayer used in this work is a Berthoud S600 axial fan sprayer (Berthoud, Cedex, France). It incorporates a GPS (Garmin 16x Series) and a set of 4 ultrasonic sensors mounted on a 3 m vertical mast. The sensors were distributed along the mast according to the target vegetation, (0.8, 1.2, 1.6 and 2 m for vineyards and 0.8, 1.5, 2.2 and 2.9 m for apple orchards).

The ultrasound sensor (Fig. 1) used in this work is the XL-MaxSonar MB7092 (MaxBotix Inc, Brainerd, MN, USA). It is water resistant (IP67), generates 42 kHz ultrasound waves, has a resolution of 1 cm and a maximum range of 7.65 m. This model has one pin to obtain the analog voltage envelope of the acoustic waveform which allows to record its echoes in a range of interest (*ROI*). This *ROI* (Fig. 2) is defined between 2 distances, ($d_1$ and $d_2$), which have to be selected in order to ensure it fully covers the scanning row despite the sensor oscillations induced by the tractor trajectory. The sound cone dimeter at the *ROI* range is about 60 cm.

### 2.2. Improved ultrasounds scanning algorithm

In order to record the *wave intensity into the ROI* ($w$) it is necessary to transform its parameters from distance domain ($d_1$ and $d_2$) to time domain ($t_1$ and $t_2$) by using the speed formula and assuming a constant speed of sound. As a nomenclature, $w$ is expressed as $w_{i,s}^k$ where $i$ is the time where $w$ was recorded, $s$ is the sample index and $k$ indicates the sensor number. Moreover $n$ indicates the number of samples, which depends on the *ROI* setup. Table 1 summarizes the *ROI* distances and $n$ for the analyzed vegetation.

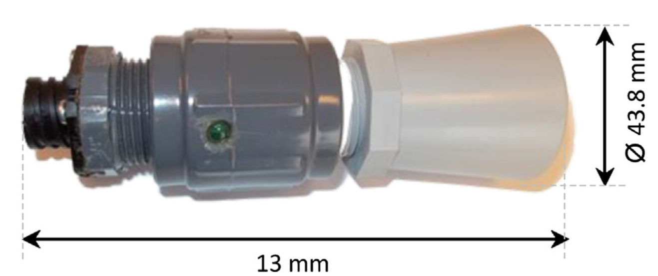


**Fig. 1.** XL-MaxSonar MB7092 ultrasound sensor plus protection waterproof case.

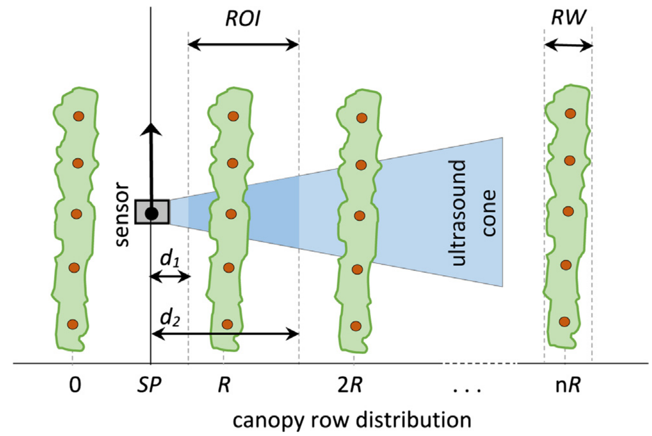


**Fig. 2.** Bird's-eye view of the *ROI* distances to fully row coverage.

The previous scanning algorithm presented problems detecting the base sensor noise (*BSN*), which is the sensor's output when no echoes are present. In this case, *BSN* should be zero but unfortunately, it is neither zero nor constant, so the *BSN* had to be estimated in every scan in order to normalize the data. In the previous work *BSN* was established as the first waveform value after the start ranging point but, sometimes, this value had an undesired peak (electric noise) that ruined the normalization. The new scanning algorithm uses three phases (Fig. 3): (A) *BSN* detection, (B) wave emission detection and, (C) *ROI* recording.

(A) *BSN detection phase*: The new BSN value is established as the average of the first 20 samples between the start ranging point ($t = 0$) and the wave emission point ($t = t_e$) with a maximum mutual difference of 0.04 V.
(B) *Wave emission detection phase*: The wave emission is the highest signal peak and it is detected by the first three consecutive samples with a minimum absolute difference of 1.2 V.
(C) *ROI recording phase*: The ultrasonic wave between $t_e + t_1$ and $t_e + t_2$ is recorded at 8.333 kHz and finally, the ultrasonic echo (wc) is computed as the average of w minus the BSN and normalized to volts (Eq. (1)).

$$wc_i^k = \frac{5}{1024}\cdot\left(\frac{1}{n}\sum_{s=1}^{n} w_{i,s}^k - BSN\right) \tag{1}$$

As a result of scanning an empty area *wc* was close to zero with no significate differences between sensors, $wc^{\{1\text{-}4\}} \approx (0.0071, 0.0052, 0.0055, 0.0071)$ V.

### 2.3. Point quadrat analysis frames

The PQA is usually performed on vineyards, at the height of the grapes, but it was necessary to estimate the average canopy density along the height of the plants. Two plastic frames were built, for vineyards (0.5 × 2 m, Fig. 4A) and apple orchards (0.5 × 2.9 m, Fig. 4B). The frames have 4 horizontal bars, matching the ultrasonic sensors' height. Each horizontal bar has 6 marks spaced 10 cm apart, indicating the position where the operator introduces the probe (1 m long, 0.5 Ø cm) to visually count the number of leaf and fruit layers (Fig. 4C). The leaves and fruits were both quantified as one layer and, the density, named *PQA*, was computed as its average. Fig. 4(D), shows an example of PQA counting, where the density is: $PQA = \frac{1}{3}(2 + 2 + 4) = 2.66$.