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Ultrasonic sensing of pistachio canopy for low-volume precision spraying

Hossein Maghsoudi [a], Saeid Minaei [a,*], Barat Ghobadian [a], Hassan Masoudi [b]

[a] Biosystems Engineering Department, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran
[b] Biosystems Engineering Department, Faculty of Agriculture, Shahid Chamran University, Ahvaz, Iran

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ABSTRACT

Effective volume rate of pesticide application on a site-specific basis can reduce the amount of agrochemicals used in precision horticulture. The prototype sprayer used in this study provided volume application rate adapted to the canopy volume in pistachio orchards on a real-time and continuous basis. An electronic control system for the detection and estimation of tree canopy dimensions was designed for application rate adjustment. Three ultrasonic ranging USS3 sensors were utilized to estimate the distance to the target at three different heights. A MLP neural network with gradient-descent back-propagation algorithm, tangent-sigmoid transfer function, and 3-7-6 topology was used for volume estimation of tree sections. Training and validation errors as well as R^2 values indicated the reliability of the network for volume prediction. Results of *T*-test for comparing the number of spray droplet impacts, coverage of (artificial) target, spray quality parameter and relative span factor between variable-rate and conventional spraying were not significant which indicates the consistency of spray distribution in selective application. Experiments showed a reduction in pesticide usage of about 34.5% by means of variable-rate technology (41.3, 25.6 and 36.5, respectively for the top, middle, and bottom sections of tree canopy). Precise application of agrochemicals reduces both costs and environmental pollution by supporting a decrease in the amount of delivered spray.

1. Introduction

Variable rate spraying of the canopy allows growers to apply adjusted volume rate of pesticides to the target, based on canopy size, season and growth stage and to apply plant protection products in an economic and environmentally sound manner. Since four decades ago, ultrasonic sensors have been employed in agriculture for different purposes (Planas et al., 2011). One of these applications is detection and ranging to obtain structural data from trees. The first advances in this field were related to the application of plant protection materials such as pesticides in different orchards. When dose adjustment according to canopy structure was proposed (Byers et al., 1971; Morgan, 1964) some researchers began to design electronic systems for measuring canopy structural parameters. The first proposed systems to determine canopy volume used many ultrasonic sensors on a vertical mast (McConnell et al., 1983) or mounted on the sprayer (Giles et al., 1988). Because of the state-of-the-art of the application technologies, using this information in real time was not possible. Usage of ultrasonic sensors has been reported only for detection of canopy presences by some researchers (Brown et al., 2008; Giles et al., 1987). In this method spraying was done exclusively when canopy was in front of the sprayer. Another application was citrus trees spraying from constant given distance (Moltó et al., 2000). The nozzles are located on a movable arm which follows the boundary of the tree according to data collected from sensors. In this research ultrasonic sensors were placed 50 and 75 cm apart. The same authors improved another sprayer which was able to spray with 3 different dosage according to width estimation of canopy made by ultrasonic sensors (Moltó et al., 2001). There was 1-without spraying when there was no vegetation, 2-half spraying when there was little vegetation in front of the sensors and 3-full spraying when sensors detected width of canopy above a given threshold. This achievement led the way to a continues variation of flow rate according to variability of the canopy along citrus groves, vineyard and fruit orchards rows (Escolà et al., 2002, 2007, 2013; Gil et al., 2007; Llorens et al., 2010; Solanelles et al., 2002, 2006). Different researches have been conducted for automatic measurement of canopy dimensions in citrus groves. Early

* Corresponding author at: Biosystems Engineering Department, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-336, Tehran, Iran. Tel.: +98 21 48292466; fax: +98 21 48292200.
E-mail address: minaee@modares.ac.ir (S. Minaei).

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works were concentrated on comparing of manual volume estimation with LIDAR and ultrasonic sensors measurements (Tumbo et al., 2002). Results indicated good correlation between the estimation made by LIDAR and ultrasonic sensors, while correlation with manual measurements was lower. Differences between electronic and manual measurements were attributed to higher resolution of data gathered with sensors by authors. This system included a vertical mast with equipped 10 ultrasonic sensors. Alternated sensors were fired in different groups sequentially, to prevent signal interference. This system was later implemented for providing a canopy volume map in citrus groves with attached DGPS receiver (Schumann and Zaman, 2005). Observation showed larger differences between manual and sensor estimations in less dense trees. This canopy information was used to adjust fertilizer dose rate (Zaman et al., 2005) and estimate fruit yield in citrus groves (Zaman et al., 2006). LIDAR sensor in relation to vertical sampling resolution can gather much more information from canopy parameters for a more accurate estimation in comparison with array of ultrasonic sensors (Gil et al., 2013; Palleja et al., 2010; Rosell et al., 2009). The results of these tests were satisfactory, but extrapolation of these results to trees with different structures is not easy.

Although several groups have developed prototypes to adjust the application flow rate to the variations in canopy structural parameters using ultrasonic sensors, a review of various targeted spraying methods (Van de Zande et al., 2008) showed that solutions for variable rate spraying in orchards are still in prototype phase, however, there are already commercially available sprayers for weed control and plant fertilization in arable land. The objective of this research was to develop a prototype that can apply a variable amount of pesticide according to the canopy variability along the crop row for agrochemical applications in pistachio orchards. Thus this paper consist of two main parts: (a) a description of the electronic system for measurements of canopy structural parameters and the calculation of the adapted flow rate; and (b) comparing of the prototype with conventional spraying to evaluate benefits of variable application method. The goal of this study is improving computational method for calculating of the output flow rate using artificial neural network, in order to solve the problem there has been in the previous researches. By automatically spraying the optimal amount of spray mixtures into tree canopies and seizing the spray application beyond target areas, the variable rate sprayer with automatic control can reduce the amount and cost of pesticides for growers, reduce the risk of environmental pollution by pesticides, and provide safer and healthier working conditions for workers.

2. Materials and methods

The variable rate prototype for precision spraying and its components are presented in this section (Fig. 1). This prototype consists of two main mechanical and electronic parts. Data collected from the sensors and the shaft encoder are delivered to the microcontroller for data processing and the output signal is sent to the actuator in order to adjust valve openings. First, changes made in the configuration of the conventional sprayer are mentioned and then the electronic parts will be described.

A tractor mounted orchard sprayer with 400 liter tank capacity equipped with a 40 bar pressure pump (ANNOVI REVERBERI Ltd., AR530 model, Italy) was implemented. This pump output was divided into 3 parts according to manufacturer's instructions. Nozzles were mounted at 3 different heights on a vertical mast bolted to the sprayer chassis (Fig. 2). In order to reduce mast vibration during tractor operation in the orchard, transverse bars were used as holders. Another vertical mast was used for attaching 3 sensors at the same height as the nozzles. Distance between the sensor's mast and the nozzles was 2 m.

In this research 3 ultrasonic sensors (USS3 model, Best technology Ltd., Japan) were used which consisted of 2 transmitter and receiver sonars (instruments for converting electronic pulses to sound waves and vice versa) located on a board (Fig. 3). The distance to the target is determined by calculating the time between transmitting and receiving the reflected wave from the target surface (Masoudi et al., 2012). This sensor has a digital output which indicates sensor distance to the nearest target in cm (accuracy of 1 cm) and its analog output (0–10 volt) is proportional to the distance from 4 to 1000 cm. The connections between sensors and pc is shown in Fig. 4. Internal parameters were adjusted according to the working conditions and the required distance for measurement (Masoudi et al., 2011) in the range of 15 to 220 cm. As the distance between pistachio rows is about 4 m and the tractor travels between the rows, this range was selected. However, any sensing

Fig. 1. Variable rate sprayer for fruit tree protection.