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Variable Rate Sprayer System for Citrus Orchards Using Tree Canopy Measurement with On-The-Go (OTG) Sensors

Laiq Hasan [1], Asif Ali Khan [2], Rehmat Ullah [3], Yasir Saleem Afridi [4]

[1,2,3,4] Department of Computer Systems Engineering, University of Engineering and Technology, Peshawar, Pakistan

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Abstract

Pesticide application plays a key role in maintaining the quality of citrus orchards and helps protect them from various biological damages. Pakistan is the eleventh largest producer of citrus with 0.192 million hectares of area under citrus cultivation and an average production of 2.001 million tons. However, production and earning of citrus is much lesser when compared to the international standards. This is mainly due to the lack of best management practices. For instance, in Pakistan, agrochemicals are applied uniformly without considering inter and intra-field variability. In conventional system, the applicator opens the sprayer's nozzles without considering the tree canopy which is not only less effective in heavy canopy trees but also result in over-use of expensive agrochemicals. The operator cannot halt the sprayer in gaps between trees in line. The Variable Rate Sprayer System (VRSS) is expected to achieve two objectives: (1) Reduce the wastage of expensive agrochemicals by halting the spray between trees, and (2) Apply an optimum amount of spray on each tree based on its canopy size. Measuring tree canopy however is a challenging task due to the irregular and inhomogeneous tree shapes. In this paper, we have proposed an ultrasonic sensors' based approach to measure tree canopy size based on which a variable rate spraying system is developed. The basic components of the system include: Ultrasonic sensors, processing unit (microcontroller), flow control mechanism and nozzles. Stepper motors are used to control the sensors' movement. Sensors measure the tree canopy size and pass it to the processing unit which activates the flow control module and set the nozzles' opening all in real time. The proposed system applies the right amount of agrochemicals at the right time and place. This reduces the pest level below the economic threshold and will improve the agricultural production in Pakistan.

Keywords: Variable Rate Sprayer System, Tree Canopy, Ultrasonic Sensors, Nozzles

1. Introduction

In Pakistan, citrus cultivation is heavily concentrated in the province of Punjab with 95% of total citrus area and 96% of total production. According to the **Pakistan Economic Survey 2023-24**, Pakistan exported **782,000 metric tons** of citrus, earning **75.465 billion rupees** during the **fiscal year 2023-24 (July-March, provisional figures)**. However, the production and earning is lower as compared to international standards due to the lack of best management practices. In Pakistan, the citrus orchards are being grown at 20' × 20' spacing with sufficient exposed area depending upon plant canopy. Traditionally, agrochemicals are applied homogeneously without taking care of inter and intra field variability by using conventional spraying methods. The mechanized sprayers, used to spray agrochemicals on orchards, spray uniformly without considering substantial variation in plant population and canopies. This uniform application of agrochemicals results in either over- or under-application. Over-application of agrochemicals is usually advised as it guarantees effectiveness. However, this raises the danger of toxic residue levels on fruit products and may also inhibit the plant's growth. Over-application in areas without trees is a wastage of expensive agrochemicals besides being an environmental hazard. The drift and leaching of applied agrochemicals can be a threat to the environment and underground water reserves. On the contrary, under-application may restrict crop yield. It is therefore necessary to apply Plant Protection Products (PPP) with utmost efficiency and according to the field conditions to prevent environmental pollution and reduce production cost as discussed in Escolà et al. (2013). The rest of the paper is structured as follows: Section 2 summarizes the state-of-the-art variable rate technologies and discusses their pros and cons. Section 3 presents the proposed system while section 4 concludes the paper.

2. Related Work

Various international researchers are working to develop accurate variable-rate flow control systems integrated with sensors that precisely apply agrochemicals at the orchards. These variable rate systems are used for spot application of both pesticides and fertilizers. The flow control system is adjusted according to the tree canopy which can be measured in different ways. For instance, Molto et al. (2001) have used ultrasonic sensors to detect and measure tree canopies. This allows adjustment of the spray volume according to the crop structure. The results showed that the spray volume significantly reduced the cost while maintaining spray parameters i.e. coverage and penetration. Tumbo et al. (2002) used ultrasonic and laser sensors to estimate canopy characteristic (height, width, volume and leaf area) and compared them with manual measurements. The two systems present valuable tools for automatic mapping and quantification of canopy volumes in citrus groves. Zaman et al. (2010) developed an automated system for long leaf weeds detection and mapping for site-specific application of agrochemicals to reduce cost and environmental pollution. The developed machine vision system includes two components: image capturing and image processing. In image processing module, every color image is downloaded to computer in real-time. It is converted into binary based on pixel's green value (which is compared to a threshold). In the next step, edge detection algorithm is applied to extract edges from the image. Peak value in Hough space of the edge image is calculated which represents the main feature of long leaf weeds. The experiment was conducted at 0.4 ha area of the selected wild blueberry field in central Nova Scotia. The results indicated that the automated machine vision system has a potential to detect weeds in real-time for site-specific application of agrochemicals in wild blueberry fields. Liorens et al. (2010) compared ultrasonic and LIDAR sensors' based systems with traditional manual canopy measurement practices to determine plant characteristics: height, width, and volume or leaf area. They showed that ultrasonic sensors determine average canopy characteristics while LIDAR sensor provides detailed information about the canopy. They concluded that ultrasonic and laser sensors are interesting tools to improve the pesticide application process. Jejcic et al. (2011) developed an automatic system, Automatic Spraying Mode (AM), for targeting spraying in orchards using an ultrasound processing system at a forward speed of 3 Km/h. This system consisted of control unit, ultrasound sensors, RGB camera and an electric box containing a tachometer unit with display. The automatic system was compared with other spraying systems not using ultrasound guidance, Control Spraying Mode (CM). Assessment of spray application of AM showed 20.2% saving of spray per nozzle in comparison to the spraying application in CM and the distribution, coverage and deposition were the same in both spraying modes.

Escolà et al. (2013) fabricated an orchard sprayer prototype running a variable-rate algorithm to adapt the volume application rate to the canopy volume in orchards all in real-time. They divided the sprayer system into three parts: the canopy characterization system (using a LiDAR sensor), the controller executing a variable-rate algorithm and the actuators. The controller determines the intended flow rate by using an application coefficient (required liquid volume per unit canopy volume) to convert canopy volume into a flow rate. The sprayed flow rates were adjusted via electromagnetic variable-rate valves. The goal of the prototype was to keep the actual application coefficients as close as possible to the objective. Strong relationships were observed between the intended and the sprayed flow rates ($R^2 = 0.935$) and between the canopy cross-sectional areas and the sprayed flow rates ($R^2 = 0.926$). In addition, when spraying in variable-rate mode, the prototype achieved significantly closer application coefficient values to the objective than those obtained in conventional spraying application mode. Gil et al. (2013) found that structural characteristics of the canopy are a key consideration for improving the efficiency of the spray application process for tree crops. They developed a variable prototype sprayer for vineyards. This prototype can modify the sprayed volume application rate according to the target geometry by using an algorithm based on the canopy volume inspired by the Tree Row Volume (TRV) model. Variations in canopy width along the row crop are electronically measured using several ultrasonic sensors placed on the sprayer and used to modify the emitted flow rate from the nozzles in real time; the objective during this process is to maintain the sprayed volume per unit canopy volume (L/m3). Field trials carried out at different crop stages for Merlot and Cabernet Sauvignon vines indicated a good relationship between the applied volume and canopy characteristics. The potential pesticide savings were estimated to be 21.9% relative to the costs of a conventional sprayer system.

3. Proposed System

The proposed variable rate orchard sprayer system is presented in Figure 1.

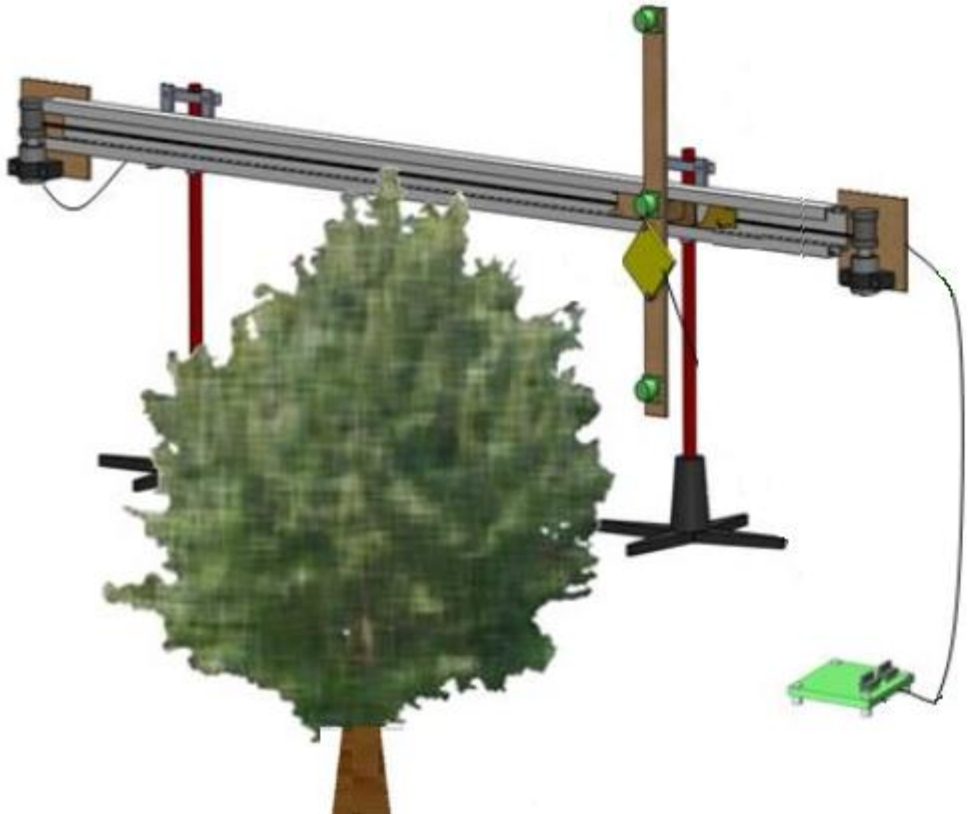

Figure 1: Block diagram of the proposed variable rate orchard sprayer system

The system is designed to achieve the following objectives:

i. Sense target i.e. detect the presence of tree
ii. Measure tree’s canopy volume
iii. Adjust spray output according to the canopy volume

The methodology adopted to accomplish these objectives is divided into two major steps.

i. Tree Canopy Measurement
ii. Flow Control

These steps are further explained in the following subsections.

a. Tree Canopy Measurement

As discussed in the previous section, canopy measurement is the most difficult and challenging task in variable rate sprayer systems. Multiple approaches are presented in literature to measure tree canopies. The most widely used approaches are as under.

a) Canopy Measurement Using Image Processing: In this approach, a light resolution camera is installed on the system to capture the tree image. The onboard computer applies multiple algorithms to extract tree parameters such as length, width and breadth. The problem with this approach is that image processing algorithms demand high computational power and are time consuming. The goal in variable rate technologies is to minimize both these factors and achieve real time performance.
b) LiDAR Based Canopy Measurement: Both airborne and ground-based LIDARs have been widely used in agriculture for various purposes. For instance, in variable rate technologies, LIDAR is the most reliable source for measuring tree canopies. However, these sensors are expensive and adds up to the overall system's cost.
c) Ultrasonic Sensor Based Canopy Measurement: These are low-cost, easy-to-use sensors having range from 2cm to 3m. Ultrasonic sensors are widely in use in variable rate systems. The sensor comes in pair i.e. sender and receiver. The sender generates the ultrasonic waves and receiver catches those waves back if reflected from a certain surface. For tree canopy measurement, these sensors are installed on either a wooden or aluminum rod as shown in Figure 1.

Due to their low cost and availability in the local markets, we have chosen ultrasonic sensors' based approach. The sensors are installed on a wooden rod which is placed on a slider. Stepper motor is used to move the wooden rod on the slider and adjust it as needed. The wooden rod moves from one end of the tree to another end to measure its width. This movement is adjusted automatically i.e. the stepper motor continues to move the rod as long as the ultrasonic sensor receives the deflections. Since step size of the stepper motor is defined, after full passing, the software counts the number of steps and multiplies it with the step size to get the total distance. For measuring tree's length, sensors have been installed on various identified lengths on the wooden rod. Recieved signals of all sensors are monitored to measure tree's lenght.

b. Flow Control

The software part of the variable sprayer system is as critical as the hardware part. In first step, the sensors' measure various parameters and forward their values to the flow control module. Based on the tree parameters, the flow control module automatically sets the nozzles' openings and pressures. Besides, opening and closing of the desired nozzle(s) is/are also controlled by this module.

4. Conclusion

Selective application of agrochemicals is desirable for various reasons. This ensures the environmental, economic and safety criterion of good agriculture practices. Available Variable Rate Sprayer Systems meet this goal of selective applications but they are either more expensive or less efficient. In this paper, we presented a customized low-cost prototype of a VRSS. We have developed this system for citrus orchards but this can be used in any other orchard as well with slight or no modifications. The components used in the system are low-cost and readily available in local market. The proposed system largely minimizes the human efforts and spray cost.

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