Computers and Electronics in Agriculture 76 (2011) 175–182

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Development of prototype automated variable rate sprayer for real-time spot-application of agrochemicals in wild blueberry fields

Qamar Uz Zaman[a,*], Travis J. Esau[a], Arnold W. Schumann[b], David C. Percival[c], Young Ki Chang[a], Scott M. Read[a], Aitazaz A. Farooque[a]

[a] Engineering Department, Nova Scotia Agricultural College, Truro, B2N 5E3 NS, Canada
[b] Citrus Research and Education Centre, University of Florida, Lake Alfred, FL 33850, USA
[c] Environmental Sciences Department, Nova Scotia Agricultural College, B2N 5E3 NS, Canada

ARTICLE INFO

Article history:
Received 13 July 2010
Received in revised form
30 December 2010
Accepted 28 January 2011

Keywords:
Controllers
Precision agriculture
Sensors
Weeds
Herbicides
Spot-application

ABSTRACT

An automated prototype variable rate (VR) sprayer was developed for control of 8 individual nozzles on a 6.1 m sprayer boom for in-season, site-specific application of agrochemicals on weeds. The sprayer boom was divided into 8 sections and mounted behind an all-terrain vehicle (ATV) at 76.2 cm above the ground. The variable-rate control system consisted of 8 ultrasonic sensors (one per spray section) mounted on a separate boom in front of the ATV, DICKEY-john Land Manager II controller and flow valve, solenoid valves and an 8-channel variable rate controller interfaced to a Pocket PC (PPC) using wireless Bluetooth® radio with Windows Mobile® compatible software. This type of VR sprayer does not use prescription maps, but relies on sensors to provide real-time weed detection information which is used to dispense correct agrochemical rates for the weeds. The sprayer can be used for in-season, spot application (SA) of agrochemicals by activating specific boom sections where the weeds have been detected.

Two wild blueberry fields have been selected in central Nova Scotia to evaluate the accuracy of the VR sprayer. Water sensitive papers (targets) were stapled to weeds randomly selected in two tracks of each field. The papers were orientated parallel to the ground. The percent area coverage (PAC) of the sprayed targets with both SA and uniform application was calculated by an imaging system. Non significance of the *t*-test for uniform versus SA targets PAC indicated that there was no significant bias in the SA and that the SA was accurate. The PAC with both applications ranged from 10.01% to 81.22% and from 5.39% to 72.67% in field 1 and field 2, respectively. Weed heights at selected points were measured and related with percent area coverage to examine the sprayer performance for spray application. Linear regression analysis showed that weed heights were significantly correlated (R^2 ranged from 0.60 to 0.75) with percent area coverage of the targets in selected fields with both applications. It is proposed that herbicide should be applied at early stage of weed growth (weed height ranged from 35 cm to 55 cm and plant height ranged from 12 cm to 30 cm) for appropriate application with these specific VR sprayer arrangements. Based on these results, the VR sprayer was efficient and accurate enough for spot-application of agrochemicals usage in wild blueberry fields.

1. Introduction

Weeds are the major yield-limiting factor in wild blueberry fields (Yarborough, 2006). Weed flora in blueberry fields traditionally consisted of slow spreading perennial species whereas many of the new species invading blueberry fields are common annual weeds of arable fields that produce large number of seeds and require control with herbicides both in prune and production year (Jensen and Yarborough, 2004; McCully et al., 1991). Traditionally, herbicides are applied uniformly in wild blueberry fields, but weeds are not distributed uniformly within fields. In these situations, spatial information management systems hold great potential for allowing producers to fine-tune the locations, timings, and rates of herbicide application.

Many researchers have attempted to develop variable rate (VR) technologies for various crops (Rockwell and Ayers, 1994; Giles and Slaughter, 1997; Steward and Tian, 1999; Tian, 2002; Carrara et al., 2004; Miller et al., 2005; Zaman et al., 2005, Schumann et al., 2006; Dammer et al., 2008) to date little attention has been paid to wild blueberry production systems. Michaud et al. (2008) developed a VR prototype sprayer to deliver pesticides based on prescription maps, developed in GIS software, using aerial spectral scans of wild

* Corresponding author.
E-mail address: qzaman@nsac.ca (Q.U. Zaman).

0168-1699/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.compag.2011.01.014

blueberry fields. The system was sensitive to positional error caused by global positioning system (GPS) and obtaining up-to-date aerial photography was expensive, the quality was quite variable, and data processing for weed detection was also intensive and difficult.

Several machine vision systems have been developed to detect weeds in different cropping systems (Sui et al., 1989; Shearer and Holmes, 1990; Zhang and Chaisattapagon, 1995; Tian et al., 1997; Zhang et al., 2009), because real-time weed detection at the time of spot spraying could be very valuable for cutting chemical costs and reducing environmental contamination. However, these vision systems, based on morphological or textural weed detection methods, generally needed a relatively high image resolution, and the detection algorithms were quite complicated and computationally expensive (Meyer et al., 1998; Zhang et al., 2009). There is a need to develop spot-specific herbicide application technologies that do not require high resolution image processing techniques, but rely on sensors to sense the weed in real-time and provide the weed detection information to fast VR controllers for spray at right targets.

Ultrasonic sensors are widely accepted for quantification of plant heights (Sui et al., 1989; Schumann and Zaman, 2005). Swain et al. (2009) developed and tested low-cost ultrasonic system for weeds (taller than plants) and bare spot mapping in real-time within wild blueberry fields during growing season. They reported that ultrasonics performed well to detect tall weeds (taller than plants) and bare spots in wild blueberry fields.

Advances in sensing technology and VR control systems have offered new opportunities for detecting weeds and spot-application of agrochemicals in a specific section of the VR sprayer boom where the weeds have been detected. Many commercial controllers have been developed to deliver agrochemicals on site-specific basis using GPS guided prescription maps within field (DICKEY-john Land Manager II: DICKEY-john Corporation, Auburn, IL; MidTech Legacy 6000 controller: Midwest Technologies, Springfield, IL; Raven 660 controller: Raven Industries Inc., Sioux Falls, SD). Schumann and Hostler (2009) with the partnership of a machinery manufacturer (Chemical Containers, Inc., Lake Wales, FL, USA) developed an 8-channel computerized VR controller consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a handheld pocket PC computer (PPC). A computerized 8-channel variable rate controller is linked with PPC using wireless Bluetooth®. Typically this controller does not use prescription maps, but relies on sensors to provide real-time weed information which is used to dispense the correct herbicide rate for the weed eradication within field. The reliable and fast ultrasonics and VR controllers could be used to develop VR rate sprayer for in-season, spot-application of agrochemicals in wild blueberry cropping system.

In this study, an automated VR prototype sprayer consisting of ultrasonic sensors, 8-channel computerized VR controller, Land Manager II controller, solenoid valves, PPC with operating software was developed. The performance of VR sprayer for in-season real-time weed detection and spot spraying was evaluated in wild blueberry fields.

2. Materials and methods

2.1. Development of prototype variable rate (VR) sprayer

The prototype VR sprayer was developed for spot-application of herbicides on tall weeds in wild blueberry cropping system. The VR sprayer is consisting of ultrasonics, computerized 8-channel VR controller (VRC), Land Manager II controller (LMC), handheld Pocket PC (PPC) with operating software, servo valve and flow meter, solenoid valves, nozzles and a tank capacity of 209 l (Fig. 1). The VR sprayer was mounted on an all-terrain vehicle (ATV). The 6.1 m sprayer boom was divided into eight sections (76.2 cm each section) and mounted behind the ATV at 76.2 cm above the ground. The boom height was adjustable so that weed sensing area and spray could be fine-tuned to crop conditions. Eight solenoid valves and nozzles (one valve and one nozzle in each section) were mounted on the boom with a uniform (76.2 cm) interval between them. The nozzles were TeeJet TP8004 nozzles (Maritime Supplies Limited, Monton, NB, Canada) with a spray angle of 110°. Using a series of T joints, the line connecting the distribution valve to each section was then connected to each solenoid valve to which a nozzle was fitted as closely as possible. The model 2201A solenoid valve (Delware Pump and Parts Limited, Delware, ON, Canada) was operated on 12-V and consumed only 13 W. The feed line from the pump was going through a flow valve and flow meter then was separated into two lines, each line (right and left) feeding four sections of the boom. The pump was operated by a Honda gas engine (Honda Inc., NS, Canada).

The wide angle beam, long range and fast measurement cycle Maxbotix LV-MaxSonar-EZ1 Sonar Module ultrasonic sensors (Robotic Inc., Boisbriand, QC, Canada) were incorporated vertically into individual boom section to detect weeds taller than blueberry plants in real-time within wild blueberry fields. The 6.1 m long sensor boom was mounted in front of the ATV at 0.90 m height above ground surface. The sensors were connected to VRC (Chemical Containers, Inc., Lake Wales, FL, USA). The VRC consists of electronic hardware with internal firmware and matching Windows Mobile 6.0 software on a PPC. VRC was interfaced to a PPC and could be operated easily from a PPC using wireless Bluetooth® radio). VRC received target (weeds taller than blueberry plants) detection signal from sensor and opened the valve in a specific section of boom where the target had been detected. The plant height raged from 12 cm to 27 cm. The VRC was installed in the ATV cab and was connected to LMC (DICKEY-John Corporation, Auburn, IL, USA). After receiving target detection information from the sensor VRC automatically communicated with LMC. The LMC regulated discharge of the nozzles in specific sections of the boom where the target had been detected based on ground speed obtained from WAAS-enabled DGPS (Garmin International Inc. Olathe, KS, USA) through a DJ servo valve and DJ flow meter (Fig. 2).

2.2. Laboratory tests

Ultrasonic sensors were calibrated to measure the distance from the ultrasonic sensor to the target in the metal shop at Nova Scotia Agricultural College (NSAC), Truro, NS, Canada. The distances (from sensor to the target; cardboard) were measured three times at ∼12.7 cm intervals up to 152.4 cm with measuring tape. The corresponding voltages were recorded using a digital multimeter at the time of distance measurements for comparison. The multimeter was connected to a sensor. The voltages were digitized by 10-bit format from analog to digital to make compatible with the program software installed in PPC. The measured distances (from sensor to target) and voltage were compared by linear regression using SAS 9.1 software (SAS Institute, Cary, NC, USA) to examine the performance accuracy of the ultrasonic distance measurements. The calibration equation was incorporated into program software installed in PPC.

An experiment was conducted in the metal shop at NSAC to calculate response time (i.e., lag time between sensor detection and target spray) for VRC to open the valve at right target after receiving target detection information from the sensor. The time to build up the cone after the discharge is started has been added in calculating response time for precise real-time spray at right target. An LED bulb was wired into switch #8 on VRC. A μEye camera (UI-1220SE/C, IDS Imaging Development System Inc., Woburn, MA,