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Laser-Guided Intelligent Greenhouse Spray System to Deliver Variable-Rate Water, Chemicals, and Nutrients

Heping Zhu[1] and Peter Ling[2]

[1]Agricultural Engineer/Lead Scientist, USDA-ARS ATRU, 1680 Madison Ave, Wooster, Ohio 44691 U.S.A.; [2]Professor, FABE, OARDC/The Ohio State University, Wooster, Ohio 44691 U.S.A

heping.zhu@usda.gov

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Summary

A precision, variable-rate spray system was developed for greenhouse applications. The system utilizes standard greenhouse booms equipped with laser sensors to detect plants and deliver targeted sprays of water, chemicals or fertilizer in a sustainable manner.

INTRODUCTION

The global greenhouse planting area is growing consistently every year. Large commercial greenhouses usually produce various types of plants with various growing sizes in a short period of time to meet the market requirements. Spray applications of pesticides, growth regulators, and nutrients along with irrigation are critical to produce healthy and marketable crops. During the crop production cycles, however, it is very common that small plants are over sprayed, large plants are under sprayed, and empty areas are unnecessarily sprayed, causing significant chemical waste and environment contamination. Thus, precision variable-rate spray technology is needed to improve application efficiency in this controlled environment plant production.

The intelligent spray system offers advantages to deliver variable-rate foliar-applied products precisely. The technology, varying spray outputs with plant architecture and foliage volume, has made significant advances for field orchard crops (Chen et al., 2020). However, due to the environment of a greenhouse being significantly different from that of a field, adapting field equipment to function well in a greenhouse is a new challenge. It would be desirable to extend the already demonstrated variable-rate technology for field applications (Shen et al., 2017) to greenhouse environments economically.

Typical greenhouse operations have the mobile boom travels, at a constant speed, from one end to the other end of a compartment to spray the whole growing area. These over-the-canopy mobile boom sprayers have shown more uniform spray deposits than that of traditional handheld equipment. For the precision variable-rate spraying, detection and characterization of plant is required to spray not only where there are plants but also the right spray volume for plants of different sizes. To reduce the costs of this technology adoption for commercial production greenhouses, minimal modifications of existing greenhouse mobile spray equipment is desirable. Thus, we took advantages of the similarity of using nozzles to manipulate spray outputs and made adaptation of variable-rate spray control systems designed for field sprayers. Our previous analysis has shown a spray control system equipped with a 270° indoor-use laser scanning sensor should be sufficient to control the variable-rate operation with precision (Yan et al., 2018, 2019).

The design of the precision variable-rate spraying technology for greenhouse applications (Figure 1) was based on the field variable-rate system.

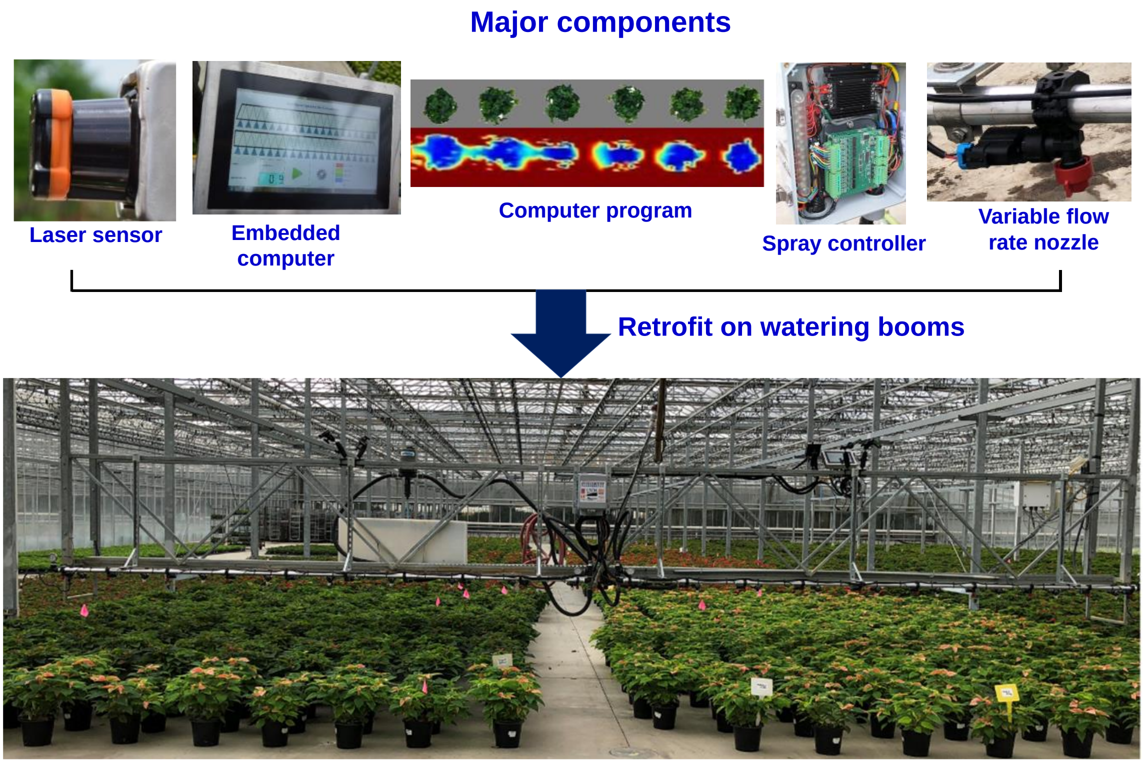

Figure 1. The intelligent spray system as a retrofit attached to existing mobile watering booms to deliver water, chemicals, and nutrients with variable rates for greenhouse crops.

The major add-on components of this greenhouse variable-rate boom spray system consisted of a laser scanning sensor to detect objects, a custom designed algorithm to process sensor signals and control spray outputs based on the presence or absence of plants and their structures, an embedded computer, a laboratory-built pulse-width-modulated (PWM) nozzle flow-rate controller, and two 3.6-m long horizontal spray booms. Each boom was equipped with 12 nozzle assemblies coupled with 12 PWM solenoid valves. The two spray booms were attached to a double overhead, mobile rail, watering boom system commonly used in commercial greenhouses. Spray rates discharged were automatically adjusted according to the plant foliage volume. Geometric parameters of the spray system were physical positions of the laser sensor and nozzles, and the sensor travel speed. These parameters were the inputs for the computer program to configure plant structures and locations in complying with acquired laser sensor signals.

The laser sensor was designed for indoor applications with the IP65 protective structure. It generated 1080 detection points at 0.25º angular resolution in a 270º fan shaped plane every 25 ms, and it could detect plants within a 10-m radial range. The distances between the laser sensor and detection points on the plants were acquired through the time-of-flight principle. The plant structure information was collected through continuously scanning the plant from its leading edge to the trailing edge when the spray boom was moving forward. The sensor was mounted in the middle of the two spray booms to access the plant information below the boom.

The embedded computer collected the laser sensor data via an Ethernet interface. The computer managed the spray control system to receive the data acquired from the laser sensor signals, characterize the plant structure, calculate the spray output, and send control commands to activate nozzles. The system performed the variable-rate spray function with the flow-rate controller which consisted of two microcontrollers to control nozzle flow outputs through manipulating duty cycles of the coupled PWM solenoid valves (Liu et al., 2014).

The algorithm for the variable-rate spray system managed the distance data acquired from the laser sensor continuously while the sensor was travelling and converted the distance data into 3-D surface profiles. Each nozzle was assigned to spray a rectangular-shaped section with a given spray width, and was activated to discharge variable-rate outputs based on its corresponding plant presence and sectional canopy volume. In order to ensure entire plants were covered by the sprays, the algorithm was designed to allow the nozzles to start spraying plants at a distance before reaching the plants and stop spraying the plants at a distance after passing the plants. The algorithm was implemented in VC++ programming language.

The system was first validated for its accuracy to synchronize nozzle activation and laser sensor detection of objects and for desired spray volume discharged to the objects. Its performance was then evaluated by quantifying spray coverage inside plant canopies and on the ground at three different travel speeds. The plants, i.e. poinsettias of different species, were at three different growth stages and were placed in different patterns to evaluate the spray system accuracy. The spray deposition, collected using water-sensitive papers, inside the canopies and on the ground were measured and compared. The test results illustrated that spray coverage inside the canopies treated by the spray control system was consistent regardless of the canopy growth stages. Spray coverage inside canopies placed in the continuous placement pattern was greater than that in the group placement pattern, followed by the single plant placement pattern. Effects of travel speed on spray coverage both inside canopies and on the ground were insignificant. Measurements of spray deposition on ground targets at the gaps between plant blocks revealed that the spray control system had the capability to close nozzles in areas with no plants. Additionally, the variable-rate spray system only consumed 21.3% to 89.3% of the spray volume compared to the constant-rate spray mode at different travel speeds.

Our research findings demonstrated the newly developed greenhouse variable-rate spray control system could provide a possibility to increase spray efficiency by greatly reducing spray volume thereby reducing production costs. The system will be further tested for its application accuracy and efficacy under commercial greenhouse conditions and will be used to prevent greenhouse production from excessive waste of water, chemicals and nutrients. Moreover, it will reduce workers from exposure to the harmful chemicals in the confined environment.

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