Design of VAV system of air assisted sprayer in orchard and experimental study in China

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Abstract. *One type of new automatic target detecting based on size of canopy with variable chemical dosage and air-flow of fan orchard sprayer was designed and developed to meet the demand of chemical pest control in orchards. Canopy parameter data scanned by infrared sensors and LIDAR (Light Detection and Ranging) were used to detect the target and to design spraying algorithm and PWM (Pulse Width Modulation) control system. Four integrated five-finger atomizers were equipped on each side of sprayer, independent brushless fan locate behind and close the five nozzles in one unit, each five-finger atomizer equipped with five nozzles and one independent brushless fan. The gasoline generator was adopted as energy source to realize fully automatic spraying and the independent brushless fan was instead of central fan without PTO (Power Take Off)-power to realize partly air volume according to canopy size.* The field test showed that deposition volume of front and back of tree were 2.52*u*L/cm^2 and 1.67*u*L/cm^2, and the droplets coverage were 71.1% and 32.4% respectively, the minimum number of droplets was 46.2 /cm^2.

Keywords: *LIDAR, variable-rate application, automatic target detection, air volume.*

Introduction

There is an urgent need for new chemical application techniques and sprayers in Chinese orchard spraying because of the requirements of environment pollution and safety for food. Variable-rate spraying is a higher technology to realize precision pesticide application by adjusting the machinery location, travel speed, and sprayer speed based on acquiring the data of crop disease, morphology, and density (Qiu, 2015).

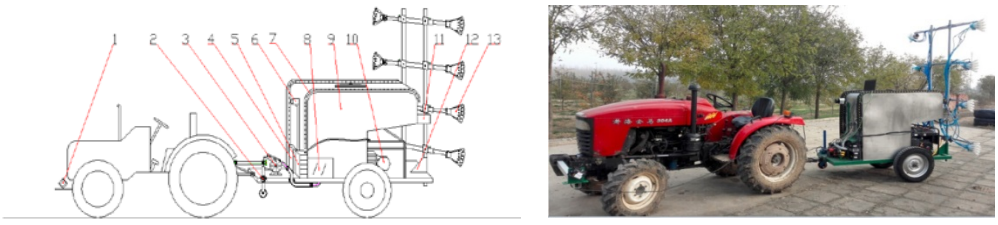
The canopy detection technology based on sensor has provided theory basis for research of orchard precision sprayer, orchard automatic-targeting sprayer has been developed which could realize targeting spraying (He et al., 2003). An orchard sprayer adopted ultrasonic sensors was designed which could save up to 37% of pesticide (Moltó et al., 2001).From then on, many scholars have made a great breakthrough based on ultrasonic sensors (E.Gil et al., 2013;).But, it was found that the detection precision was greatly affected by the detection range, temperature, humidity and travel speed. To make up for the detection accuracy, a variable-flow-rate sprayer based on LIDAR was developed which has better effects than the ultrasonic machinery (Escolà et al., 2013).Also, a variable rate orchard sprayer was developed based on LIDAR, which could adjust each nozzle's flow rate to meet the different part of canopy(Chen et al., 2011).

At present, variable-rate orchard sprayer based on sensors can mostly only adjust flow rate. The volume of air mostly full adjusted by central fan rotating speed and area of outlet, partly air volume and use-dosage according to canopy size was not to realize so far. By the limitation of fan's reaction speed and the weak real-time performance, the real-time variable air volume based on detector used on orchard sprayer has not been reported. In this research, the real-time VAV (Variable Air Volume) system was developed for orchard sprayer and the experiment was done in China.

Material and methods

Prototype

The overall structure of prototype was shown in figure 1, mainly including LIDAR, gasoline generator, diaphragm pump, ground speed sensor, tank, Electromagnetic valve, brushless motor, five-finger atomizer, transformer module and so on. The sprayer was traction type, which forms a complete set of 22kW-power tractor. For the convenience of realizing the function of automatic control, the system power was provided by the gasoline generator.



a. Schematic view

b. Photograph of prototype

1.Speed sensor 2.Screw return roller 3.Hydraulic pump 4.Transformer 5.Microprogrammed control unit 6.Laser sensor 7.Cable drag chain 8.Drive system 9.Sprayer tank 10.Electric generator 11.Solenoid valve1s 12.Boom frame 13.Five-finger atomizer

Fig.1 Overall structure of automatic variable rate orchard sprayer based on LIDAR

VAV control system

When the sprayer was working, the LIDAR scanned the target and transfer the data to PC, PC calculated the air flow and flow rate based on algorithm and the speed information collected by MCU (Microprogrammed Control Unit). Then the results were sent to the signal-chip microcomputer control module to transform into PWM signal. Electromagnetic valve actuations (40 ways) and brushless motor drivers (8 ways) adjusted duty cycle individually after receiving signal.

Air volume and flow rate

Eight independent brushless motors were adopted as the air power source, which were ranked on

both sides of the orchard sprayer. The rotating speed of each brushless motor could be adjusted in real-time by PWM signal according to the canopy parameters of fruit tree. The fan performance was shown as table 1. To meet the design requirement of the five-finger atomizer, HVV-L-8004 fan nozzle was designed and the diameter of nozzle was 6mm. The spray angle was 80° and the flow rate was under the pressure of 0.3MPa and frequency of 25 Hz has a linear relationship with duty cycle , the equation was $q = 1.25a - 0.042$ (***q***, flow rate, L/min; ***a***, duty cycle, %).

Table1. Test results of fan performance

Items	Duty cycle/%						
	10	20	40	55	70	85	100
Fan speed/(r·min^{-1})	9955	12850	18462	21968	24600	27023	28576
Wind speed of air outlet/(m·s^{-1})	14.58	21.44	30.35	37.53	45.21	49.74	51.39

Field test

The field experiment was conducted in Beijing, which contained the test of deposition distribution in the canopy, drift in the air, drift on the ground and the deposition test between trees. The tree row space was 5×2m, the average height of tree was 4.1m, the canopy diameter was 2.1m. Water sensitive paper (3.8cm×2.6cm), metallic screen mesh (3cm×8.5cm) and mylar card (10cm×10cm) was adopted to receive droplets. The results showed that the deposition volume of front and back of tree were 2.52*u*L/cm^2 and 1.67*u*L/cm^2, and the droplets coverage were 71.1% and 32.4% respectively, the minimum number of droplets was 46.2 /cm^2. The actuation delay time could cause false spraying, the highest deposition volume was 2.5*u*L/cm^2. Drift behind the tree was fewer than between trees, and drift between trees was four times that of behind tree. The mount of drift on the ground was 0.8*u*L/cm^2.

Conclusion

This sprayer light weighted, highly efficient, reduces pesticide use and is friendly to the environment. Conventional PTO-fan was replaced by the brushless fan with biggest rotating speed of 28000 rpm, which could fast response once receive signal. The field test showed that deposition volume of front and back of tree were 2.52*u*L/cm^2 and 1.67*u*L/cm^2, and the droplets coverage were 71.1% and 32.4% respectively, the minimum number of droplets was 46.2 /cm^2. This study proposes a new equipment of plant protection for fusiform-type fruit tree, and also provides reference for design and performance optimization for plant protection machinery.

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