Application of variable spray technology in agriculture

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Abstract. As one of the representatives of precision agriculture, variable spray technology has made great progress in the development and application of technology in recent years. This paper describes the principle and characteristics of variable spray technology, and outlines the development results of variable spray technology in target detection, automatic control, and spray application. In terms of target detection technology, automatic target spray technology based on real-time sensors and automatic target spray technology based on geographic information technology are introduced; In control technology, pressure control flow regulation technology, PWM control flow regulation technology and liquid chemical concentration mixed regulation system are described. In the field of spray technology, it mainly describes the research and application of variable nozzles and forecasts the application prospect and development direction of variable spray technology.

1. Introduction

According to the department of agriculture statistics, at present, China's pesticide production technology in the international advanced level, but excessive pesticide residues pesticide, low effective utilization, agricultural products, such problems as environmental pollution, the operator poisoning is outstanding, the main reason is technology and equipment backward, applying pesticide applying pesticide differ with the European and American developed country 30-50 years. The backwardness of the application technology of pesticide application machinery and pesticides is not commensurate with the rapid development of pesticides in China, which has hindered the prevention and control of crop pests and diseases and caused undue losses and bad consequences [1]. Traditional agricultural application techniques have made the contradiction between economic development and environmental protection in agricultural production increasingly acute. Therefore, precision agriculture represented by variable spray has received more and more attention.

2. The principle and characteristics of variable spray

2.1. Principle of variable spray
Sensors are used to detect the target and the external structure features of the target, including the acquisition of target feature information and the data processing of the Information. The spray rate of the spray device is adjusted in real time by the control unit, the spray volume is adjusted in real time according to the different objects of the crop. Due to the variability of the entire canopy section and its leaf density, precise sprays are required on all parts of the canopy [2].

2.2. Characteristics of variable spray
Variable spray technology is widely used in crop farming, animal husbandry, horticulture and forestry. The developed countries attach great importance to the research and development of variable execution machinery. The investment is huge, and a more mature map-based and real-time sensing technology-based variable pesticide spray application system is formed. At present, international consensus has emerged on the prospects and potential of variable-injection sprays in increasing the utilization of pesticides, reducing pesticide residues, and reducing environmental risks. In addition, variable sprays can be adjusted in real time based on changes in influencing factors [4-7]:

- Increase the utilization rate of pesticides. Increase the use of pesticides. The sprayed objects in orchards and nurseries are trees, and the obvious characteristics closely related to spraying are the dispersibility of canopy structure and density is relatively large; there is a gap area between trees and trees, between rows and rows of trees, and such gaps Usually not uniform, variable spray technology will be based on the above issues to take full spray, semi-spray, no spray measures to deal with, but also according to the degree of thick leaves to adjust the initial speed of the spray to achieve effective penetration, improve the pesticide adhesion rate, Thereby reducing the cost pressure caused by spray operations.

- Reduce pesticide residues. According to the information obtained by the sensor, the processor identifies the target, analyzes the structure of the identified target, then calculates the amount of drug dispensed, this method reduces the adverse impact of the excess pesticide on the environment, and fully reflects social and ecological benefit.

- Real time. There are many influencing factors in the spray environment, such as temperature, air pressure, natural wind, plant growth, plant density and other dynamic factors. In order to achieve the precise application of pesticides, variable spray can make timely and accurate adjustment according to the changes of parameters.

- Cost saving. Because the variable spray can effectively use the advantages of pesticides, it greatly reduces the amount of pesticides used while reducing the number of spray, thus saving manpower and material resources, reflecting its obvious economic benefits.

- High compatibility. According to the characteristics of the crops and the difference of the spray requirements, it can be collected or analyzed through the modular platform with the most suitable device for detection.

3. A review of variable spray studies

3.1. Research on variable spray detection technology

3.1.1. Automatic target spray technology based on real-time sensor
Automatic target spray technology is based on the sensor through the information collection equipment such as laser, ultrasonic, camera, according to the targets in the presence of automatic target spray, compared with continuous spray, physic liquor can save 24%-51% [8]. Brivot R et al. [9] used near-infrared image segmentation in diffuse light conditions, and transplanted cauliflower, weed and soil identification effects were above 73%. Compared with traditional methods, the segmentation effect is not affected, and the accuracy of image segmentation is greatly improved. Artificial neural networks have high potential in visual recognition of agricultural machinery [10]. Yufeng Ge et al. [11] established an automatic accurate and accurate indoor pesticide spraying system based on machine vision, and conducted in-depth research on the main issues such as signal acquisition, image
processing, application decision-making, and data exchange, and proposed trees image segmentation algorithm based on relative color factors. In the application of ultrasonic sensors, Llorens et al. [12] used the method of measuring the volume of vine crowns and applying ultrasound sensors to vineyards to install the ultrasonic sensor on the sprayer. At the same time, this solution showed a clear economy compared with laser sensors. Chun Yang, Chieh et al. [13] used artificial neural network and fuzzy control to simulate the herbicide application amount, as shown in Fig. 1. The camera was used to collect field information and the artificial neural network was used to distinguish the types of crops and weeds. Image processing was used to determine the coverage and distribution of weeds, and fuzzy control was used to determine the herbicide spray volume. The test results showed that the target coverage of the herbicide was 80% - 90%.

Figure 1. Neural network and fuzzy control structure diagram

Tian [14] studied and tested an automatic spray system based on real-time machine vision. The system uses dual cameras to obtain weed information. The speed of the radar is used to obtain the forward speed information of the sprayer. After data processing by the computer, the spray amount information is transmitted to the spray head controller to achieve variable spray. Moltó et al. [15] developed a three-state target spray system. As shown in Fig. 2, the core of the technology is to use two ultrasonic sensors to establish a target detection system, and adopt a three-state spray control strategy of full-spray, half-spray, and no-spray. The interpretation of the “target” was expanded to introduce the concept of crop morphology and crop density.
Figure 2. Schematic diagram of target spray system with three states.

1. tractor 2. spray tank 3. spray rod motor 4. vertical spray rod and nozzle. 5. ultrasonic sensor 6. Tree

Pfeifer et al. [16] and Rosell et al. [17-18] used the laser and LIDAR to perform crown detection respectively. It not only obtained the distance information between the sensor and the measurement target, but also obtained the 3D cloud point map information of the measurement target. The 3D cloud point diagram fast algorithm can further get the geometric details of the measurement target. Changyuan Zhai [19], studied the method of tree contour detection. The crown of the homemade rule tree and the cherry tree canopy test at the flowering period showed that the crown volume detection accuracy was 92.8% and 90.0%, respectively, indicating that the contour profile based on the ultrasonic sensor tree target the detection method has a high detection accuracy. Xiangyue Yuan, Chundu Wu, Jinyu Chu et al. [20] used infrared detection technology and automatic control technology on the sprayer to develop a new type of pesticide sprayer—orchard automatic target sprayer. Tests have shown that the machine has good performance and solves problems such as waste of pesticides polluting the environment and existing orchards. Tumbo et al. [21] conducted an experimental study based on ultrasonic detection of crop morphologies. The experimental scheme can be described in Figure 3. During the experiment, it is necessary to ensure that the plants are cultivated in a row and that the direction of advancement of the machine is parallel to the line of plant cultivation.
3.1.2. Automatic target spray technology based on geographic information technology

Automatically based on the technology of geographic information of target variables drug-delivery system based on geographic information system (GIS), global positioning system (GPS), remote sensing (RS), decision support system (DSS) based on intelligent plant protection machinery according to the variation in the field, the production process to implement a set of accurate positioning and quantitative management integration technology [22]. An important aspect of this technique is the ability to dynamically change job parameters as required. The following data flow: the field data acquisition (aviation imaging, weed identification system), image data processing, data map form, data file copy, intelligent sprayer with the support of global positioning system (GPS) according to the map data for prevention and control work [23]. Gerhards et al. [24] designed a precise herbicide spray system based on GPS map information to store the field weed distribution map in a computer connected to the spray control system. The GPS system was used to timely detect the position of the sprinkler, and the data signal is transmitted to the control unit via the data bus system. Through four years of research, it has been found that using this technology can actually reduce the amount of herbicide used. Baijing Qiu et al. [25] developed an automatic target-to-target variable spray control device based on geographic information technology, as shown in Figure 4. In the implementation of the spraying operation, the computer console forms a spray instruction control signal according to the positioning of the GPS on the equipment, the speed information transmitted by the radar sensor, the loop pressure, and the information generated by the decision. The computer controls the total flow to the boom through the servo valve. The flowmeter is used to detect the system flow in real time and fed back to the computer console to achieve closed-loop control and improve the accuracy of the system [23].
3.2. Research of variable spray control technology

3.2.1. Pressure flow control
When the pressure adjustment technology is adopted, the cross-section of the outlet of the nozzle is fixed, and the flow is adjusted by adjusting the pressure of the liquid medicine. When the pressure rises, the flow rate through the nozzle cross-section increases per unit time; when the pressure decreases, the cross-sectional flow through the nozzle per unit time decreases. Anglund E A, Ayers P D [26] developed a pressure-controlled sprayer and tested its corresponding performance in the field. Studies have shown that issuing a command from the control system requires changing the spray pressure until the nozzle pressure reaches the desired value for about 2 seconds. Shi Yan et al. [27] established a control mathematical model and transfer function for a pressure-type variable spray system based on a self-designed pressure-type variable spray system, and facilitated the user to simulate the system model. Tests have shown that the model can achieve satisfactory results. At the same time, they also developed pressure-type variable nozzles for unsatisfactory conditions of pressure variable sprays. [28]. For a flat fan-shaped nozzle variable spray, Stone et al. [29] recommended a system pressure set between 0.2 and 0.4 MPa, and pointed out that exceeding this pressure range will result in worse droplet size distribution, increased risk of droplet drift, and distribution of pesticide foliage deposits is not equal. Baijing Qiu et al. [30] constructed a variable spray system with an electric control valve as a component of the variable flow device. According to the experimental results, the cost of the pressure sensor is lower than that of the flow sensor.

3.2.2. PWM control flow
Pulse Width Modulation (PWM) is a general-purpose technique that controls electronic actuators by rapidly switching on and off (pulse) switching devices. The speed at which a switching device is pulsed is the frequency. Giles et al. [31] further studied the relationship between system pressure and flow under PWM flow control conditions by installing an electromagnetically actuated valve at the inlet of the spray head, determined the flow control range, and predicted the feasibility of a commercial variable sprayer. King et al. [32] developed a variable flow nozzle that adjusts the nozzle opening area by adjusting the moving pin located in the nozzle to adjust the nozzle flow. Wei Deng [33] analyzed the atomization characteristics of the variable-spray spray under three conditions of PWM continuous, intermittent, and pressure, and compared the three types of variable sprays, and found that the PWM continuous variable spray has the widest flow adjustment range, and continuously adjustable,
the impact of the control method on droplet size is small. Wei Xinhua et al. [34] related the PWM intermittent spray variable spray system with the forward speed of the sprayer. DSP56F805 chip was used as the core to develop a PWM variable spray controller. A PWM variable spray system was constructed to implement PWM variable spray. A PWM variable spray system was constructed to implement the automatic control of the process of PWM variable spray. Jiabing Gu et al [2] developed the new five-finger air-feeding variable sprayer independently based on USDA-ARS-ATRU (National Laboratory for Agricultural Engineering and Applied Technology, US Department of Agriculture), using PWM to control the on-off time of solenoid valves, individually controlling each the liquid flow rate of the spray head provides a theoretical basis for the wind speed variable variable sprayer to control the wind speed variable. Liu Wei et al [35] developed a PWM variable spray control system for knapsack sprayers, and spray volume, spray angle, and droplets at duty ratios of 40%, 60%, 80%, and 100% respectively. The particle size and the droplet velocity field were analyzed. Liu et al [36] developed a multi-channel PWM integrated controller for the needs of wide-beam spray nozzles, which can implement independent PWM control for each head of a multi-head system.

3.2.3. Mixing regulation system of liquid concentration
The concentration of drug solution mixed with the control variable spray refers to a spray method that changes the drug concentration in real time through a drug mixer. There are mainly two types of drug injection control systems and drug infusion control systems [6]. The drug injection control system uses a drug pump and a controller to control the amount of chemical injection, rather than directly controlling the flow of the mixed drug solution. The flow of water in the system is usually constant, and the amount of injection of the agent changes according to the command signal of the speed or the amount of spray. This system does not need to treat the remaining liquid, which reduces the risk of direct contact between the operator and the pesticide. Moreover, since the pressure in the system can be kept constant, the spray head can ensure that the droplet size and the spray distribution pattern do not change. However, the system has a long delay in changing the concentration of the chemical solution. This delay will inevitably result in an error between the amount of pesticide sprayed and the actual demand, thus affecting the effectiveness of the application [37]. Tompkins et al. [38] measured at least 12 seconds delay from the change of the control concentration to the concentration of the drug solution to the nozzle, and also found that the injection position of the drug was moved toward the nozzle, that is, the injection of the agent near the nozzle can effectively eliminate the time delay, but this method will greatly increase the cost of the system, and more importantly, it is difficult to maintain a uniform concentration of the liquid between each nozzle. Sudduth [39] tested the delay of a Raven SCS 700 side-by-side variable-injection variable sprayer. The results were very different from the theoretical ones. The first nozzle (the injector closest to the injection of the chemical) was measured and the concentration of the liquid sprayed was changed. The delay is 15 seconds, while the delay of the 3rd nozzle is 19.0s. Obviously, this method is difficult to achieve the desired effect. At the same time, the system composition of this method is relatively complex, which increases the cost of the spray operation, and because the total amount of liquid injected into the pipeline changes, the pressure of the system changes, which changes the droplet size and spray quality. Zhizhuang Liu et al [40] to design a set of vehicular real-time automatic sprayer potion separate storage, liquid mixing device, and the performance of the system was tested, the results show that the maximum relative error of flow and the target flow within ±3.0%. It ensures a relatively good spray flow and pressure, thus ensuring a better spraying effect.

3.3. Study of variable spray spraying technology
The variable spray mainly includes three stages: (1) The detection stage, obtaining the information of the spray target; (2) The spray control decision stage, the analysis of the target information, and the optimization scheme; (3) The spraying stage, according to the required spray amount and Liquid characteristics, implementation of variable spray. Therefore, the spray phase plays a decisive role in the three phases. A lot of research has been conducted on the detection stage and control decision-
making stage in the agricultural precision spraying system \cite{41}. However, the research on the implementation of variable spray on the spraying stage is still relatively lacking. Variable sprinkler head is compared to traditional fixed nozzle. “Fixed” means the internal structure of the nozzle at work is fixed. Variable sprinkler head is based on the conventional sprayer. Jiabing Gu \cite{2} by adjusting the inlet diameter to change the way that the nozzle outlet wind speed, and in the study under different speeds, it is concluded that speed change on the nozzle exit velocity and the distribution of the dynamic air pressure had no significant effect of conclusion. Walker, et al. \cite{42} designed a variable outlet variable nozzle using a nozzle-area-pressure-actuating scheme. The structure is characterized by the fact that the hole consists of two thin metal plates that are internally articulated. The two metal plates move with pressure. In order to achieve changes in the size of the nozzle hole with pressure. However, this spray head has a smaller spray fan angle. Stark et al. \cite{43} developed an irrigation system that uses a modular sprinkler with 3 conventional sprinklers per spray point, each controlled by a microcontroller. The flow rate adjustment range of this combination sprinkler is 25\%, 50\%, 75\% and 100\%. Combined showerheads are expensive, complex structures, and large in size. Camp, et al. \cite{44} developed a numerical control variable irrigation sprinkler, its principle is: water at a constant pressure into a water pipe, water pipe in the water out by pulse of high pressure air nozzle, numerical control system of a certain amplitude square wave to control the air flow. The performance of the nozzle is influenced by the volume of the water storage pipe, the pressure of air and water, the working cycle time and frequency, and the need for additional air compressors. Funseth et al. \cite{45} invented a variable nozzle for the flow control valve inside the nozzle, which is controlled by the stepper motor, as shown in Figure 5.

Figure 5. New type of agricultural spray nozzle

1. spray head 2. nozzle body 3. furnace inlet stream 4. spray nozzle 5. cylindrical chassis 6. the level of flange

Bui \cite{46} introduced a follow-up constant flow core for two-stage nozzles based on the follow-up orifice area and designed a variable-speed nozzle with two follow-up devices. Bui's solution has been used by Spray Target, USA Adopted, formed the Var Target series, Ver Jet series and Var Flow series products. Daggupati \cite{47} presented an integrated variable nozzle that controls the opening and closing of the solenoid valve to actuate the spool. Needham et al. \cite{48} proposed a method of coupling the proportional solenoid valve to the spray head, which can control the spray volume and the droplet size separately. The application of solenoid valve technology on the spray head greatly reduces the response time and spray efficiency of the spray.
4. Conclusion

Compared with foreign countries, China’s variable drug application technology lags behind for about 30 years. The negative effects caused by this problem such as the low utilization rate of pesticides and environmental pollution, are increasingly attracting attention from all walks of life. The key to improving the quality of precision application is the development of a variety of high-performance variable application techniques with different atomization characteristics [6]. In recent years, as the country pays more and more attention to environmental protection and food safety, investment in scientific research is increasing day by day. The most accurate agricultural representative of variable spray technology will naturally develop. To sum up, a few noteworthy aspects are summarized:

- For the detection of information on crop morphology, density, and location, the future development focuses on improving measurement reliability, stability, and expanding the application of multi-sensor arrays.
- The detection and recognition of the target, although divided into hardware and software, but the new development is mainly focused on software, especially signal processing and pattern recognition. Due to the multidisciplinary characteristics of signal processing and pattern recognition, and the existence of specialized international academic organizations, academic activities are very active and many new ideas, methods and algorithms are available. With the new ideas, there are still many areas for improvement and innovation.
- Variable sprays should also consider the atomization characteristics of the spray and the effect of spray on spray control. Therefore, further study can be done on how to optimize the spray effect of the spray device.
- For variable spray servo systems, in order to reflect the specificity of agricultural equipment, use control technology to improve the performance of low-cost devices and equipment, and develop algorithms specifically.

Acknowledgement

This work has been developed by Shandong Provincial Key Research and Development Plan of China (Grant Nos. 2017CXGC0215); Shandong Province Agricultural Machinery Equipment Research and Development Innovation Plan Project (Grant Nos.2017YF047); Shandong Province Natural Science Foundation , China (Grant Nos. ZR2017LEE010); Supported by National Natural Science Foundation of China (Grant Nos. 51305164) has supported the fund and expressed its sincere thanks.

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