Design of Parallel Injection Online Compound Control System for Liquid and Water Solvent

Xingtong Jiang\textsuperscript{1,2,3,4}, Zhuo Wang\textsuperscript{1,3,4,*}, Xiaoping Bai\textsuperscript{1,3,4}, Feng Xiong\textsuperscript{1,3,4} and Deqiang Li\textsuperscript{1,3,4}

\textsuperscript{1} Shenyang Institute of Automation, Chinese Academy of Sciences, shenyang 110016, China
\textsuperscript{2} Institutes for Robotics and Intelligent Manufacturing, Chinese Academy of Sciences, Shenyang 110169, China
\textsuperscript{3} College of Information Science and Engineering, Northeastern University, Shenyang 110819, China
\textsuperscript{4} Key Laboratory of Agricultural Equipment Intelligent Technology, Liaoning Province, shenyang 110016, China

*Corresponding author e-mail: zwang@sin.cn

Abstract. The variable spraying technology includes premixed drugs and online mixed drugs. The operators need to be in contact with pesticides in the premixed operation. It is harmful to the operators. Meanwhile it has the disadvantages of large amount of pesticides and environmental pollution. In order to solve this problem, an injection-type online mixed drug spray control system for variable spraying and width control was designed. In this paper, a novel injection-type online mixing pesticide control system is designed to solve this problem for variable spray and width control. The mixing ratio of water solvent flow and the pesticide flow is adjusted in real-time spraying by using a sprayer equipped with the proposed online mixing pesticide control system according to the specific prescription map. The concentration of pesticide at the nozzle is controllable consequently. The real-time dynamic response test and the steady state error test were carried out during the pesticide injection. Results show that the steady state error of the proposed system with using DMC strategy is no more than 5%. The uniformity of the mixed pesticide was tested under different mixing ratios of the system, and the calculated spatial variation coefficient is less than 5%. It shows that the injection-type online mixing pesticide control system has better mixing uniformity.

1. Introduction

The trend of agricultural development has shifted from traditional agriculture to precision agriculture. Variable spray technology is an important part of precision agriculture [1-3]. The mixed mode from premixed to online hybrid is the development trend of the urgent need for the transformation of plant protection equipment and application technology in China, and it is a reliable guarantee for safe medication. At present, the online mixing technology of pesticide syrup at home and abroad mainly includes two types of jet mixing device online mixing and external energy mixing [4-6]. The jet mixing device uses the spray pipe system to complete the extraction of pesticides and the mixing of pesticides.
and water in the pipeline, that is, the use of momentum exchange. The jet mixing device has certain defects, and has the disadvantages of low pressure ratio, large mixing ratio and instability. The external energy source is used to set up the medicine box and the water tank, and the external energy source is used to extract and mix the water solvent and the liquid medicine. The hydraulic system of the pipeline system will not affect the stability of the external energy-mixing device. The metering pump and other devices can accurately measure the pesticide.

Many foreign plant protection spray teams have been strengthening the research and development of online drug-mixing devices, and have made breakthroughs in the use of sprayers and tractors. Vondricka J[7] developed a direct nozzle injection-type online mixing device based on this research. The contribution is that the pesticide is injected before the water flows into the nozzle with reducing response time of the sprayer and adjusting the pesticide concentration in time. However, the mixing effect is relatively poor. Zhigang Chen [8] designed an online mixing control system based on DSP and LabVIEW. The water flow and pesticide flow are still controlled by traditional PI controller. He did not give a specific analysis of the uniformity and response time of online mixing pesticide.

Aiming at the problem of poor uniformity of mixed drug and delay of mixed drug in the current online drug-mixing system, this paper designs a set of injection-type online mixed drug spray system designed for variable spray and width control. The online mixed medicine spray system adjusts the water solvent flow rate and the liquid medicine flow rate in the current sprayer system circuit according to the mixing ratio provided by the user setting or the prescription chart, and controls the concentration at the spray head, thereby realizing the variable adjustment of the spray operation.

2. Online mixing device

The injection type online mixing device is constructed according to the characteristic that the incompressible fluid in the branch line flows to the direction in which the mechanical energy is reduced and the mass conservation law of the fluid flow. The injectable in-line mixing device includes a water solvent conditioning system and a drug injection system. The sprayer rod is 6 meters long and has 12 nozzles. The nozzles are spaced 50cm apart. Three sets of solenoid valves are designed for width control. Each group of solenoid valves controls the start and stop of four fan-shaped nozzles. The design is shown in the figure.

![Injection variable spray line diagram](image)

1. Water tank 2. filter 3. diaphragm pump 4. overflow valve 5. electric regulating valve 6. pressure sensor 7. pressure gauge 8. flow sensor 9. water separator 10. solenoid valve 11. medicine box 12. metering pump 13. back pressure valve 14. SK static mixer 15. pulsation damper S1-S6, nozzle

3. SK static mixer design

There are four types of pesticides, namely emulsifiers, creams, solvents and suspending agents, most of which are low viscosity liquids. During the application process, the agent and the water solvent are
almost all fluids in a turbulent state, and in the turbulent state, the SK static mixer has a better mixing effect. Assuring the homogeneity of mixed drugs is one of the difficulties and key points of online drug mixing. In this paper, the SK static mixer is designed to achieve uniform mixing of liquid and water solvent. SK static mixer consists of one water inlet, one medicine inlet and one mixing. The liquid outlet and the mixing chamber are composed. The mixing tube has a diameter of 15mm and a length of 30cm. The inside is a twisted blade. The physical diagram of the drug mixture is shown in the figure 2.

4. Main factors affecting the accuracy of online mixed pesticide spray

4.1. Quantitative error of online mixing pesticide spray

In the actual operation of the online mixing pesticide spray, the flow rate of the pesticide solution and the water solvent is adjusted in real time according to the mixture ratio provided by the prescription map. The flow sensor collects the pesticide and water solvent flow in real time as feedback information and sends it to the online mixing controller. There is a certain difference between the actual spray amount and the set amount. That is the quantitative error. Pressure control is used for water flow. The spray volume is proportional to the pressure at the nozzle [9-10]. The spray pump used herein has a working pressure of 0.8 MPa. The spray pressure is generally between 0.2 and 0.5 MPa. The spray volume of a single nozzle is in the range of 0.8-1L/min. The atomization effect is good.

4.2. The impact of speed

The goal of online hybrid spray control is to automatically adjust the actual spray volume to match the set spray volume, regardless of whether the sprayer’s travel speed is constant or the change. In real time, the vehicle speed needs to be measured and collected in real time. The relationship between the vehicle speed and the set spray volume function is:

$$Q = \frac{R \times q}{v \times W} \quad (1)$$

where
- $Q$: spray per unit area, $L / m^2$
- $W$: width, $m$
- $v$: forward speed, $m / s$
- $R$: number of nozzles
- $q$: single nozzle unit time spray, $L / m^2$

It can be seen from equation (1) that the forward speed has a large influence on the accuracy of the spray device. In this paper, the Hall speed sensor is used to measure the speed signal. The Hall speed sensor output pulse signal is measured. The forward speed is:
\[ v = \frac{2\pi rn}{N} \]  

where 
- \( r \): wheel radius, \( m \)
- \( n \): the number of pulses received by the controller
- \( N \): the number of pulses output by the speed sensor of one turn of the wheel

4.3. System delay
There is delay time in the injectable online mixed pesticide variable spray system. System delays can cause a certain amount of spray error. The delay time mainly includes a transmission time delay of several seconds between the change of the nozzle concentration and the change of the injection point concentration, the response time delay of the electric regulating valve and the metering pump, and the speed measurement time delay. According to the Frost theory, the transmission time delay of the mixing pesticide from the injection point to the nozzle is the ratio of the total volume of the pipeline from the injection point to the nozzle to the flow rate of the mixture. The specific relationship is as follows:

\[ T_d = \frac{V_{di}}{Q} = \sum_{i=1}^{n} \frac{\pi d_i l_i}{4Q} \]  

where 
- \( T_d \): transmission time delay
- \( V_{di} \): total volume of the injection point to the nozzle
- \( Q \): the flow of pipeline \( i \)
- \( d_i \): the diameter of pipeline \( i \)
- \( l_i \): the length of pipeline \( i \)
- \( n \): the number of injection points to the nozzle pipeline

5. Online real-time mixing pesticide spray performance test

5.1. Real-time dynamic response test of pesticide injection volume
This test consists of verifying the dynamic characteristics of the in-line mixed spray control system with different injection settings and the dynamic characteristics of the mixture. When testing the dynamic characteristics under different injection setpoints, set the water solvent flow rate to 10 L/min. When the water solvent flow rate is stable, the pesticide injection flow control is turned on. The injection amount of the pesticide solution was set to 45 ml/min, 60 ml/min, 85 ml/min, and 105 ml/min, respectively. The test results are shown in Figure 3.

(a) Control results when the set value is 45 ml/min  
(b) Control results when the set value is 60 ml/min
As can be seen from Figure 9, the dynamic matrix control algorithm can stabilize the flow rate of the pesticide injection system with a large delay at a set value. As the set value increases, the system's average steady-state error becomes smaller and smaller. Table 1 describes the absolute average error and steady-state error of the actual injected flow and setpoint for the four different steady-state phases. The data in Table 1 shows that under the control of DMC, the step response time of each stage of the system is about 5s, and the steady-state error does not exceed 5%.

### Table 1. Steady-state error analysis under different injection settings

| Set value (ml/min) | Absolute average error value (ml/min) | Steady-state error(%) |
|--------------------|--------------------------------------|-----------------------|
| 45                 | 2.24                                 | 4.97                  |
| 60                 | 2.35                                 | 3.87                  |
| 85                 | 2.48                                 | 2.91                  |
| 105                | 2.39                                 | 2.25                  |

5.2. Mixing pesticide uniformity test

Assuring the uniformity of mixing pesticide is the difficulty and focus of online mixing pesticide. Mixed pesticide uniformity is an important indicator to measure the performance of online pesticide mixture[11-12]. The online mixing pesticide uniformity measurement is measured by the coefficient of variation (C.V) of the mixing pesticide, which is used to describe the degree of coefficient of variation of the pesticide at different nozzles of the entire spray system at the same time. The coefficient of variation is calculated as:

\[
CV = \left( \frac{S}{\bar{X}} \right) \times 100\%
\]

where

- C.V: coefficient of variation, %
- S: standard concentration of sample concentration, g/L
- \(\bar{X}\): sample concentration average, g/L

The spectrometer must be calibrated before measuring the mixed solution. The same set of cuvettes were used during the measurement to reduce detection errors. In order to reduce the harm of pesticides to humans and the environment, this paper selects carmine red solution to simulate pesticides. Weighing carmine with a precision electronic scale, the 10 sets of calibration solutions are: 0.01g/L, 0.02g/L, 0.03g/L, 0.04g/L, 0.05g/L, 0.06g/L, 0.07g/L, 0.08 g/L, 0.09 g/L, and 0.1 g/L. The absorbance of the above 10 concentration solutions was measured at a wavelength of \(\lambda = 507\text{nm}\) by using Shanghai Hengping 754 UV-Vis spectrophotometer.

The above experimental data was recorded and the measurement was repeated three times. The three data of the 10 mixed pesticide concentration points were averaged. The relationship between the
absorbance and the concentration of the mixed pesticide solution was obtained by linear fitting with least squares method. The carmine red solution concentration and absorbance calibration equation is:

\[ C = 0.15474 + 0.0074 \cdot R^2 = 0.999 \]

The test procedure for the homogenization of mixed pesticide is as follows:

1. Add 8g/L carmine red solution to the medicine tank as the pesticide solution. Start the online mixed pesticide spray control system. Open 3 solenoid valves and open 12 nozzles.

2. The water solvent flow rate was set at 10 L/min. The injection amount of the pesticide solution was set to 40 ml/min, 60 ml/min, 80 ml/min, and 100 ml/min, respectively. The sampling was started 10s after the start of the mixed pesticide uniformity test. At the time of sampling, 12 nozzles were simultaneously sampled for 5 s to obtain a sample mixed solution at a set mixing ratio.

3. The concentration values of the respective samples were measured at a wavelength of \( \lambda = 507nm \) by using an ultraviolet-visible spectrophotometer. The average and standard deviation of the sample concentrations are obtained.

The mixed pesticide solution was collected for each nozzle under different set mixing ratios for analysis. The results of the mixed pesticide uniformity test are shown in Table 2. The test results show that the spatial coefficient of variation is less than 5%. It shows that the uniformity of the mixed pesticide is superior.

**Table 2. Mixing uniformity analysis of online mixing system**

| Nozzle Number | Mixing proportion 0.4% | Mixing proportion 0.6% | Mixing proportion 0.8% | Mixing proportion 1% |
|---------------|------------------------|------------------------|------------------------|----------------------|
|               | Absorbance (g/L) | Concentration (g/L) | Absorbance (g/L) | Concentration (g/L) | Absorbance (g/L) | Concentration (g/L) | Absorbance (g/L) | Concentration (g/L) |
| 1             | 0.041                | 0.01133               | 0.073                | 0.01824               | 0.118                | 0.02517               | 0.148                | 0.02979               |
| 2             | 0.042                | 0.01347               | 0.07                 | 0.01778               | 0.117                | 0.02502               | 0.147                | 0.02964               |
| 3             | 0.047                | 0.01424               | 0.079                | 0.01917               | 0.114                | 0.02456               | 0.139                | 0.02841               |
| 4             | 0.049                | 0.01455               | 0.075                | 0.01855               | 0.116                | 0.02486               | 0.136                | 0.02794               |
| 5             | 0.037                | 0.01270               | 0.081                | 0.01947               | 0.121                | 0.02563               | 0.152                | 0.03041               |
| 6             | 0.042                | 0.01347               | 0.079                | 0.01917               | 0.127                | 0.02656               | 0.153                | 0.03056               |
| 7             | 0.05                 | 0.01470               | 0.075                | 0.01855               | 0.121                | 0.02563               | 0.152                | 0.03041               |
| 8             | 0.048                | 0.01439               | 0.082                | 0.01963               | 0.124                | 0.02610               | 0.154                | 0.03072               |
| 9             | 0.047                | 0.01424               | 0.073                | 0.01824               | 0.119                | 0.02533               | 0.153                | 0.03056               |
| 10            | 0.046                | 0.01408               | 0.071                | 0.01793               | 0.116                | 0.02486               | 0.147                | 0.02964               |
| 11            | 0.042                | 0.01347               | 0.074                | 0.01840               | 0.118                | 0.02517               | 0.144                | 0.02918               |
| 12            | 0.041                | 0.01331               | 0.072                | 0.01809               | 0.117                | 0.02502               | 0.147                | 0.02964               |

| Spray pressure (g/L) | 0.01383 | 0.01860 | 0.02533 | 0.02974 |
| Standard deviation of concentration (g/L) | 0.00059 | 0.00059 | 0.00054 | 0.00084 |
| Coefficient of variation C.V(%) | 4.27 | 3.16 | 2.15 | 2.84 |

6. Conclusion

1. The online mixing pesticide control system designed in this paper can provide the mixture ratio according to the prescription map to adjust the water flow and the injection amount of the pesticide in real time. The system can complete online mixing and achieve variable adjustment of the spray job.

2. The SK static mixer is used to enhance the uniformity of the mixing pesticide. The maximum coefficient of variation of the mixing pesticide uniformity of the online mixing pesticide spray system was 4.27%, which was less than 5%. It shows that the mixing pesticide control system has better uniformity of mixing.
Acknowledgments
This work was financially supported by National Key R&D Program (Y7EA220A01) fund.

References
[1] Liu Z. Key Technology of Variable-rate Spraying System of Online Mixing Pesticide[J]. Transactions of the Chinese Society for Agricultural Machinery, 2009.
[2] Ling R, Yafei Y, Zhuo J, et al. Current Situation on Mixing Apparatus of Sprayer[J]. Journal of Ningbo Polytechnic, 2016.
[3] Mahmood H S, Ahmad M, Ahmad T, et al. Potentials and prospects of precision agriculture in Pakistan - a review.[J]. Pakistan Journal of Agricultural Research, 2013, 26(2):151-167.
[4] Zhi L, Shuran S, Tiansheng H, et al. Online Drug Mixing Technology and Prospect in Pesticide Spraying[J]. Journal of Agricultural Mechanization Research, 2018.
[5] Li J, Xu J, Yang Z, et al. Design and experiment on real-time mixing system for air-assisted sprayer[J]. Transactions of the Chinese Society of Agricultural Engineering, 2016.
[6] Shi W P, Wang X, Wang X Z, et al. Study on Variable Rate Spraying Technology Based on Pulse Width Modulation and Volume Control[J]. Journal of Agricultural Mechanization Research, 2007.
[7] Vondricka J., Lammers P.-Schulze. Measurement of Mixture Homogeneity in Direct Injection Systems[J]. Transactions of the ASABE, 2009, 52(1): 61-66.
[8] Zhigang C, Shuli Z, Baijing Q. Online jet mixing control system of pesticide concentration[J]. Journal of Drainage & Irrigation Machinery Engineering, 2012, 30(4):463-468.
[9] Zhou Y, Mengmeng N, Jun L, et al. Design and experiment of an electrostatic sprayer with online mixing system for orchard[J]. Transactions of the Chinese Society of Agricultural Engineering, 2015, 31(21):60-67.
[10] Youlin X. Mixing Uniformity of Chemical and Water in Direct Injection System[J]. Transactions of the Chinese Society for Agricultural Machinery, 2011, 42(8):75-79.
[11] Zhizhuang L, Wenzhao Z, Ailin L, et al. Uniform Experiment on Variable Rate Spray of Real-time Mixing Pesticide[J]. Journal of Agricultural Mechanization Research, 2014.
[12] Baijing Q, Jing M, Bin D, et al. Experiment on mixing performance of on-line mixing spray system[J]. Transactions of the Chinese Society of Agricultural Engineering, 2014, 30(17):78-85.