Design and Optimization of the Target Spray Platform

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***Abstract*— The target-oriented spraying is an effective way to minimize the chemical input in agricultural production and is important to realize a sustainable agriculture. In this paper, we focus on design and optimization of the target spray platform. The spray platform consists of three parts: the vision system, the spray system, and the moving platform. All components are effectively connected together and optimized especially regarding the fast response time and target spray accuracy. An indoor experiment setup is built up to test and optimize the parameters of overall system, which is relatively flexible. Afterward, the outdoor tractor based equipment is designed to verify the system for the field environment. The experimental result shows that our system can reduce around 46% usage of the chemical compared to the uniform spray method.**

I. Introduction and Related Work

Spray technology plays an important role in agriculture production. Nearly 45% of agriculture products can be saved because of using kinds of pesticide, and 40% of agriculture production is increased by the fertilizer [1]. Generally, these chemicals are sprayed into the filed with equipments uniformly. However, overusing these chemicals can bring some pestilent influence. Early from the 1950s, researchers started paying attention to these points because it has brought many environment and food safety problems [2]. According to statistic data from Chinese government, in 2015 the efficiency of fertilizer and pesticides are 37.8% and 38.8% respectively, which indicates that most of chemicals does not contribute to functionality but remains in the soil media. In 2015, China used 178.3 million tons of pesticide which takes 1/3 of worldwide usage. During these years, million tons of pesticide was poured into field and thus caused terrible damage to the environment. In USA, it is said that 53% of urban streams had the pesticide increasing from during 1992-2011 to 90% during 2002-2011, largely because of fipronil and dichlorvos [3]. Even though with advanced technology development, how to reduce the usage still remains a problem due to e.g. government polices, stress of the population increasing, and cost of solution.

The research of reduction of chemical usage has been performed since 1950s. With the development of computer vision technology, one of important research direction is the target spray technology which spray chemical liquid only on the target plant. This technique can save a lot of chemical usage especially for the weeds control compared to spray uniformly in the field. Tian et al. [4] developed a weeds control equipment based on the target spray using computer vision. Tillett et al. [5] developed a mechanical device which remove the weed within-row based on computer vision without using any herbicides. They already commercialized this equipment and it is said the cost for USD17000 per row and speed limited to 3 km per hour [6]. In 2015, Michaels et al. [7] from Robert Bosch GmbH developed a novel mechanical weed control method which a mobile manipulator is used to punch the weeds to death with high speed image processing. Sa et al. [8] used the Convolutional Neural Network (CNN) based weedNet to detect the weeds with images captured by micro aerial vehicle (MAV). The Blue River Technology intergraded the deep learning based image processing technology into the tractor platform for weeds control with spray herbicide which can be a very promising machine for the rapid weed control in the large field [9]. In 2017, this start-up company is acquired the John Deere with price of USD305 million which is biggest deal in history for agriculture robot [10].

With development of deep learning technology, it makes possible of using only camera with normal images to robustly recognize the crop and weed. The advantage of avoiding usage of multi kinds of sensors is that it can make the cost of overall equipment at a low price, which can potential be very helpful to spread out the equipments and thus reduce the usage of the chemicals. In this paper, we focus on the building up and optimizing the target spray platform with cheap components. The main contributions of the paper are listed as follows,

- The response time of system is analyzed and reduced especially for the solenoid valve without any sensor.
- We build up two platforms, one indoor experiment platform which is flexible for components integration and algorithm test, and the field platform is also built up to verify the overall system in field environment.

II. Method

We developed the indoor experiment setup based on conveyer first and test the overall system especially for optimization of the response time to improve the target spray accuracy. Afterward, a tractor based platform is built up and intergraded all of the components.

A. Indoor Experiment Setup

The indoor experiment setup is mainly used for the system integration test and parameters optimization, which can reduce a lot of effort compared to test on the tractor based system directly. The experiment setup is shown as Fig. 1. The setup consisted of vision system, spray control system. The plastic plants are pasted on the conveyer. The camera(2) capture the images of plants on the conveyer(1), and a plant detection algorithm is implemented on the computer(3) to segment and obtain position information of plant. The position information is send to STM32F407

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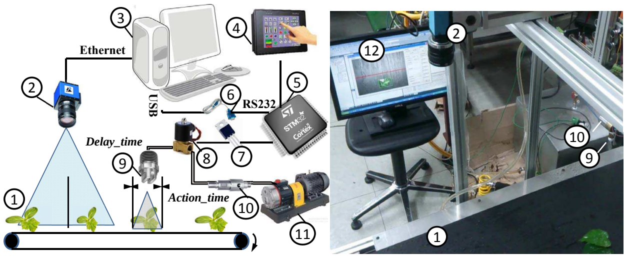


(a) (b)

Fig. 1. (a): The overall design of indoor target spray platform. (b): The actual setup in lab. (1)conveyer, (2)Camera, (3)Computer, (4)Touch controller, (5)STM32 controller, (6)USB-serial converter, (7)Field effect transistor, (8)Solenoid valve, (9)Nozzle, (10)Pressure relief valve, and (11)Pump.

controller(5) via usb-serial converter(6). The pump(11) and pressure relief valve(10) are adopted to generate a properly spray pressure based on the requirement of nozzle (typically 0.1-0.4 MPa). We used a air pump to press water out a water tank since in this way the noise of generating the pressure water is much less compare to the water pump. The spray control system will fuse information of conveyer speed, the image processing overhead, and distance between camera and nozzle to obtain the delay time for spray action. Afterward, the solenoid valve will keep open for the spray action to make the droplet cover the whole plant.

1) Plant Segmentation: The designed target spray platform is primarily designed for the leaf fertilizer on the cabbage. The leaf fertilizer is sprayed on the leaf to provide extra nutrition for growth. In this paper, our main target is to build up and optimize the system, so here we do not consider the weed segmentation from the crop. Based on the color transformation and $Ostu$ automatic threshold algorithm, we could segment the green plant from the background [11]. Afterward, spray area is obtained by calculating the envelop rectangle of binary image. However, one plant may generate several envelop rectangles, the distance between them is usually smaller than that from different plants. The following formula was introduced to substantiate whether two connected domains belong to one identical plant.

$$D = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, i \neq j \qquad (1)$$

Where D is the distance between centers of two envelop rectangles in pixel, (x_i, y_i) is the coordinate of one rectangle center and (x_j, y_j) is coordinate of the other rectangle center. If the value of D is smaller than the threshold value, we can deem the two rectangular boxes belong to one plant and merge the two rectangular boxes, otherwise the two rectangular boxes belong to two plants. The threshold is defined by measuring of all distance between bounding box in the same plant.

2) Solenoid Valve Response Time Analysis: After we get the position of plant, the next important factor we need to consider is how much response time of the solenoid valve. The response time for solenoid valve can be considerable large since the mechanical motion during the on and off process. Electromagnetic attraction force was generated by the coil to open the valve body against the spring force when the field-effect transistor was on, and the valve body was kept open until electromagnetic attraction force was weaker than the spring force. Due to the inductive effect, the current can not be changed simultaneously with the state of the field-effect transistor. Fig. 2 shows the latency between the valve press data and control signal state. The valve press data is collected via the pressure sensor with Kalman filter [12].

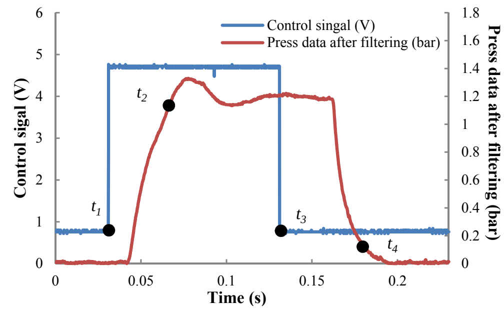


Fig. 2. The pressure data with normal on and off signal. Several key points were marked to make the response time of solenoid valve more available, where t_1 is the time-point when control signal starts, t_2 is the time-point when the pressure near the nozzle reaches P_a and solenoid valve is going to completely open, t_3 is the time-point when control signal ends, and t_4 is the time-point when the pressure near the nozzle reaches P_b and solenoid valve is going to be completely closed.

As shown in Fig. 3, several parameters could be controlled to generate different types of modified pulse width modulation (PWM), leading to a different response time. These parameters included control voltage, initial pulse width, keeping plus frequency, and keeping plus duty cycle. Considering that the inappropriate value of keeping plus frequency may disturb the control system, pulse frequency was considered as a constant value equal to 10 kHz. Y_1 is the response time for opening the solenoid valve which equals to $t_2 - t_1$, Y_2 is the response time for closing the solenoid valve which equals to $t_4 - t_3$, and Y is the total response time for operating the solenoid valve which equals to $Y_1 + Y_2$. We applied the response surface optimization method to build up the relationship between the Y and the parameters. Thus, a modified PWM control method can be used to reduce the response time with 21.2% compared to the normal on-off signal.

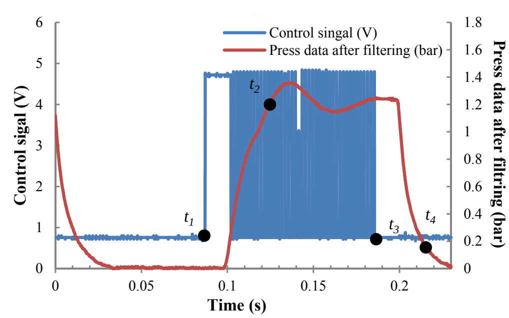


Fig. 3. The pressure data with modified PWM signal.

3) The Target Spray Response Time Analysis: In order to achieve accurate target-oriented spray, the information processing and response time of all electric and mechanical components should be considered. To realize all the functions we described before, we developed the accurate target spray

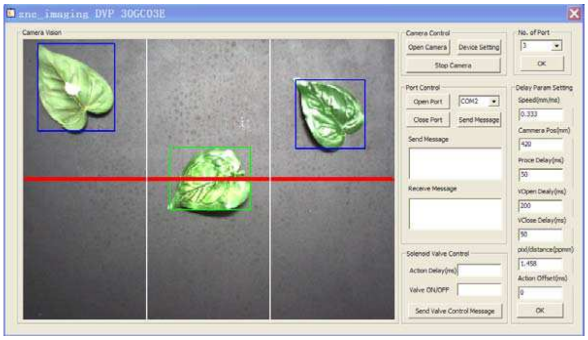


Fig. 4. The target spray software GUI..

software, as shown in Fig. 4, which was developed based on VC2010 and OpenCV. It contained camera control, serial port control, solenoid valve control, number of channel selection and the time-delay parameters adjustment. Combining the Fig. 5, the specific computing method of time-delay T_d and time-action T_a parameters are calculated as below,

$$T_d = t_p + \frac{d - l \times r_p}{v} - Y_1 - \frac{h}{v_d} - t_e \tag{2}$$

$$T_a = \frac{L}{r_p} - Y_2 - \frac{h}{v_d} \tag{3}$$

where, t_p denotes the time (ms) for processing one frame image, d is the distance (mm) between red line in camera and nozzle on the ground projection, l denotes the number of pixels for the from the front edge to the red reference line, r_p denotes a single pixel which represents the actual length (pixel per mm), v denotes the speed of camera refer to the movement of conveyor, h represents the distance (mm) between the nozzle and the ground, v_d denotes the speed of the spray droplet from the nozzle, t_e denotes time latency for the command transmission and execution, and L denotes the number of pixels for length of bounding box for the detected plant.

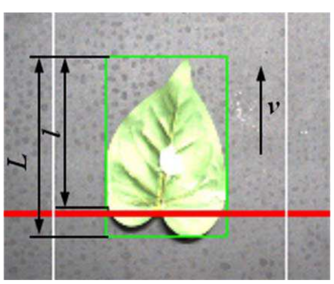


Fig. 5. The relationship of detected bounding box and red line.

The color of detected bounding for plant is blue when the plant is in the front of the red line. When the bounding box has the intersection with the red line, the bounding box will change into green and a command line is generated and send to slave controller. In order to realize a high speed of command transmitting and execution, STM32F407 was selected as the slave controller. The basic frequency of this controller is up to 168 MHz with 17 timers, which is very suitable for developing real-time control system. One timer was used to receive and analyze the data from the USART port and the other timer was triggered to check and execute the command list in every millisecond. The communication speed between the computer and slave controller is set as 115.2 kbps.

B. The field target spray equipment design and verification

Based on the the platform built indoor, we furthermore develop a field target spray equipment using the tractor as the moving base. The system is designed in virtual model to pre-define the system setup and elements arrangement, as shown in Fig. 6. The liquid tank is suspended on the back of the tractor, thus it is near to the power-output shaft. The spray boom and camera is arranged at the front of the tractor. The enclosed cab can prevent the poison of droplet drift. All the extra electronic elements on the tractor are power by the storage battery with the inverter. The details and connection graph of all components are shown in the Fig. 7.

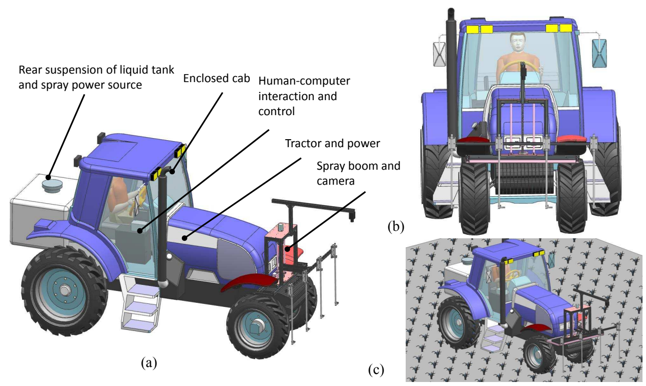


Fig. 6. (a) The virtual design of the field target spray equipment. The spray equipment is consisted of four parts: (1)Rear suspension of liquid tank and spray power source, (2)Tractor and power, (3)Human-computer interaction and control, and (4)Spray boom and camera. (b) The front view of the design. (c) The working scheme in the field.

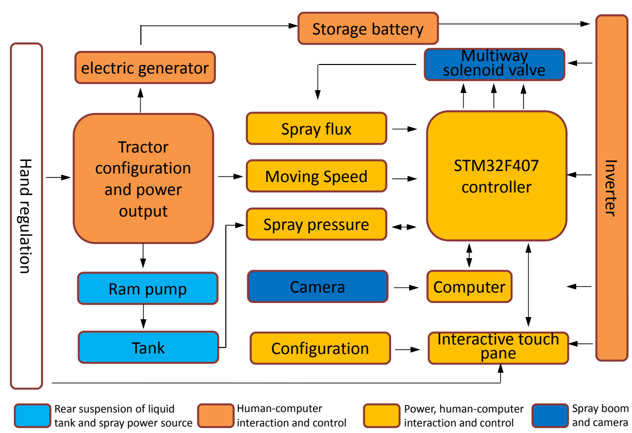


Fig. 7. The details and connection graph of all components.

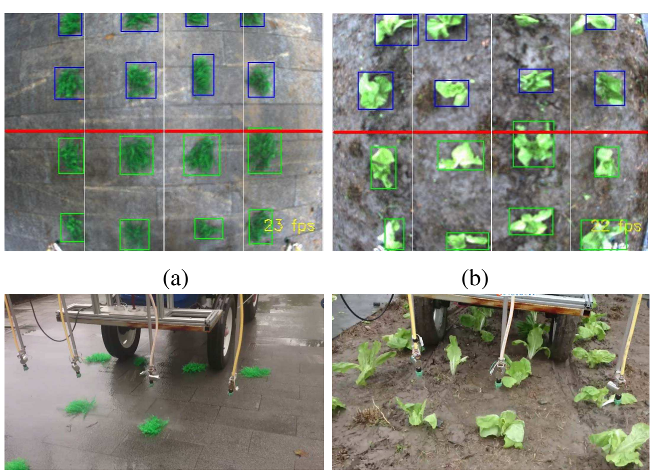
With these preparation and design, we build up the equipment shown in Fig. 8. Two control panels in the drive cab are assisted the driver to manage and inspect the work state for each components. The communication and data transmission between the human-machine interface and STM32 controller was completed by RS232 port and MODBUS communication protocol. As the port of human-machine interface was R232 level, we needed to change it into TTL level by max232 chip and then connected it to STM32 pin.

(a) (b)

Fig. 8. (a) The view from the driver inside the enclosed cab. (b) The back view of assembled equipment.

III. Experiments

We carry out the experiments using both two platforms. The indoor experiment platform is mainly used to fast verify the configuration of overall system and communication of each components. The field target spray equipment is tested under two situations, the first situation is in outdoor using plastic plant with rectangle shape for easy calculation of the target spray accuracy. The other situation is in the field that with the Chinese cabbages. In order to make sure the full coverage of the target, the spray target bounding box is set 1 cm larger in the bottom and top edge sides than the detected bounding box of plant. The experiment setup is shown in Fig. 9. The correct spray action is 525/530 with 99.1%, the missing targets may due to (1) the spray time calculated by Eqn. 2 is too small due to the small target which less than the response time of solenoid valve, and (2) the missing detection of plant due to the sudden changes in external illumination. In the plant growth condition like in Fig. 9(50 cm of plant spacing), the experimental result shows that this spray can reduce around 46% usage of the leaf fertilizer compared to the uniform spray method.



(a) (b) (c) (d)

Fig. 9. (a) The image processed result with four ports for plant segmentation for plastic plant. (b) The image processed result with four ports for plant segmentation for Chinese cabbages. (c) The equipment spray on the plastic plant outdoor. (d) The equipment spray on the Chinese cabbages in the field.

IV. Conclusion&Discussion

In this paper, we focus on design and optimization of a target spray platform. All components are effectively connected together and optimized especially regarding to the fast response time and target spray accuracy. An indoor experiment setup is built up to test and optimize the parameters of the overall system, which is relatively flexible. Afterward, the tractor based equipment is designed to verify the system for the outdoor environment. The correct spray action is 99.1% for average of all kinds of experimental conditions. The experimental result shows that our system can reduce around 46% usage of the chemical compared to the uniform spray method. The further work will focus on implementation of deep learning method to realize weed and crop segmentation such that the entire weeding and fertilization spray system can be developed.

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VI. Supplement Material

The demo video can be found in following link: https://youtu.be/CdPkR2AMIL4

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