DEVELOPMENT OF VARIABLE RATE SYSTEM FOR SOIL DISINFECTION BASED ON INJECTION TECHNIQUE

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ABSTRACT

A variable soil pesticide injection system was developed for control of soil pesticide amount by PWM. The paper analyzed a algorithmic model of control system, and designed hardware, algorithm and control of soil pesticide, mainly software flow and a feedback control way. In the paper, the variable-rate control system was consisted of infrared sensor, speed sensor, PWM valve, and pump motor. According to the amount of soil pesticide information, controller can automatically control flow amount by adjusting solid solenoid valve and PWM valve based on working speed, which changes the pulse duty cycle to achieve the variable work. Injection experiments of soil pesticide was pre-set different dosage, the results shown that pesticide amount was precise in fact, and the errors was less than 3.2%. The system could achieve variable rate injection of liquid pesticide into deep soil based on infrared sensor. Fitting equation of flow amount by adjusting PWM valve based on working speed could draw the R^2 value of 0.935.

The chip can calculate the output PWM duty cycle according to the pre-set injection of soil pesticide amount after collected the speed of tractor. The feedback control is to regulate the PWM signal duty cycle according the real liquid flow obtained by the microcontroller chip which collected the output signal of liquid sensor which fixed on pesticide pipeline.

Keywords: Crop Protection, Soil-borne disease, variable rate injection, control system

Introduction

In the suburbs of Beijing in China, greenhouses for agricultural production has developed very rapidly, mainly because of the rapid urban development and the population explosion in Beijing (Liyan Wang *et al.*,2008). Due to limited land area, while the demand for fresh agricultural products continues to grow, so farmers began to think of ways to solve the problem of how to increase in food production. The key of all of the ways is crop and crop planting and make the land without a break (Chaying Zou *et al.*,2012).On this basis, one method of further improving the efficiency is partition management in as cope of a town, the technical management staff gather in one venue to provide potted tray seeding and seedling services for the entire town of farmers. Such a way that would allow farmers to directly foster very healthy seedlings and transplanted directly into the ground. This management is conducive to significantly increase production of agricultural products. To save costs, farmers in the same greenhouse base are willing to cultivation of the same crops continuously, such as tomatoes(Yan Zuo *et al.*,2014).Many farmers have planted with a variety of tomatoes for many years in the same piece of ground. The aim is to take the advantage of their own experience, while buyers are willing to cooperate in long-term , so farmers do not want to have crop rotation. Soil bacteria will breed and even cause serious problems while the same continuous cultivation on a piece of greenhouse land if there is no good soil disinfection technology and equipment. Taking Beijing as a example, the occurrence of the disease in the soil, leading to large-scale production reduction of tomato crops or total loss of the crop yields in the year of 2010(Yingmei Li *et al.*,2010). And there are a lot of similar things. Such soil diseases cause huge losses to farmers, while an enormous impact on produce planting structure of the entire region. Reporting from Beijing, the frequency of soil diseases result in farmers in Qingyun Town of Daxing District in Beijing can not grow eggplant, while eggplant here were with high yield, good quality and highly popular to citizens a decade before. Due to a large area of crops reduction caused by continuous soil diseases, farmers abandoned cultivation of eggplant.

Farmers try to use pesticide on soil disinfection, taking examples as bellow: 1. By the method of solution to fill the root with pesticide, but it will reduce the quality of vegetables; 2. With the method of changing new soil, but it can lead to cost doubled. Thanks to the government's training program, soil fumigation disinfection technology was studied by our basic-level technicians from abroad (such as Netherlands) and has carried out on the pilot application. Some other physical methods, such as soil flame spray, irrigating soil with high temperature boiling water, microwave sterilization etc. These methods have certain effect on the soil disinfection, but will destroy the soil microbes which have important significance on crops(Yingmei Li *et al.*,2009).

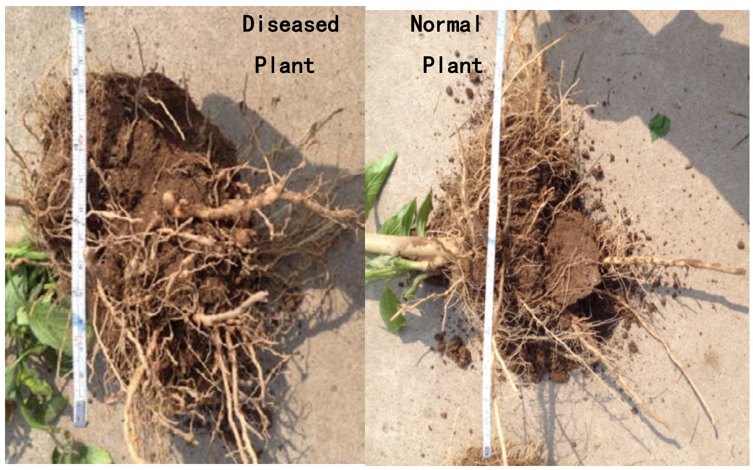
Precision agriculture, is the development trend of future agriculture, and a implementation of a set of modern farming operation technology and management mode, which is supported by the information technology according to the spatial variation, positioning, timing, quantitative(Min Yao et al.,2001). Precision agriculture technology has been used to solve farmers' problems in the greenhouse bases on the outskirts of Beijing. The technology, injecting pesticide directly, makes the storage of pesticide liquid be separated from water, the pesticide liquid, which is controlled by a peristaltic pump, flow into the main water pipe quantitatively to mix with water. It solved the issue of pesticide liquid treatment and equipment cleaning(Landers,1992). Underground spay machinery need to solve the problem of soil environment. Pesticide air jet injector cultivated shovel is a kind of device to inject pesticide into the soil by high-speed air jet. No target spray causes pesticide deposition outside spraying target, it is one of the important reasons of low utilization rate of pesticide. While target spraying is a technology, which identify weeds by the use of near infrared light reflection, to spray selectively with targets through the control circuit and spray system (Cooke et al.,1996). It can save 60% ~ 80% of pesticide by using target spraying technology(Hanks et al.,2009). It is feasible to separate plants and soil by using camera sensitive to near infrared wave band when they studied the reflection characteristics of plant canopy and soil in visible light and near infrared band (Guyer, 1996).Fehon designed a kind of photoelectric sensor which identify soil and weeds by sensing reflectance on the weeds and background in the visible and infrared light section, its recognition rate of the soil and weeds is as high as 95% (Fehon *et al.*, 1991).Deng Wei designed an infrared detection system targets based on infrared sensor technologies, different probe group with different coding modulation pulse infrared signal, can eliminate the interference of light paths between probe groups and other light signal (Deng Wei et al.,2008).Chen Zhigang measured and analyzed the different influence factors of infrared target detection effect in spray pesticide technology by actual plant, and indicated that plant appearance, light intensity, walking speed of detectors and plant spacing is relatively significant effect on the detection performance, while particularly the effects of plant shape and light intensity (Chen Zhigang *et al.,* 2009).

This paper studies the test of soil disinfection by injection technology to develop a variable control system to realize the precise control and variable regulation of soil disinfectant.

Materials and methods

Experimental crop: eggplant, Bliss tower (Rijk Zwaan seed company, Netherlands), engraftment time is August 20, 2013, planting base is Beisishang

a. plant height compare b. root compare



c. diseased roots measuring d. normal roots measuring

Figure 1. There is visible difference in height and root between the normal and diseased eggplant plant. The left side in picture a is the healthy plants excavated, with large distribution root and high plant. The right side of in picture a is the plants infested by Meloidogyne, with small roots and low plant. It is easy to distinguish due to obvious difference respectively. Picture b is a comparison of roots. It is need to increase the dose for roots will stop growing after illness. Figure c is disease roots measuring. Figure d is normal roots measuring.

village of Daxing district of Beijing（E:116.6295498320，N:39.69441545747）. The test land was being used for eggplant planting from 2011. 20 samples were collected on March 31th, 2014, and of which four are infested plant samples by root-knot nematode. The roots of normal plants and diseased plants were measured after excavation. The photograph of real object as shown in Figure 1.

The experiment was done in two parts according to the plant detection and precision dosage control. For the first experiment，six infrared sensors, 0.5m,E3F3-DS50N1(Yueqing city Gaode electric co., LTD,China), was used to get a infrared diffuse reflectance light feed with difference sensor fixed at different heights. Delayed response time is less than 2.5ms. The part used a group spectral sensors which is to detect target crops. Six sensors was fixed to both front sides of the tractor. The mounting height of the bottom sensor was set to be 220mm from the ground because the weeds height was not higher than 200mm.

The second part used PC software processing signals of infrared sensor for target detection and the speed sensor, and calculating the interval of acquisition time, obtaining the data of pesticide volume for different target root and sending it

Figure 2. Structural diagram of variable rate system for soil disinfection showed six sensors fixed to both front sides of the tractor to detect target crops.

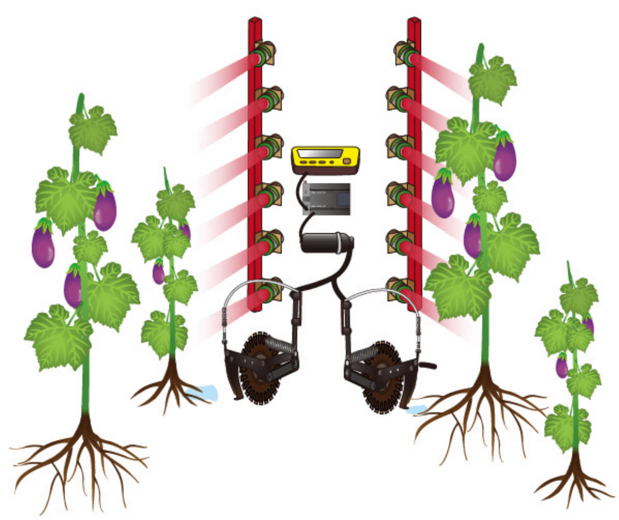


Figure 3. The controller of fixed-point pesticide injection acquires data of target plant and adjusts different volume of pesticide for different target root injected into soil.

to the lower control computer. PWM was applied by the controller to regulate the dose. The controller calculated out the injection start and end time to control the injection volume. As shown in Figure 3.

Control methods

Microcontroller detects the position of the crop leaf by infrared sensors in order to determine the growing position of the crop root and to determine the level of the crop. And then it predict whether the roots is diseased according to the growing height obtained by detecting, and obtain the Q value. The controller automatically adjusts the duty cycle of U. The control system will uniformly injected the liquid into the region of the root according to the calculated injection time T. The scope of the root zone is obtained by the detecting time T_S and the injection time T.

In order to avoid the influence of plants overlapping, it is necessary to improve the mounting height of the sensor as possible under the premise of detecting the plant, so that the upper side of the sensor can detect the top of the tallest plant. In order to avoid interference of multiple sets of sensors infrared light, multiple infrared sensors are used to detect by turns in queue.

The microcontroller detects the plant height H through infrared sensor. Base on the start time Ti_1 of and the end time of Ti_2 of the i-th sensor to detect the plant, it is feasible to calculate parameters as follows: the theoretical capacity Q of plant spraying, the start time T_s and the end time T_t of soil injection, and the duty cycle U of the spraying solenoid valve. The calculation of Q, T, U as bellow:

$$Q=Q_1-aH;$$

$$T_c=[(\sum_{i=1}^{6}T_{i2})/6-(\sum_{i=1}^{6}T_{i1})/6]/2+(\sum_{i=1}^{6}T_{i1})/6=(\sum_{i=1}^{6}T_{i2})/12-(\sum_{i=1}^{6}T_{i1})/12$$

$$T_x=bH / V$$

$$T_d= L_0 / V$$

$$T_S= T_c- T_x / 2+ T_d$$

$$T_t= T_s+\frac{bH}{V}$$

$$U=f（Q\frac{bH}{V}） T_{i1}$$

Wherein,

Q1: the base reference dosing, viz. the maximum capacity of spraying.

a: computational model coefficients of dosing capacity, reduction in the dosage scale factor with the increase in plant height

b: the correlation coefficient of the plant root region that be invaded by root knot nematode and the plant height

H: the crop height H

V: the actual travel speed of the spraying machine
T_c : the time of the infrared sensors passing the plant center axis (vertical)
T_x : the required total time for pesticide injection to the root zone
L_0: the delay distance set by user, viz. the horizontal distance between the fixed points of the infrared sensors and the injection nozzle in the traveling direction
U_a: the controller duty cycle calculated based on the model
f (x): the function relationship of the pesticide injection capacity per unit time and the duty cycle
N_1 and N_2 is created base on the start time Ti_1 of and the end time of Ti_2 of the i-th sensor to detect the plant, and used to store the value of T_{i1} and T_{i2}. i is the cursor of N_1 and N_2.

$$V=\frac{\Delta l}{\Delta t}$$

Δl : the traveling distance of speed sensor per pulse generated by the sensor
Δt : the time length per pulse generated by speed sensor
n: the multiple of the total traveling distance to Δl

Control flow as shown in Fig. 5. Modeling for the target of the crops to be detected(Fig. 4), confirmed the sensor mounting height as per the character of each plant layer, i layer to layer i +5 was divided to be the scan range, boundary overlap was 10mm for the total 6 scan layers.

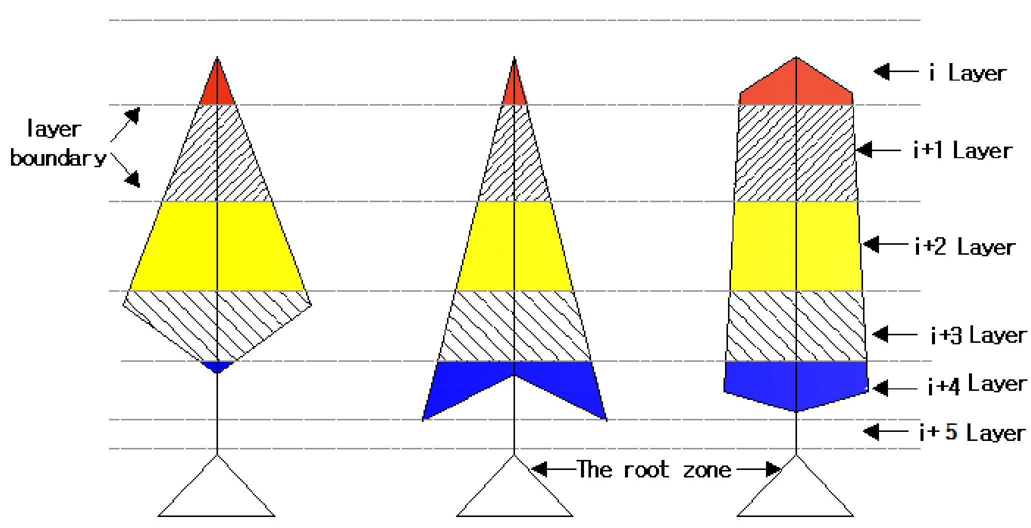


Fig. 4. Plant model of target detection could confirm the sensor mounting height as per the character of each plant layer, and i layer to layer i +5 is divided to be the scan range independently.

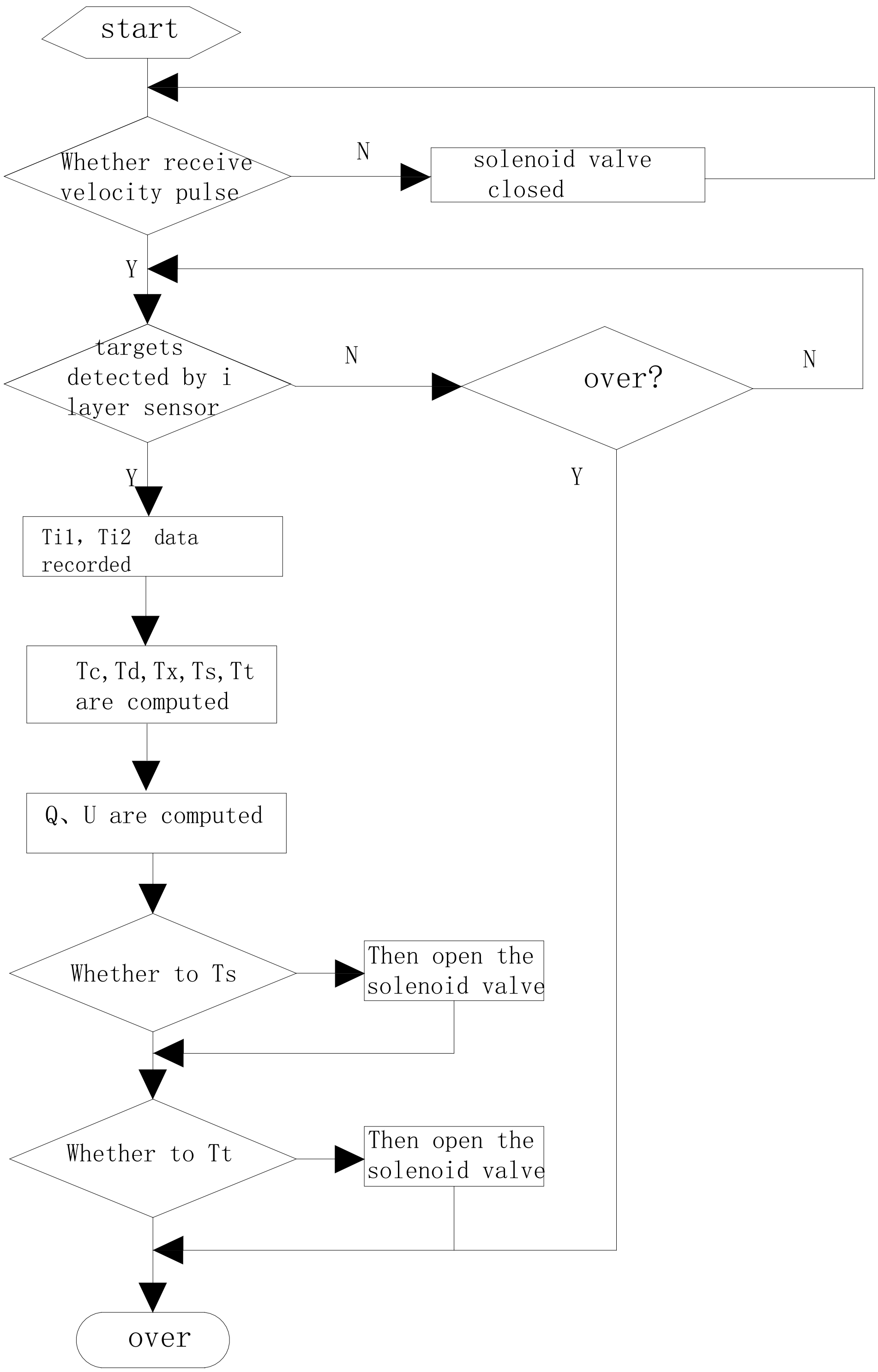


Fig. 5. The flow chart of fixed-point pesticide injection expressed the logic of control program intuitively. The dose and the injection position is computed out quickly according to this process.

PC control software design

A control system for the PC control software was developed by using SamDraw3.3 development platform (Shenzhen display control automation technology co., LTD). PC software issue commands to control the duty cycle of spraying pump voltage after its calculation base on the data of distance from infrared sensor to the nozzle, the correlation coefficient between the output pulse of wheel speed sensor and the vehicle speed , the transfer function between the biomass detected by infrared sensors and the duty cycle of the solenoid valve on output pipeline, the base reference dosing per plant, the acquisition of biomass signals of the infrared sensor, speed pulse signal of the vehicle speed sensor and quantitative flow rate signal of the flow sensor.

Results and Discussion

Flow variables control test

The relationship between duty and amount of pesticide is simalar to linear approximation in experiment. The R^2 gives how much variance is explained by the model in term of overall variance in data. The R^2 is relative measure and is very intuitive. Fitting curve equation of duty ratio and flow linear relationship is $y=12.163x+7.6$，of which $R^2=0.935$, R^2 for the quadratic fitting curve equation is 0.9714(Fig. 6).

Quantitative control test

In order to test the precision of the dosing quantitative adjustment module quantitative, the pc controller software sent commands to the lower computer, the lower computer control dose automatically after receiving commands. The lower machine started the pressure unit to begin the injection, meanwhile collected flow sensor signal and the internal clock signal. When the actual collection of the dose reached the set value, the lower machine automatically shut down the pipeline solenoid valve. The actual flowed out dose was collected with the plastic collection dish and weighed using a balance, each measuring 3 times and got the average value. The real measured value was a bit of larger due to the delay response of the solenoid valve. But the deviation was reduced after the system correction. The test data about the liquid quantitative adjustment are shown as in Table 2 with 3.2% of maximum error of quantitative adjustment, 0.4MPa of the maximum system pressure, -3.07% of error after correction.

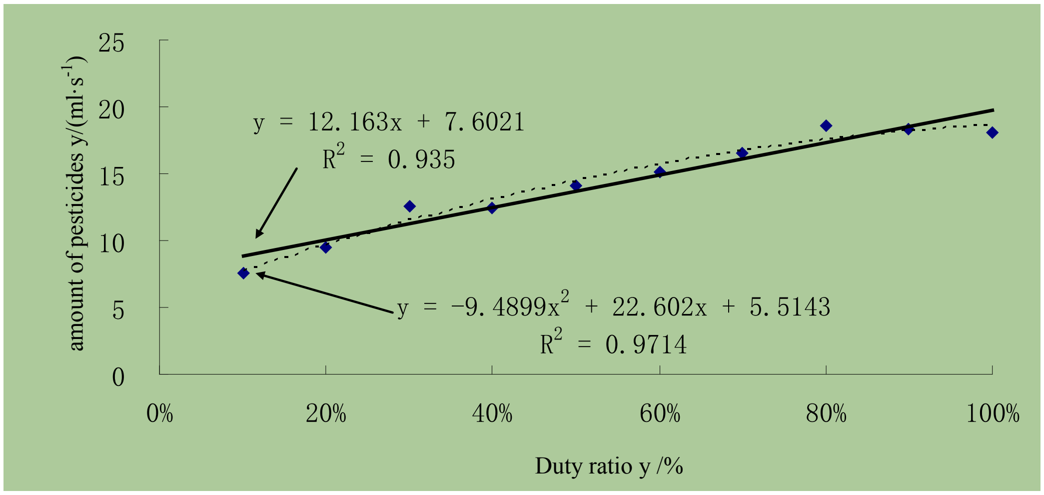


Fig 6. Duty ratio and flow have a good linear relationship. Fitting curve equation of duty ratio and flow linear relationship is y=12.163x+7.6.

In order to test the target crop model, time tree was set up. The detect time of start T_{i1} and end T_{i2} for each six layers, the root zone injection time of start T_s and end T_t, and intuitive analysis of location and width of the injection zone. If the crop is tilted, the exact injection area of the root zone should be obtained relying on the model.

Table 1. At the pressure of 0.1MPa, the controller controlled the injection quantity automatically according to the calculated value by PC software.

Set press. /MPa	Volume of liquid /(ml)					Relative error /%
	Set volume /*ml*	Test value 1/*ml*	Test value 2 /*ml*	Test value 3/*ml*	Average value/*ml*	
0.1	50	52.3	50.6	51.9	51.6	3.20%
0.1	100	107.2	104.5	102.7	104.8	2.47%
0.1	150	151.3	152.4	153.5	152.4	1.60%
0.1	200	202	200.3	205.2	202.5	1.25%
0.1	250	255	250.9	253.6	253.2	1.27%
0.4	250	239.3	245.8	241.9	242.3	-3.07%

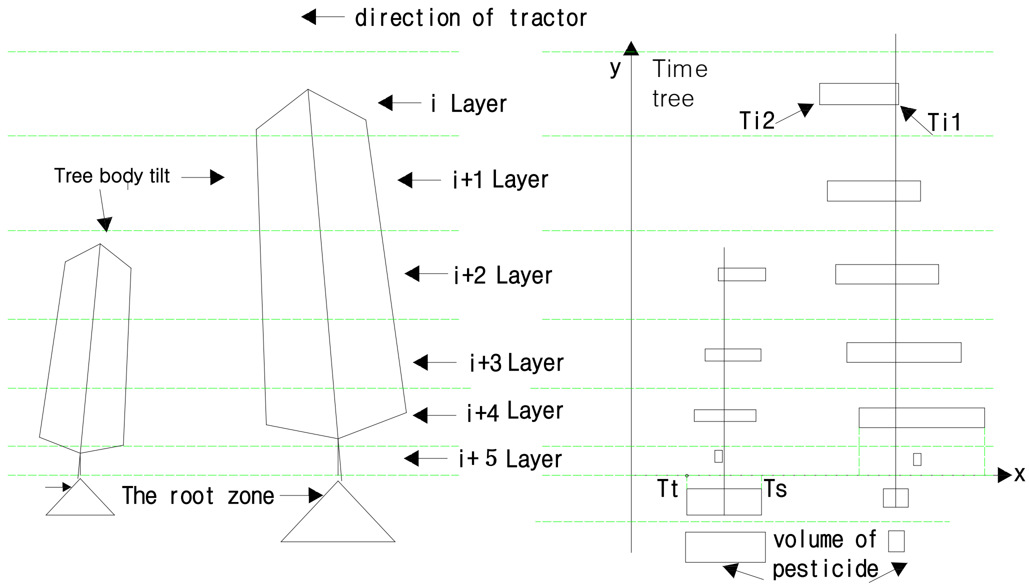


Fig. 7. Time points of optimized target model used to process the plant shape to time value that can be identified and computed by computer.

Prediction of relative position of injection range for soil root zone is a very difficult thing. It is a certain uncertainty that the disease severity, of the underground root invaded by root knot nematode, was predicted according to the growth vigor of the target eggplant. The proposed approach is meant to be used in mathematical model for computing the relative time according to benchmark time point. The problem was to be solved in two steps, the first step was to detect target and obtain the height information and position of the branches and leafs. Wherein the height of which was used to determine the prevalence of root crops and to calculate the pesticide amount need to be injected, and the position of the branches and leafs was used to build the computation model of time tree and calculate the injection width of the root and the relative benchmark time point. The second step was dynamic online adjustment of the flow and dose. Wherein the flow was calculated by controller according to the linear relationship to duty cycle, and sent commands to lower computer to realize. And the dose was obtained from the corresponding number of pulse to certain flow volume fed back by flow pulse sensor. Soil variable injection system(Fig 8) was traction to travel in the field.

Conclusion

A solution for injection into soil of root zone is demonstrated, which is used for crop infected by Meloidogyne detected by six sets of infrared sensor. The six sets of sensors detected targets independently and obtained corresponding

Fig. 8. Soil variable injection system included disc, plow and injector, and traveled by traction in the field. The outline of the soil variable injection system could be figured out.

scanning signal to each layer separately and sent the signal to the controller. As per circuit theory to analysis, Due to the response time is less than 2.5 ms for sensor to detect the target and the computing time is less than 1 ms for single-chip, the reaction time was very fast. So only one sensor could be used to detect at the same time, interfere with each other could be avoided completely in the actual test with multiple sensors used.

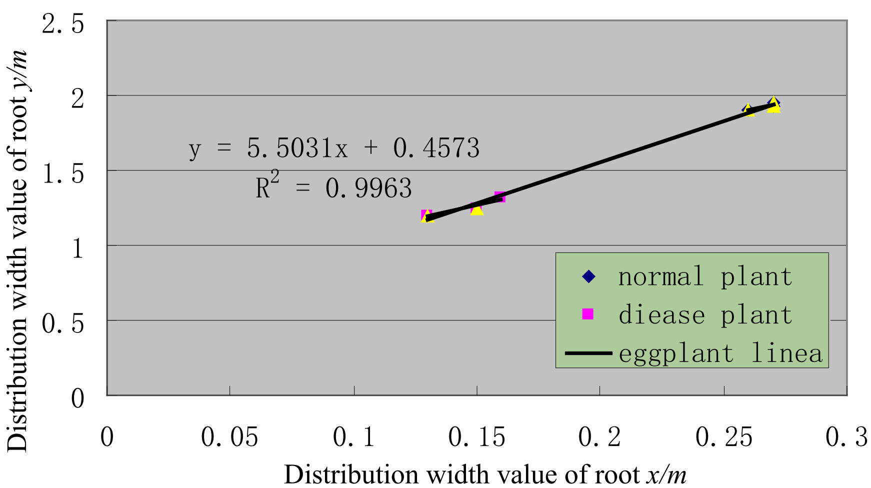


Figure 9. The relationship between eggplant height and root could be obtained by measuring the root excavated. And it is linear for eggplant with the same species and planted at the same time.

In the test, walking speed was 1 m / s, the degree of fit of the actual target signal was not less than 95% after the signal be treated by controller model, and the relative error was not more than 3.2% for dosing adjustment by the controller. It is linear relationship between the duty cycle for flow control and per unit of time, the linear regression equation was y = 12.163x +7.6, where R2 = 0.935. From measuring data, a linear relationship could be seen between the diseased plant height and root growth range.

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