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Development of Variable Rate Fertilizer System Based on Optical Sensor

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Abstract: A variable rate fertilizer system was developed for control of fertilizer amount by optical sensor measured NDVI of crop. The paper analyzes the input and output conditions of control system, and designed hardware, algorithm and control of fertilizer, mainly software flow and a feedback control way. In the paper, the variable-rate control system consisted of 6 optical sensors mounted on a boom in front of the tractor, interface module, micro controller, speed sensor, rotation sensor, PWM valve, and hydraulic motor. This type of VRT system does not use prescription maps, but relies on sensors to provide real-time crop detection information which is used to dispense fertilizer amount for the crop need. According to the amount of fertilizer information, fertilizer controller can automatically control flow amount by adjusting hydraulic valve based on working speed, which changes the hydraulic motor rotation to achieve the variable work. Experiments of fertilizer by pre-setting different dosage, the results shown that the errors of fertilizer amount are well in fact, and the errors are less than 5.17 %, and it shown CV is from 0.35 % to 2.67 %. The fertilizer response time of controller system is less than 0.875 s, it can meet the need of practical production. The system is well resolves to achieve variable rate fertilizer based on optical sensor. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Crop growth status, Optical sensor, Variable rate fertilization, Control system.

1. Introduction

As the voice of sustainable development of agricultural production increasing, the environment pollution caused by chemical fertilizers be concerned, most developed countries have established relevant laws to restrict the use of chemical fertilizers. However, variable-rate technology (VRT) used has become a common practice implemented by precision agriculture (PA) practitioners. VRT is accomplished by applying only what is needed based on local soil conditions and crop requirements compared to fertilizer inadequate applications in traditional. In addition, reducing over and under-application of inputs will enhance productivity, profitability, and environmental concerns. However, the whole agricultural machinery and the technological level lower than developed countries today, in the study of variable rate fertilization technology, mainly is the introduction of foreign advanced technology and equipment to carry out digestion and absorption and follow-up studying.

Currently, VRT has replaced traditional fertilization working in some developed countries of precision agriculture, in the work of variable rate fertilization, one is the variable rate fertilization work based on the prescription map, and another is based on sensor for real-time control. Because our country for variable fertilization technology research later, the variable fertilization in domestic mainly variable rate fertilization operation is based on prescription map [1-4]. It is the mainly way by measuring the nutrient information of soil in advance, then the fertilizer prescription map is provided based on soil nutrient information by fertilization decision analysis, and variable fertilization machinery can obtain operation geographic position coordinates by the GPS navigation in the real-time, in under the control of the control system, the system can guide fertilization according to fertilizer prescription map. thus the system can fertilization much in the soil nutrient lower, soil nutrient higher place reduce fertilizer, so as to achieve rational fertilization, improve chemical fertilizer use efficiency. But the variable rate fertilization way based on prescription map need to advance to test the soil nutrient information in laboratory, calculation, the process is relative trouble, and the analysis time is long, the cost is high.

In recent years, with continually research to variable rate fertilization technology, variable rate fertilization technology based on the optical sensor becoming popularity [5-13], the principle is based on crop spectrum index and crop growth characteristics take on a good correlation.

The nitrogen detection is mainly through gathering vegetation index information of crop, then calculate fertilization amount according to vegetation index by optical sensor. Thus the system can rapid measure crop nutrient information and can achieve VRT based on the optical sensor. Currently, there are some relevant measuring device prototype was reported and application [14-18], but have not to combine with fertilization mechanical, and lack of further field experiments. Therefore, the development of the variable rate fertilization system based on optical sensor is important practical significance and it is an important direction of VRT development. So in the paper, a variable rate fertilizer system was developed for controlling of fertilizer amount by optical sensor measured NDVI of crop.

2. Framework of the System

The application system mainly includes four parts: crop nutrition monitoring system based on optical sensor, interface module, variable fertilization controller and variable fertilizer applicator. Crop nutrition monitoring system installed in front of the tractor, for acquisition crop growth state and nutritional status, the sensors were connected to interface module, and the collection data transmission to interface module. The interface module has serial and power connections. The interface module connected with variable fertilization controller by serial. The variable fertilization controller combined with fertilization model to make the best use of fertilizers decision, this decision information can transmit fertilization information to variable applicator by the fertilization controller, the fertilizer applicator control system through the control hydraulic valve opening size which scatter the needed fertilization in the surface of the soil.
Variable rate fertilization system is designed to achieve demand of fertilization application.

The paper is based on a variable input signals to output the electric signal to control hydraulic valve opening size. A rotation sensor was used which fixed with hydraulic motor rotation axis. The flow rate of valve can be controlled by adjusting the opening position of hydraulic valve. And the flow rate can be controlled by changing hydraulic motor rotation speed as feedback based tractor speed. The input signals of controller include crop nutrient information by optical sensor, per-axis fertilizer amount, fertilizer applicator parameters and pre-set fertilizer amount; the feedback of sensors; tractor speed; and GPS / GIS / PC input signals, etc. Output signal is mainly hydraulic valve opening size which used to control flow rate, the pulse-width modulation (PWM) used to control the hydraulic control valve and the serial data which output to the LCD screen. In addition, the controller has a serial data interface to allow for the extended application (to connect some testing equipment, such as bin level sensor etc.).

The system structure shows in Fig. 1.

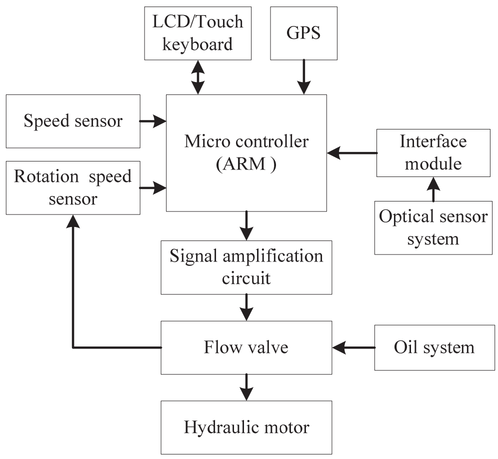

Fig. 1. The system structure.

3. Design of Controller System

3.1. Hardware Design

The core control unit used to carry out the data processing and exterior control which including serial ports, AD. Considering the measurement system upgrade, cost of general price, power consumption and compact, the system chosen STMF103VC as the whole system processing core. The core is Cortex™-M3 CPU used ARM 32-bit. It provides low cost of the platform, reduced pin number and reduced the system power consumption to achieve the needs of MCU. At the same time, the STM32 product embedded two 12 analog/digital converter (ADC), each ADC share up to 16 external channels, conversion rate can reach 1 μs.

The system chosen A/D converter was MAX186 of the MAXIM company production. The chip containing eight channel multipath switch, high bandwidth tracking/retainer, 12 byte successive approximation A/D converter, serial interface circuit, etc., the resolution is 1mv, internal tracking and tracing, 133 kHz sampling rate, 4.096 V internal reference, SPI, QSPI, Micro wire, TMS320 compatible 4 wire serial interface. Software configuration unipolar and bipolar input and 20 pin SSOP package. It can well satisfy the system requirements.

Due to the need for measuring different reflectivity of the light intensity, so based on the actual application, choose the silicon photocell as photoelectric conversion element, because the cell as a detector has some characters of a larger photosensitive area, higher frequency response, photocurrent with illumination linear change etc. The chip designs with the silicon photocell and operational amplifier two input connected with polarity, two amplifier two input terminal of the input impedance is silicon photoelectric load resistance, can think of silicon cell is in short circuit working condition, and can output to the ideal of the short circuit current. This study in the comprehensive consideration, choose high performance 2 CR1227-01 silicon photocell as photoelectric sensor, the photosensitive area is 10×10 mm^2, and it can meet the requirements of performance indicators, the price cheaper. Silicon cell transformation out of the current signal will current signal amplification converted into a voltage signal through the integrated operational amplifier.

3.2. The Algorithm of Fertilizer

Lukina developed nitrogen fertilizer optimization algorithm (NFOA) based on *NDVI* in Oklahoma State University [19], Johnson and Raun found exist ratio relationship in the between conventional fertilization under the conditions of production and yield in conditions of adequate fertilization [20]-[22]. Lukina based on the original model has been adjusted in 2003. The algorithm as follows:

1. The nitrogen requirement (Fertilizer Nitrogen Requirement, *FNR*) formula:

$$FNR = 23.9\frac{YP_N - YP_0}{\eta}, \quad (1)$$

where 23.9 is the wheat nitrogen content, η is the nitrogen utilization, YP_0 is the yield potential of conventional fertilization conditions, YP_N is the yield potential in conditions of sufficiency fertilization.

2. The potential yield under conventional fertilization conditions:

$$YP_0 = 0.359e^{324.4INSEY}, \quad (2)$$

where *INSEY* is the yield estimation coefficients of the season, which calculate by *NDVI* divided the number of days:

$$INSEY = \frac{NDVI}{DAYS}, \quad (3)$$

3. The potential output after topdressing nitrogen fertilizer:

$$YP_N = YP_0 \times RI_{NDVI}, \quad (4)$$

where RI_{NDVI} is the vegetation reflectivity of near infrared light.

But Oklahoma wheat is mostly growing in dry land, in China the wheat field is irrigated land; in particular the testing ground has sufficient water. As a result, the paper chooses nitrogen use efficiency is 0.4 by referring to expert advice on agronomy. And the combination of the Raun model can further increase the utilization rate of 15 % by comparing to original model, so the paper nitrogen use efficiency take 0.46.

And the potential yield (YP_N) after applying nitrogenous fertilizer is a variable parameter in Lukina's model. It is positive relationship with *NDVI* value. If *NDVI* value small, then the calculated results of YP_N small, it will result to calculate the final fertilization amount(*R*) is small, too. The view from this algorithm formula of thought is based on wheat growing in strength, strong growth place more fertilizer, in bad growing place less fertilizer, not consider consistency of yield, and it is easy to cause excessive fertilization. In fact, we need more fertilizer in the growing bad place, and less fertilizer in the growing good place.

So the paper improved model can be expressed as:

$$FNR = 23.9\frac{YP_T - YP_0}{0.46}, \quad (5)$$

According to the test area production, the paper chooses experience value based on advice of agronomist, takes 6.75 t/hm^2 replaced with the target yield (YP_T), the YP_0 in model still use the original formula.

The improved model can use more fertilizer in poor growing field land, less or no fertilizer in growing good place based on the test *NDVI* values.

3.3. Design of System Controller of Fertilization

When does not consider other machinery, the influence of the environment, fertilizer applicator fertilization per hectare is

$$Q = \frac{n \times q \times N_1 \times 10000}{v \times L}, \qquad (6)$$

where q is the fertilizer amount of fertilizer applicator and q can measure by experiment, v is speed of working, n is the rotation speed of fertilizer applicator, L is the working breadth, N is the quality of fertilizer applicator.

The tractor speed through the hall sensor for test, and its principle is in the measured signal T time, the speed sensor measured pulse counting, the working speed can be obtained by follow formula

$$\upsilon = 2\pi R / TN_2, \qquad (7)$$

where R is the distance of measuring wheel axis to the ground, m; N_2 is the number of magnet in wheel.

When the PWM output signal pulse width increases, PWM duty ratio ascend, distributing shaft speed also will increase the test to distributing shaft speed and PWM signal pulse width has good linear relationship, determination coefficient of 0.988. The relationship is

$$n = 0.085B - 4.742, \qquad (8)$$

where n is the speed of fertilizer axis, r/s; B is the width signal pulse, %.

3.4. Software Design

The whole procedure of the process, the bottom of the system initialization, allocation of each module corresponding address space, the system output control signal, so that the valve reset, and then the controller in the timer interrupt program gathering outside of the fracture in the interrupt signal, through the acquisition signal phase coupling, the valve opening adjustment, at the same time will motor speed signal through the interrupt testing return controller, through processing and valve opening phase comparison, through the deviation to adjust the balance of the valve, make the fertilization stable.

In the whole control process, to crop growth information, operation speed and motor speed sampling, first through the light sensors to grow crops for information collection, the signal amplification transmitted to the control system, the application for the calculation of the energy storage register for call in a program, also set up a sensor pulse signal from the external interrupt, here is equivalent to the function of the counter, and as a speed sensor information sampling time timing interruption, in the timer interrupt program, calculation work speed, stored in a register, and be ready to call.

The system mainly software flow chart shown in Fig. 2.

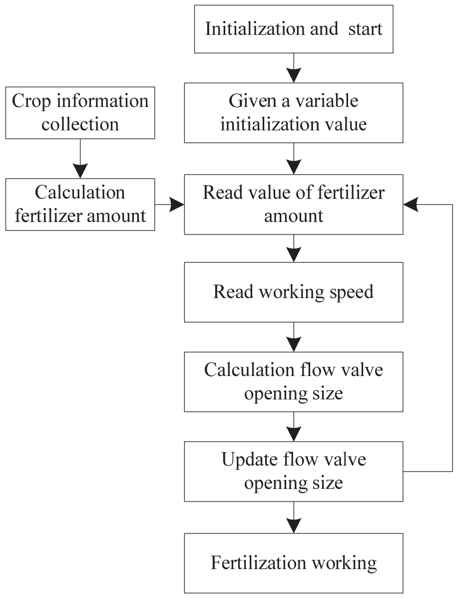

Fig. 2. Software flow chart.

3.5. Fertilization Amount Feedback Control

The chip can calculate the output PWM duty cycle according to the pre-set fertilizer amount after collected the speed of tractor.

The feedback control is to regulate the PWM signal duty cycle according the real revolution speed of hydraulic motor by the microcontroller chip collect the rotary encoder output signal which fixed on the hydraulic motor. The new PWM signal controls the oil flow of the hydraulic flow control valve to control hydraulic motor which achieved to adjust the hydraulic motor revolution speed. Software design flow chart shows in Fig. 3.

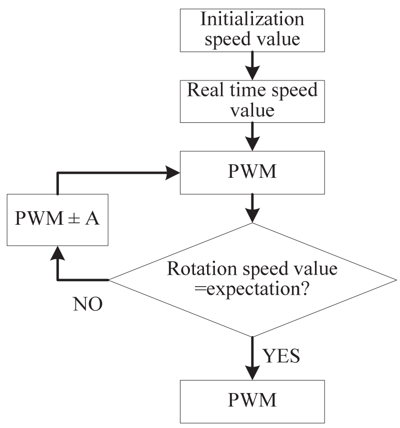

Fig. 3. Feedback control design.

4. System Test and Experiment

In order to test the actual performance, carry out field trials and testing to the automatic controller of variable rate fertilizer applicator. Before the experiment, fix the controller, hydraulic motors, Hall switches and the other implementation units to these positions and connect the oil hydraulic circuit to the tractor. The DC power is controller, sensors and hydraulic need provided by tractor battery and its specifications is +12V/240 Ahr. Fertilizer uses the better mobility of chemical fertilizers - urea in the experiment. Check the corrects of the system, then power up, after initialization, the operator through the keyboard input the preset data, after controller calculate these collected signals output PWM signals to control the hydraulic motor, hydraulic motor driven gears through chains to achieve the precise variable rate fertilization. Table 1 showed the measured results of different preset fertilizer amount.

Table 1. Different preset fertilizer amount experiment.

Number	Pre-set amount (kg/hm^2)	Actual amount kg/hm^2	Relative error (%)	CV (%)
1	75	75.49	0.65	0.45
2	105	108.25	3.09	2.51
3	120	125.11	4.26	0.36
4	150	157.76	5.17	2.38
5	180	184.43	2.46	0.35
6	225	223.11	0.84	2.67
7	255	252.42	1.01	1.11
8	300	302.44	0.81	2.55
9	345	341.20	1.10	1.60
10	375	365.17	2.62	1.93

In the actual measurement, the maximum relative error is 5.17 %, and it shows CV is from 0.35 % to 2.67 %. So it can well meet the purpose of variable rate fertilization and its standards.

In the other experiment, place three rows of fertilizer boxes in the fields, distribute according with the fertilizer hopper both sides and the middle, 29 boxes per row and interval 0.5 m, and the area of each box is 0.35 × 0.25 = 0.0875 m^2. The test has changed the pre-fertilizer volume from 150 kg/hm^2 to 375 kg/hm^2 under working speed at 2 m/s and 2.5 m/s.

The system fertilizer response time (t) is

$$t \prec \frac{0.5\times 2 + 0.25\times 3}{2} = 0.875s, \qquad (9)$$

From Fig. 4 we can see that the response is the rapid and timely in fertilization. The response time of fertilizer volume changes is less than 0.875 s; this time is less than the desired time of the controller designed. The experiment has proved that fertilizer controller can meet the requirements of field fertilization.

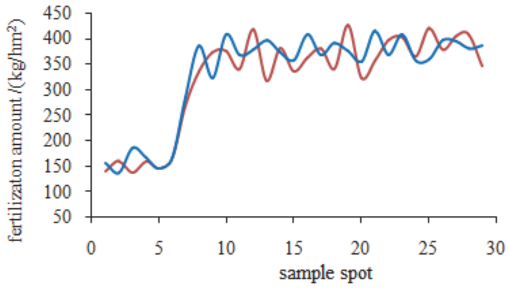

Fig. 4. Data distribution.

5. Conclusions

Aim at variable rate fertilizer based on optical sensor, the paper analyzes the input and output conditions of control system, designed a hardware control system based on ARM chip, designed mainly software flow and designed a feedback control way. The system can automatically control flow amount by adjusting hydraulic valve size, and can change hydraulic motor rotation based on working speed at the same time.

The system used the hydraulic motor as a drive mechanism is more reasonable than motor, which can overcome the small torque and start out-of-step phenomenon. And used control chip is faster, reliability well, and has a good real-time online display.

Carried out systematic laboratory testing, field testing and analyses experimental results of errors. Field experiment results show that fertilizer amount in fact is well to target fertilization amount, the maximum relative errors is 5.17 %, and it shown CV is from 0.35 % to 2.67 %. Experimental indicated that the variable rate fertilization control system to control fertilization, which can achieve the aim of saving fertilizer and reasonable fertilization. The fertilizer response time of controller system is less than 0.875 *s*.

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References

[1]. Wang Xiu, Zhao Chunjiang, Meng Zhijun, et al., Design and experiment of variable rate fertilizer applicator, *Transaction of the CSAE*, 20, 5, 2004, pp. 114－117.

[2]. Meng Zhijun, Zhao Chunjiang, Liu Hui, Development and performance assessment of map-based variable rate granule application system, *Natural Science Edition, Journal of Jiangsu University,* 30, 4, 2009, pp. 338－342.

[3]. Fu Weiqiang, Meng Zhijun, Huang Wenqian, et al. Variable rate fertilizer control system based on CAN bus, *Transaction of the CSAE,* 24, supp. 2, 2008, pp. 127-132.
[4]. Geng Xiangyu, Li Yanming, Miao Yubin, et al., Development of variable rate fertilizer applicator based on GPRS, *Transaction of the CSAE,* 2007, 23, 11, pp. 164-167.
[5]. Labus M P, Nielsen G A, et al., Wheat yield estimates using NDVI satellite imagery, *Int. J. Remote Sens.,* 2002, 23, 20, pp. 4169-4180.
[6]. A. Calera, C. Martínez and J. Melia, A procedure for obtaining green plant cover：relation to NDVI in a case study for barley, *Int. J. Remote Sens.,* 22, 17, 2001, pp. 3357-3362.
[7]. Galvao L. S., VitorelloI, Pizarro M. A., An adequate band positioning to enhance NDVI contrasts among green vegetation, senescent biomass, and tropical soils, *Int. J. Remote Sens.,* 21, 9, 2000, pp. 1953-1960.
[8]. Lukina E. V., Freeman K. W., Wynn K. J., et al., Nitrogen fertilization optimization algorithm based on in-season estimates of yields and plant nitrogen uptake, *Plant of Plant Nutrition,* 24, 6, 2001, pp. 885-898.
[9]. Rondeaux G., Optimization of soil-adjusted vegetation indices, *Remote Sensing of Environment,* 55, 2, 1996, pp. 95-107.
[10]. Kyle H. Holland, James S. Schepers, Use of a virtual-reference concept to interpret active crop canopy sensor data, *Precision Agriculture,* 14, 1, 2013, pp. 71-85.
[11]. Luciane F. Oliveira, Peter C. Scharf, Earl D. Vories, et al., Calibrating Canopy Reflectance Sensors to Predict Optimal Mid-Season Nitrogen Rate for Cotton, *Soil Science Society of America Journal,* 77, 1, 2012, pp. 173-183.
[12]. B. S. Tubana, D. L. Harrell, T. Walker, et al., In-Season Canopy Reflectance-Based Estimation of Rice Yield Response to Nitrogen, *Agronomy Journal,* 104, 6, 2012, pp. 1604-1611.
[13]. Lucas Rios Amaral, Jose Paulo Molin, Optical sensor to support nitrogen fertilization recommendation for sugarcane crops, *Pesquisa Agropecuaria Brasileia,* 46, 12, 2011, pp. 1633-1642.
[14]. Li Xiuhua, Zhang Feng, Li Mingzan, et al., Design of a for-waveband crop canopy analyzer, *Transactions of the Chinese Society for Agricultural Machinery,* 42, 11, 2011, pp. 169-173.
[15]. Zheng Wengang, Sun Gang, Shen Changjun, et al., Development of a visible-infrared photoelectric instrument for measuring crop nitrogen, *Transactions of the CSAE,* 26, 3, 2010, pp. 178-182.
[16]. Jose F. Reyes-Aroca, David F. Berrios-Araya, Rodrigo A. Ortega-Blu, et al., Static Calibration of A System for Automatic Control of Fertilizer Variable Dosage, *Agrociencia,* 46, 1, 2012, pp. 51-62.
[17]. Peter C. Scharf, D. Kent Shannon, Harlan L. Palm, et al., Sensor-Based Nitrogen Applications Out-Performed Producer-Chosen Rates for Corn in On-Farm Demonstrations, *Agronomy Journal,* 103, 6, 2011, pp. 1683-1691.
[18]. P. J. Bennur, R. K. Taylor. Evaluating the Response Time of a Rate Controller Used Withe a Sensor-Based, Variable Rate Application System, *Applied Engineering in Agriculture,* 26, 6, 2010, pp. 1069-1075.
[19]. Wibawa W. D., Dludlu D. L., Swenson L. J., et al., Variable fertilizer rate application based on yield goal, soil fertility and soil map unit, *J. Prod. Agric.,* 6, 1993, pp. 255-266.
[20]. Mullen R. W., Freeman K. W., Johnson G. V., et al. The Magruder plots: Long-term wheat fertility research, *Better Crops,* 85, 2, 2001, pp. 6-8.
[21]. Solie J. B., Raun W. R., Stone M. L., Submeter spatial variability of selected soil and Bermuda grass production variables, *Soil Sci. Soc. Am. J.,* 63, 1999, pp. 1724-1733.
[22]. Raun W. R., Solie J. B., Johnson, et al., In-season prediction of potential grain yield in winter wheat using canopy reflectance, *Agron. J.,* 93, 2001, pp. 583-589.