Design and experiment on intelligent fuzzy monitoring system for corn planters

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Abstract: When sowing summer corn without tillage, it is necessary to ensure that the furrow opener is free from straw congestion and that the spacing of the sowing can be adjusted according to the breeds of corn and the preset seeding rate per acre. On the basis of the structural features of newly developed no-tillage corn fertilizers, an intelligent fuzzy monitoring system for corn planters was developed in this study. The system facilitates automatic control of the spacing adjustment and the status monitor for the fertilizer tank, seed tank, and seeding orifice. According to the preset number of rows, line spacing, number of plants per acre, and seed germination rate, the control rate can be calculated through designing in surveillance software. The control rate is output to the fuzzy controller through the digital output module of the CAN bus. Fuzzy control is applied to the DC motor for stepless adjustment of the spacing. A system for video surveillance of the working status of a planter is developed for displaying a real-time video image of the planter operation and achieving an anti-congestion status monitoring of a no-tillage planting operation in a dusty environment. Through field trials, the detection accuracy was 91.4%. The seed-clogging fault-alarm accuracy was 96.0%. The entire system remained stable and reliable.

Keywords: corn planters, stepless adjustment, plant spacing, fuzzy control, monitoring system, fault alarm

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1 Introduction

After several years of development in China, some achievements have been made in precision planter monitoring systems, but there remain issues such as mediocre system operational reliability, high manufacturing costs, a low degree of modularity and inadequate adaptability, all of which restrict the wide application of precision planter monitoring systems. Currently, the following seeding performance detection methods exist in China and abroad: (1) manual inspection, (2) photoelectric effect, (3) piezoelectric effect, (4) high-speed photography, (5) strobe photography and (6) machine vision detection. According to information gathered by the authors at an agricultural machinery show held in Hanover, Germany in 2011, internationally, the technology for monitoring the precision of wheat seeders with regard to quantity as well as that of combine

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harvesters in real-time concerning feed has become quite mature. The research focus has been transferred to automatic control technology. Internationally advanced electronic monitoring systems for planters can not only display the real-time working status of a planter, but also adjust and control the sowing amount per row, the number of grains per meter and the rotational speed of the seeder. For example, German HORSCH precision seeding machinery can calibrate equal distances between any two seeds at a sowing speed up to 15 km/h. The U.S.A. has been able to achieve intelligent navigation and autopilot functions in field operation processes. An autopilot system can be configured into various modes such as precision variable-rate fertilization, variable-rate spraying, and others for variable operating control. The application effect of an automatic navigation system is significant, thus easy for farmers engaged in large-scale commercial cultivation.

With the accelerated process of agricultural modernization, mechanization will become the dominant mode of production. The trend of reducing labor and increasing automation is irreversible. The demand for farm machinery and equipment has rendered rigid growth. At present the overall development of China’s agricultural mechanization has entered the intermediate stage from the primary stage, with the advanced stage being approached at an increasingly progressive rate. Development of precision planting and fertilization is an inevitable path of agricultural mechanization and is the basis for harvest. Precision planting can help substantially save seeds for sowing, save hours of thinning work, or completely eliminate the thinning process, thereby improving the tidiness, health, nutrition, collective balance, and production of crops. Precision fertilization can conserve fertilizer and protect the environment by meeting the exact needs after measuring the soil nutrition level. In no-tillage sowing of corn, there is an urgent need to achieve a breakthrough in the entire process of mechanization, to improve agricultural efficiency, and save on cost. In this study, on the basis of the characteristics of no-tillage corn sowing and fertilizing equipment, a corn planter operation monitoring system was designed, to achieve surveillance over the status of automatic control of seeding spacing and the positions of the fertilizer and seed tanks as well as the seeding orifice[1].

2 Materials and methods

2.1 General system design

Our system for monitoring the working status of a corn planter consists of the following items: Onboard computers, GPS receivers, digital cameras, a tilt sensor, a USB-CAN interface module, displacement sensors, an electronically controlled stepless spacing regulator, a CAN bus analog input module, CAN bus digital input and output modules, a CAN bus pulse counting module, a seed tank sensor, a fertilizer tank sensor, a seeding orifice sensor, a gear speed sensor, and other components.

The CAN bus module is embedded with microcontrollers. Therefore, the onboard computer and CAN bus modules constitute a distributed systems via the CAN bus. The topology of the entire system is shown in Figure 1[2-6].

The GPS receiver monitors the travel speed, latitude and longitude of the planter. Data is transferred through the USB interface to the onboard computer. Latitude and longitude data are transferred via system software into plane coordinates x and y, which can be used to calculate the acreage.

A digital camera is used to capture video images, which are sent via the USB interface and transmission lines to the onboard computer, enabling a real-time display of the work status of the planter so that the driver of the tractor can be aware of what is happening behind the vehicle without looking back.

The tilt sensor is used to monitor the working or shipping mode of the planter, which helps the system software determine which programs to execute.

The displacement sensor monitors the position of the electronically controlled stepless spacing regulator. The onboard computer collects information and compares it with the desired seeding rate, calculates the deviation, and outputs a motor-control signal to drive the stepless spacing regulator in accordance with the walking speed of the unit, which in turn outputs the desired shaft speed and realizes the adjustment of variable sowing spacing.

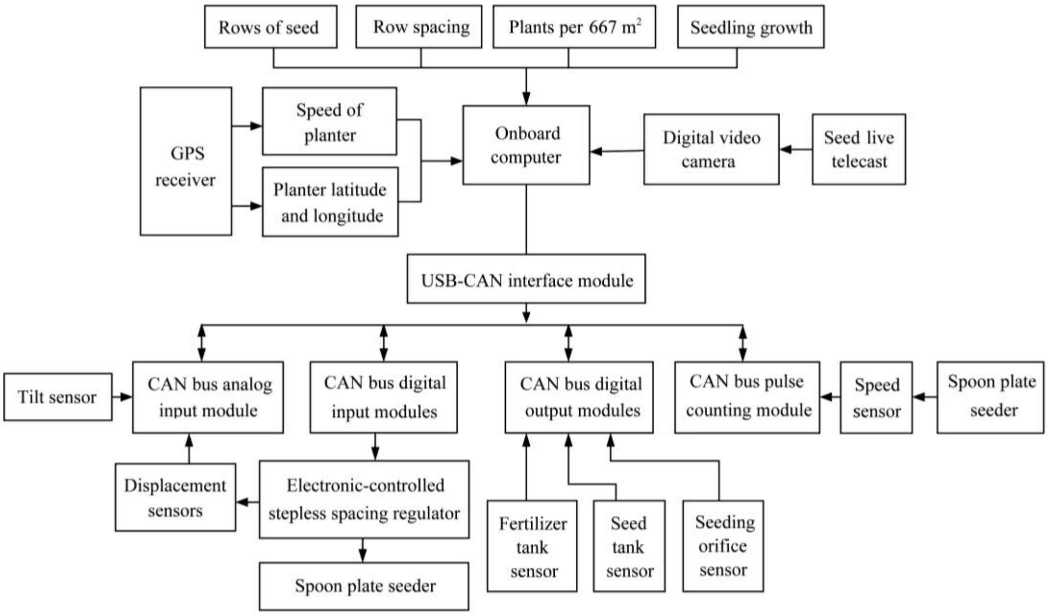

Figure 1 Topology of planter monitoring system

The fertilizer tank sensor is used to monitor the residue in the fertilizer tank. If the amount is insufficient, the sensor will send alarm information.

The seed tank sensor is used to monitor the remaining amount of seed in the tank. If the amount is too small, the sensor will send a warning. The seeding orifice sensor is used to monitor possible blockage in the orifice. If the situation is abnormal within, the sensor will send alarm information. The speed sensor is used to generate the rotation pulse of the drive shaft of the spoon-plate seeder. The onboard computer counts the pulses via the CAN bus pulse counting module. If the pulse signal is abnormal, the onboard computer will determine whether there is ground wheel slippage, on the basis of the traveling speed of the planter.

The tilt, displacement, fertilizer-tank, seed-tank, seeding-orifice and speed sensors are all connected to the onboard computer through the CAN-bus analog and digital input modules, plus CAN cables and USB-CAN interface, respectively. The topology of the monitoring system is shown below.

2.2 System hardware design

An onboard computer is installed in the tractor cab. When working in the fields, the tractor travels at a high ambient temperature with heavy vibrations and dust. From the viewpoint of reliability and durability for onboard use, an industrial touch tablet computer is selected, with the following specifications: CPU (Onboard INTEL Atom N450, 1.66GHZ), LCD Type (TFT), screen size (12.1 inch), resolution (1024 × 768).

A spoon-plate corn seeder is used to connect to the planter system for precision seeding. The seeder is driven by a ground wheel and a transmission device. When the planter is moving, the ground wheel rotates, thereby driving the rotation of a hexagonal shaft through the transmission device of the sprocket and chains. The shaft drives the spoon-plate seeder through the sprocket and chains. A gear-speed sensor is installed on one end of the shaft to monitor the output state of the per-second-speed pulse signal conduct signal processing. In this way the working status of the seeder can be determined. Together with the travel speed of the planter, the ground wheel slippage ratio can be calculated. The installation of the gear-speed sensor onto the planter is shown in Figure 2.

Figure 2 Gear-speed sensor

Figure 2 shows a measuring gear with 60 teeth installed on the outer end of the hexagonal shaft. A magneto-resistive sensor is installed facing the circumference of the gear. Whenever the gear rotates by a pitch, the sensor converts the movement into an approximate sine wave signal and outputs it. The signal is filtered and amplified into a pulse signal. For every circle in which the gear rotates, the sensor outputs 60 pulses.

The measuring gear is of the driven type, meaning that when the hexagonal shaft rotates, the gear rotates. Therefore, by measuring the rotational speed of the gear, the speed of the spoon-plate seeder can be calculated. The monitoring system uses the CAN bus pulse-counting module to measure the pulse signal output by the gear-speed sensor.

When the result obtained from the pulse- counting module is C, the pulse-number per-circle output of the gear from the speed sensor is P, the counting time is t seconds, and the gear speed is n (r/min), the following equation is established:

$$C=\frac{P\cdot t\cdot n}{60} \tag{1}$$

where t = 1 s and P = 60, C = n.

By rearranging Equation (1), the formula to measure the gear speed becomes

$$n=\frac{60C}{P\cdot t} \tag{2}$$

Equation (2) shows that if the counter counts the pulse signal in t seconds, the speed n of the measuring gear can be calculated.

In this study, the GPS receiver receives the traveling speed of the planter and its positioning information. With the assistance of a HOLUX GR-213U, GR-213U built-in satellite receiving antenna and a third-generation GPS receiver chip designed by SiRF, the receiver communicates with other electronic devices through the USB interface. With its built-in rechargeable battery, the receiver stores satellite data such as signal status and the last recorded location, date and time. The receiver collects position information every 0.1 second and performs an update every second.

2.3 Crop-spacing stepless regulating unit

Corn, soybeans, peanuts and other field-planted crops are the major ones in China. They are used not only for food and forage but are also important sources of industrial raw materials, food ingredients and bioenergy. To meet the demand for crops for sustainable development of China’s national economy, rapid development of animal husbandry, population growth and energy production, to further improve crop production remains a current goal for Chinese agriculture. Since the yield of corn and other crops is closely associated with planting density and patterns, and the various regions have different requirements for planting density, together with the diverse illumination times, temperatures, soil and crop varieties in different regions, there are differing requirements for the spacing of crops. This situation requires that planting spacing be adjusted steplessly. The control mechanism for the stepless spacing-regulating planter designed in this study is shown in Figure 3.

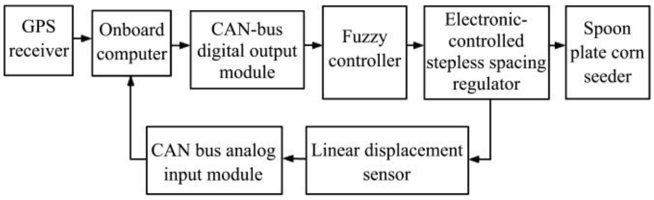

Figure 3 Control mechanism of stepless spacing-regulating planter

The onboard computer receives GPS location information and the traveling speed of the planter through the USB interface. On the basis of the set number of rows, row spacing, number of plants per acre and seed germination rate, the control amount can be calculated by self-developed software. The control information is sent via the CAN-bus digital output module to the fuzzy controller, which performs fuzzy control over the DC motor in the stepless spacing regulator, thereby achieving the requisite adjustment.

The linear displacement sensor inside the stepless spacing regulator monitors and adjusts the position information which is sent to the onboard computer via the CAN bus analog input module. The computer calculates the displacement error and the rate of change in errors in the stepless spacing regulator[7-10].

3 System software design

3.1 Coordinate calculation of GPS positioning of planter

The GPS positioning coordinates of the planter and the calculation baseline vector of the relative positioning belong to the WGS 84 geodetic coordinate system. In China geodetic measuring data use the Chinese geodetic coordinate system or a local system (also called local reference coordinate system). Therefore, coordinate conversion is necessary. In the system software, the $GPGSV, $GPRMC, and $GPVTG phrases are all collected through a serial port. The latitude and longitude of the planter can be obtained after string manipulation. Then a conversion from the WGS 84 geodetic coordinates into the Gauss-Krüger coordinate system is performed to obtain the x, y coordinate data for the planter position.

3.2 Fuzzy control algorithm of stepless spacing regulator

The key to precise adjustment by a stepless spacing regulator is the displacement accuracy of the slider on the regulator. This type of regulator is a nonlinear system characterized by a pure-time delay phenomenon. Lag errors occur when classical control methods are used; however, fuzzy control does not need to establish a mathematical model of a controlled object. The robustness of a nonlinear delay system is suitable for the control thereof; therefore, fuzzy control is a good choice for a stepless spacing regulator.

3.2.1 Structure of fuzzy controller

The fuzzy controller of the stepless spacing regulator uses regulator-slider displacement errors and the changing rate of the errors as input. The output variable is the control value of the DC motor. The structure of this controller is shown in Figure 4.

The DC motor ~~of~~ on the stepless spacing regulator has only ~~o~~n-and-off modes while running; hence, it is not adjustable. In fuzzy control, the Mamdani Model requires division of the control value into several levels during the fuzzy process. Different levels of control value have different adjustment values, thereby requiring the controller to be adjustable. There is another model for fuzzy control: the Sugeno Model. The latter part of the fuzzy rule for this model can be in the form of a function or a constant, 1 for on and 0 for off, which match the two-end control state of the DC motor on the stepless spacing regulator. Therefore, the control of this motor uses the Sugeno Model[10].

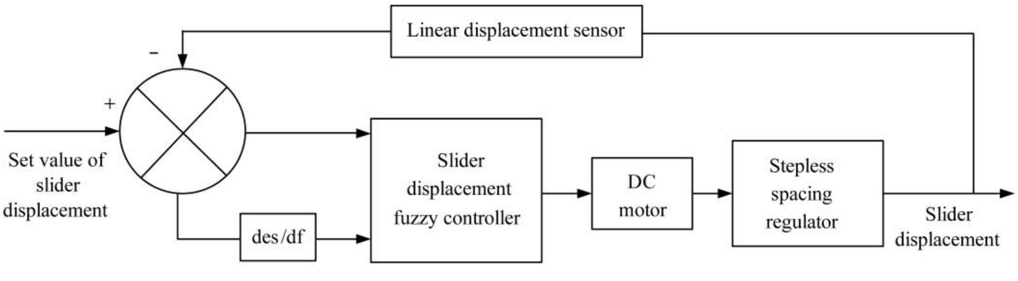

Figure 4 Structure of fuzzy controller of stepless spacing regulator

3.2.2 Approach to fuzzification

1) Domain of input variables, linguistic variables and membership function

The slider displacement error of the stepless spacing regulator is denoted by e_s, referring to the difference between the actual measured value of the displacement and the set value. The displacement error ranges between -1 and 1, the fuzzy domain between -5 and 5, the quantization factor ke_s = 5; the changing rate of slider displacement error ranges between -0.5 and 0.5; the quantization factor ke_s = 10.

2) Fuzzy subsets of input and output variables

In the fuzzy model, the shapes of the fuzzy-rule former membership function include triangles, bells, which have little impact on the performance of the control; however, the size of its width has a greater impact on its performance. As long as the adjacent former membership function has sufficient overlap, the output of the fuzzy model is a smooth function of the input variables. To ensure that the various subsets of the fuzzy variables can adequately cover the entire domain in order to avoid a dead zone, and to avoid a loss of control, ~~t~~he total number of elements in the domain should be two to three times of that of the fuzzy sets. The overlapping rate should be between 0.2 and 0.6. The value of overlapping robustness is usually greater than the overlapping rate, generally ranging between 0.3 and 0.7.

The higher the values of the overlapping rate and the overlapping robustness, the higher the fuzziness of the control system can be. Therefore, the system that has a vague relationship between the values can be better controlled. A low overlapping index is suitable for systems with clearer correlations between input and output. To enable the fuzzy control system to operate more smoothly, a mature overlapping rate and overlapping robustness should be chosen. In this project, the overlapping rate of the membership function for the slider displacement error of the fuzzy control system is 0.25 to 0.4, when the overlapping robustness is 0.5. The overlapping rate of the membership function of the displacement error changing rate is 0.33, the overlap robustness is 0.5.

To reduce the amount of calculation, the shapes of the membership functions of the slider displacement error and the error changing rate are triangular in this study, which are shown in Figures 5 and 6, respectively.

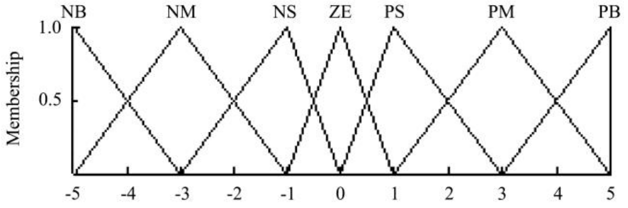

Figure 5 Membership function of the slider displacement error (e_s/mm)

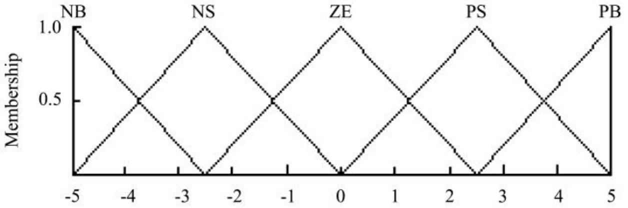

Figure 6 Membership function of the displacement error changing rate (e_{ds}/mm)

The slider displacement error has seven fuzzy variables: PB (positive big), PM (positive medium), PS (positive small), ZE (zero), NS (negative small), NM (negative medium), and NB (negative big). The slider error rate has five fuzzy variables: PB (positive big), PS (positive small), ZE (zero), NS (negative small), and NB (negative big).

3) Control of on/off output

The motor control value of the stepless spacing regulator is U_s. This DC control has only two statuses: on and off.

When the constant of the latter part of the zero-order Sugeno model is 1, it designates connection to the DC motor; whereas, 0 designates off, thereby matching the two states of the control in the regulator. In this way the fuzzification of the control value of the regulator is settled.

4) Direct reasoning of fuzzy rules and defuzzification

In fuzzy logic theory, the inference of the fuzzy rules is generally a synthesis and calculation depending on the fuzzy relation R. This method has problems, including a long computing time, a large amount of computer memory, inconvenience in modifying the fuzzy rules, etc. This system uses real-time software online for reasoning, which uses a single-point fuzzy set to render the exact amount of the input signal fuzzy, and applies the direct method to reasoning about the fuzzy rules. Suppose that there are two fuzzy control rules:

$$\begin{cases} R_1: \text{if} \quad x = A_1 \quad \text{and} \quad y = B_1 \quad \text{then} \quad u_1 = f_1 \\ R_2: \text{if} \quad x = A_2 \quad \text{and} \quad y = B_2 \quad \text{then} \quad u_2 = f_2 \end{cases}$$

where, A_i and B_i are the former fuzzy set, and f_i is the latter constant. Assume that the current input is $x = x_0$, $y = y_0$. First obtain the degree to which these two inputs belong to the former conditions $A_i(x_0)$ and $B_i(y_0)$. Then the former matching degree of the entire rule can be calculated:

$$\alpha_1 = A_1(x_0) \wedge B_1(y_0) \tag{3}$$

$$\alpha_2 = A_2(x_0) \wedge B_2(y_0) \tag{4}$$

The overall reasoning result u_0 is derived from the weighted average of u_1 and u_2:

$$u_0 = \frac{\alpha_1 u_1 + \alpha_2 u_2}{\alpha_1 + \alpha_2} \tag{5}$$

For the control rules formed by m pieces of fuzzy conditional phrases, the overall result u_0 is

$$u_0 = \frac{\sum_{i=1}^{m} \alpha_i u_i}{\sum_{i=1}^{m} \alpha_i} \tag{6}$$

3.3 Software design and anti-jamming measures of computer control system

The system software uses the visual programming language Delphi 7.0 in the Windows XP environment. The HMI is the “simulate real” interface, which is shown in Figure 7.

行数: 4
行距: 60 cm
种子发芽率: 90 %
种植密度: 3000 株/亩
株距设定: 0.0 cm
变速器位置: 0.0 mm
已播种: 0 株
已播面积: 0.0 亩
实际株距: 0.0 cm
滑移率: 0.0 %
2012.12.17
卫星: 8

Figure 7 System interface for monitoring working status of planter

In Figure 7, left-click the computer-shaped icon, and the screen will pop up sowing a parameter-setting window. Left-click the icons to the right of each selection in the setting window, and a parameter selection list will appear. After the appropriate parameters have been left-clicked, the parameter selection list disappears. To set the appropriate seeding parameters, left-click on the icon “determine”; then, the window will disappear.

Left-click the camera icon and the video window pictured in Figure 8 will appear. This window shows a video image of the operational status of the planter behind the tractor. Thus, the driver can monitor the working status of the planter from the window without having to look back.

Figure 8 Planter video-cam window

In Figure 7, a strip below the window displays the current date, time, planter running speed, headed direction and longitude/latitude data.

The following anti-jamming measures are adopted to guarantee the operational reliability of the system functions in the system:

1) The signal transmission uses the method for electronic currency to avoid external interference.

2) Data is transmitted via CAN bus. The data line uses a metal-shielded UTP, grounded at the signal-receiving end.

3) An optocoupler is used to isolate the inside and outside of the system to block outside electrical contact with the computer and to avoid external interference on the computer.

4) An analog signal is acquired with the double-end approach to improve the system's ability to resist common- mode interference.

5) All the temporarily unused analog channels of the multiplexer are shorted to an analog ground to avoid crosstalk among the channels.

6) Data acquisition is accomplished by taking the average value of the repeated samples to eliminate spikes and grid frequency interference.

7) A car-carried isolated power supply is used to isolate the regulated power supply to prevent internal interference.

4 Experiments and analysis

On May 23, 2011, after the experimental production of the four-row planter was finished in the prototype modular planting unit, field tests were conducted to examine the performance of the mechanical and monitoring systems of the planter in plots belonging to the Yiyuan Agricultural Machinery Manufacturing Company in Qingyun, Shandong Province. Through those tests, improvements were made on the ditching forms, metering device selection, installation dimensions of the components, and the detection effect of the sensors.

On June 16 2012, after the improvements on the prototype were finished, planting tests were run on the Yiyuan Company’s plots in Qingyun and in the nearby smaller fields in Dongxindian Town after the wheat harvest.

Wheat stubble of various heights, different straw mulch, and varying humidity had been left in the tested fields. Three types of seeders were tested: (1) passive roller-driven mechanical-seeding, (2) furrow-opening disc-rollover, and (3) rotary-knife furrow-opening rollover-seeding. The technical parameters tested and compared included furrow-opening proficiency, planting precision, stepless-spacing regulation, consistency of seeding depth, seed damage, soil-covering proficiency, and monitoring system operations. According to the examination results from the Quality Supervision and Inspection Station of Agricultural Machinery Products of Shandong Province, the detection accuracy for counting corn seed was 91.4%; the seed-clog fault-alarm accuracy rate, 96.0%; the fertilizer-clog fault-alarm accuracy, 95.5%. The results indicate that the entire system was stable and reliable.

5 Conclusions

1) The distributive system for monitoring planting status developed in this study has the following features: achieves bidirectional information transfer between upper and lower PCs; monitors spoon-plate speed and status of fertilizer and seed tanks; sends audible alarms; has real-time display of actual planting spaces; enables real-time control and regulation of spacing; and displays real-time video of the planter during the planting process.

2) The intelligent stepless spacing regulator developed in this study satisfies the precision requirements for sowing and regulating the spacing of corn. The device can achieve stepless spacing regulation of manually- and electronically-controlled automatic seeding, in which the transmission ratio ranges from 0.8 to 3.1 (corresponding to the spacing 15-50 cm). The regulator uses a micro-motor to implement stepless CVT, which enables the planter to change speed steplessly during operation.

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