RESEARCH ON THE SEEDING DEPTH ADJUSTMENT DEVICE BASED ON THE TIP OF FURROW OPENER FORCE MEASUREMENT

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基于铲尖测力的播深调控装置的研究

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ABSTRACT

An active-action seeding depth automatic control system was designed, with the purpose of effectively ensure the consistency and stability of the seeding depth when the seeder is operated in the field. Strain-gauge pressure sensor was used in the system, which can detect the force on the tip of the furrow opener in the soil in real time, proceed to the next step judge the change of the seeding depth in the soil according to the change of the pressure signal. In order to achieve consistency and stability of seeding depth, the control signal formation circuit will send a control signal when the pressure on the tip of furrow opener exceeds the appropriate pressure range, and the motor will be controlled to rotate clockwise or counterclockwise to drive the rack and pinion movement to realize the vertical lift of the furrow opener, so that the force on the tip of furrow opener in the soil remains within the appropriate range. The test results indicate that the seeding depth adjustment device based on the tip of furrow opener force measurement has stable and reliable control performance for controlling the seeding depth with an average seeding depth qualification rate of 94.56% and an average seeding depth variation coefficient of only 9.29%, which greatly ensures the consistency and stability of the seeding depth under the condition that the seeding depth is 30-70mm and the working speed is 3-7km/h.

摘要

为使播种机在田间作业时能有效保证播种深度的一致性和稳定性，设计了一种主动作用式播种深度自动控制系统。该系统采用应变式压力传感器实时探测开沟器铲尖在土壤中的受力情况，进而根据压力信号的变化判断开沟器在土壤中开沟深度的变化情况。为了实现播种深度的一致性与稳定性，控制信号形成电路会在铲尖受到的压力超出合适压力范围时发出控制信号，通过控制电机顺时针或逆时针旋转带动齿轮齿条运动进而实现开沟器的垂直升降，使开沟器铲尖在土壤中的受力保持在合适的范围内。试验结果表明，在开沟深度为 30-70mm,工作速度为 3-7km/h 情况下，基于铲尖测力的播深调节装置对控制播种深度具有稳定可靠的控制性能，平均播深合格率高达 94.56%，平均播深变异系数仅为 9.29%，极大保证了播深的一致性与稳定性。

INTRODUCTION

Seeding depth is one of the strict indicators required by agricultural technology *(Li et al. 2003)*, and in actual agricultural production, the germination, emergence, and growth of seeds are severely affected by seeding depth *(Gupta S C et al., 1988; Berti M T et al., 2008; Zhang et al., 2016)*. Inconsistent seeding depth can affect the uniformity of seedling emergence, leading to high and low seedling phenomena and ultimately affecting yield *(Wu et al., 2011)*. Therefore, conducting in-depth research on the control of the seeding depth of the seeder and controlling the seeding depth within a reasonable range is of great significance for creating a better environment for seed germination and emergence *(Karayel D et al., 2002; Poncet A M et al., 2018; Hakansson I et al., 2011; Knappenberger T et al., 2012; Fu et al., 2019).*

Researchers have conducted extensive research on seeding profiling device, and in order to ensure the stability and consistency of seeding depth, passive adjustment methods were often used, including adjusting springs, parallel four-linked rods or manually adjusting the relative distance between the profiling assembly and the furrow opener in the vertical direction to achieve individual profiling *(Gao et al., 2019; Zhao et al., 1989).*

However, due to the unstable performance of passive seeding depth control, researchers have gradually begun to focus on the research of active seeding depth control *(Bodhoff B V D et al., 1970; Jr J E M et al., 1988; Yuan et al., 2018; Mouazen A M et al., 2004; Anthonis Jet al., 2004).* Among them, Li Yuhuan et al. *(Li et al. 2016)* designed a pneumatic corn seeding depth control system, which measures the pressure of the press wheel using a pressure sensor. According to the magnitude of the compaction pressure, an electric push rod was used to adjust the amount of soil covered by the soil covering device, thereby achieving the effect of controlling the seeding depth. Zhao Jinhui et al*. (Zhao et al. 2015)* designed a displacement sensor based control system for seeding and furrow depth, which achieves synchronous profiling and controllable seeding depth by controlling the hydraulic cylinder at the profiling mechanism. Cai Guohua et al. (*Cai et al. 2011*) and WEN et al. *(Wen l, et al. 2014)* used ultrasonic sensors to monitor the seeding depth in real-time and designed a control system to adjust the seeding depth through a hydraulic system. The development of active depth control technology in foreign countries was earlier, in which Amazon Company produced an electronic depth control device, which was an ultrasonic detector installed on a furrow opener. It not only can detect the depth of the seeding in real-time but it can also be adjusted through the hydraulic system when the depth of the seeding deviates from the specified value to achieve a consistent depth of seeding. E. T. Weatherly and C.G. Bowers Jr. *(Weatherly E T et al. 1977)* developed an active automatic control system for seeding depth of a seeder based on drying front sensors (DFS), which uses DFS to detect soil electric resistance to obtain soil moisture content, and then adjusts the disc furrow opener to the appropriate position through controllers, hydraulic systems, adjustment mechanisms, etc., that is, seeds are sown at a depth with appropriate soil moisture content. The above studies may achieve consistency in seeding depth by controlling seeding or by controlling soil cover thickness, but the machine structure is relatively complex and the response time of pneumatic, hydraulic and other transmission methods is long, resulting in significant adjustment errors. Therefore, further research is needed.

In this paper, for the problems of complicated structure and long adjustment time of existing seeding depth adjustment device, an active control adjustment device which can monitor the force of the furrow opener in the soil by pressure sensor and adjust the seeding depth in real time by the force on the tip of furrow opener is developed, which has fast response speed, short adjustment time and simple structure, and has important guiding significance to ensure the stability of seeding depth.

MATERIALS AND METHODS

Overall structure of seeding depth control device

The seeding depth control device mainly consists of three parts: the tip of furrow opener force measurement system, the motor lifting control system, and the human-computer interaction interface, as shown in Figure 1.

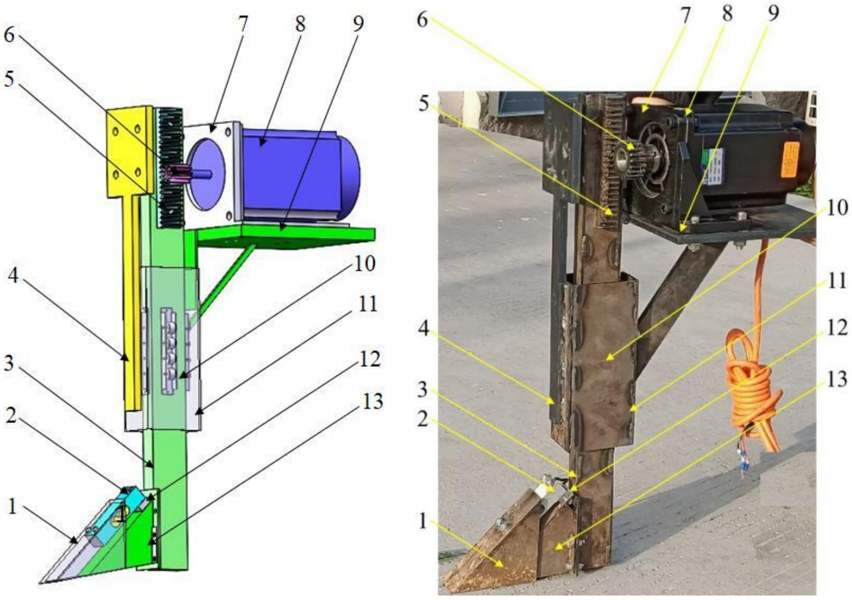

Fig. 1 – Overall structure of seeding depth control device

1 – Pressure sensor protective shell; 2 – Strain type pressure sensor; 3 – The shaft of furrow opener; 4 – Fixing frame; 5 – The straight gear; 6 – The straight rack; 7 – Motor base; 8 – Stepper motor; 9 – Motor fixed plate; 10 – Cylindrical guide; 11 – Guide shell; 12 – Pressure sensor gasket; 13 – The tip of furrow opener

The tip of furrow opener force measurement system consists of a shovel body and a Strain type pressure sensor, which is used to detect the force of the furrower tip in the soil in real time. The motor lifting control system consists of a stepper motor, a slide rail and a straight tooth gear rack, which is mainly used to adjust the lifting of the furrow opener and adjust the depth of the seeding in real-time. The human-computer interface consists of a serial screen and a control panel for the setting of seeding depth and the display of operating parameters. The main technical parameters of the whole machine are shown in Table 1.

Table 1

Main technical parameters of the machine

Parameters	Numerical value
Whole machine size (L×W×H) / (mm×mm×mm)	220×200×580
Whole machine quality / kg	20
Operating speed / (km/h)	3 - 7
Seeding depth adjustment range / mm	0 - 100
Power supply / V	220vAC

System working principle

Before the depth control system officially starts working, the tip of furrow opener force measurement system was used to measure the range of force exerted on the tip of the furrow opener under different seeding depth conditions in the soil. Then, the measured pressure range corresponding to the set seeding depth was inputted into the human-computer interaction interface. When the seeding depth control system officially starts to work, the tip of furrow opener force measurement system working in the soil monitors the situation of force exerted on the furrow opener in real time, and transmits the monitoring data to the microcontroller. After judgment and calculation, the microcontroller sends instructions to control the motor lifting to adjust the depth of the furrow opener entering the soil. The human-computer interaction interface can display the situation of force exerted on the tip of the furrow opener in the soil in real-time, and present the pressure data in the form of a curve. The system working principle is shown in Figure 2.

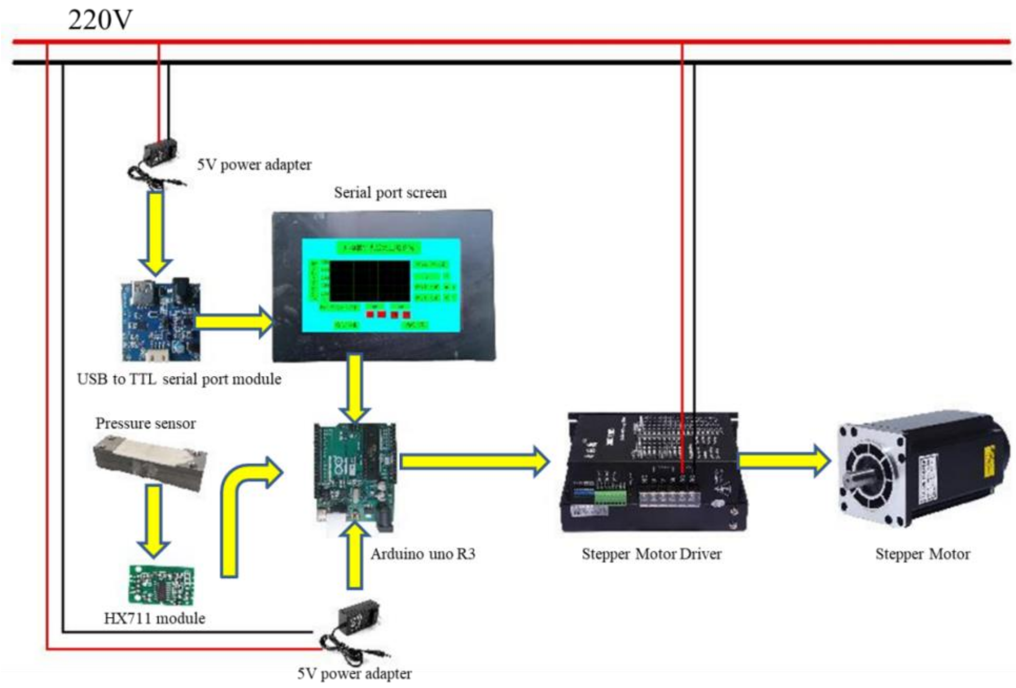

Fig. 2 – Working principle diagram

Design of shovel tip force measurement system

The tip of furrow opener force measurement system is mainly composed of a pressure sensor protective shell, a strain type pressure sensor, a pressure sensor gasket and the tip of furrow opener. The strain type pressure sensor was installed between the pressure sensor protective shell and the tip of furrow opener. When the furrow opener contacts the soil, the resistance of the soil to the pressure sensor protective shell causes the strain gauge of the pressure sensor to produce continuous deformation, and the generated pressure data will be displayed through the serial port screen, the specific connection method is shown in Fig. 3.

The pressure sensor used in this design was a strain gauge with a maximum range of 500 N produced by Sincere Electronics Technology, which was paired with the HX711 weighing module. In order to prevent damage to the pressure sensor caused by excessive deformation of the pressure sensor, a pressure sensor gasket was designed with a height equal to the maximum range deformation of the pressure sensor, so that when the deformation of the pressure sensor reaches its maximum value, the pressure sensor gasket will prevent further deformation of the pressure sensor, thus achieving the purpose of protecting the pressure sensor.

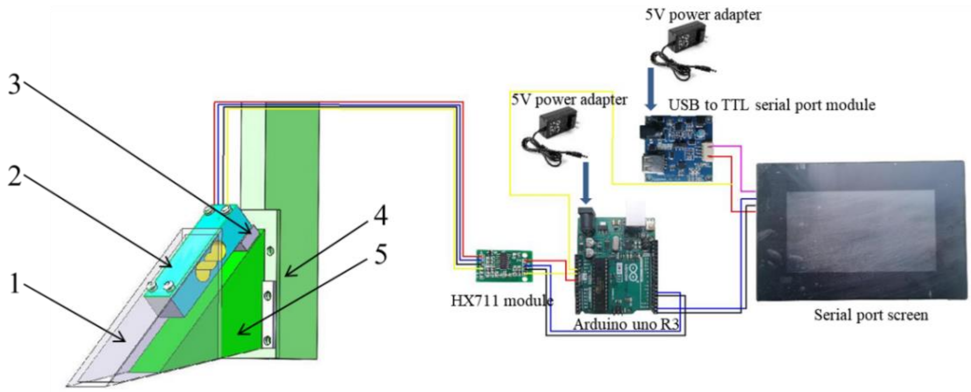

Fig. 3 – The structure diagram of furrow opener

1 – Pressure sensor protective shell; 2 – Strain type pressure sensor; 3 – Pressure sensor gasket; 4 – The shaft of furrow opener; 5 – The tip of furrow opener

Design of motor lift control system

As shown in Figure 4, the motor lifting control system is mainly composed of stepper motor, motor base, motor fixed plate, straight gear, straight rack, shovel shaft of furrow opener, cylindrical guide rail, guide rail shell, etc. Weld the straight gear rack onto the upper end of the shovel shaft of furrow opener, the straight gear is fixed on the motor shaft by key connection, the stepper motor is fixed on the guide rail shell through the base together with the motor fixed plate, and weld the four cylindrical guide rails to the same height in all four directions of the shovel shaft of furrow opener, use the guide rail shell as the track to form a sliding device for adjusting the lifting of the furrow opener. When the stepper motor receives instructions from the microcontroller to rotate, the straight gear will drive the straight rack to move up and down, thereby achieving the lifting and lowering about shovel shaft of furrow opener.

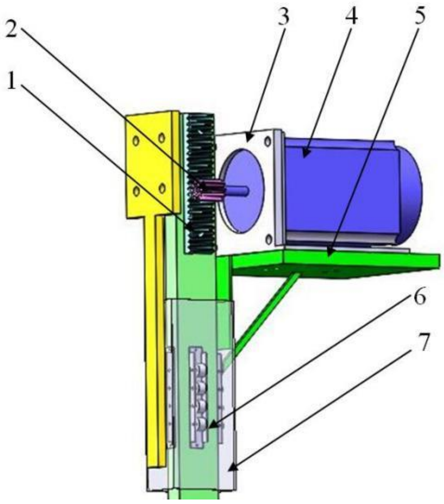

Fig. 4 – Motor lifting system

1 – The straight rack; 2 – The straight gear; 3 – Motor base; 4 – Stepper motor; 5 – Motor fixed plate; 6 – The cylindrical guide; 7 – The guide shell

To meet the lifting and lowering requirements of the furrow opener, a three-phase stepper motor with a torque of 50 N • M is selected, paired with a 3ND2283 driver, controlled by an Arduino Uno microcontroller. The physical connection is shown in Figure 5. The straight gear with an inner diameter of 19 mm and an outer diameter of 44 mm, with 2 modules and 20 teeth, and the straight rack with a length of 150 mm and a height and width of 20 mm, with 2 modules and 40 teeth, were used respectively.

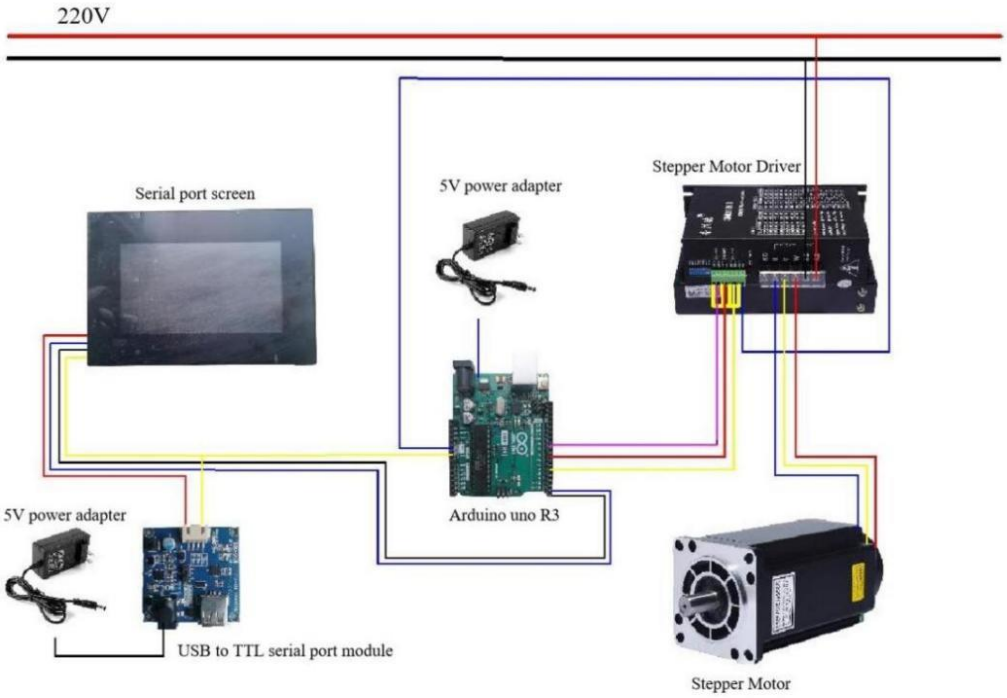

Fig. 5 – Motor lifting system physical connection diagram

Motor response time verification tests

The system used a three-phase stepper motor with a torque of 50 N•M. When the motor speed was below 200 r/min, the speed had no effect on the size of the torque output from the motor. To ensure the sensitivity during the adjustment process of the system, the torque of the stepper motor, and the accuracy of the furrow opener lifting, the maximum speed of the stepper motor was set to 60 r/min, and the acceleration and deceleration of the stepper motor adopted an S-shaped acceleration and deceleration curve. Due to the fact that the response time of the stepper motor from receiving the command to the start of the motor reaction was only a few milliseconds. Therefore, setting the response time of the stepper motor to increase its speed from 0 r/min to 60 r/min after the microcontroller sends instructions was called the response time of the stepper motor, the speed change during the process of the motor speed increasing from zero to the set speed after the microcontroller sent the command was recorded by an SD card, and the motor speed change curve is shown in Figure 6.

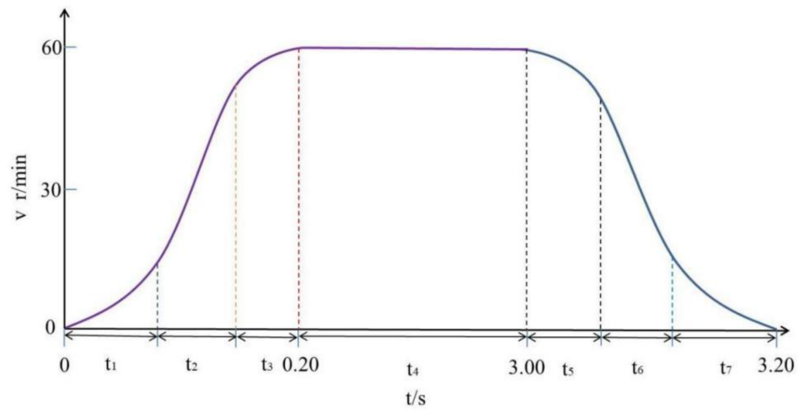

Fig. 6 – Motor response time curve

As can be seen from Figure 6, the motor acceleration process was divided into seven stages, accelerated motion phase t1 with increasing acceleration, uniform acceleration stage t2, accelerated motion phase t3 with decreasing acceleration, uniform speed stage t4, decelerating motion phase t5 with increasing acceleration, uniform deceleration stage t6, deceleration motion phase t7 with decreasing acceleration. In this process t1-t3 stage was called the response time of the stepper motor, that is, the response time of the stepper motor is 200 ms.

Since the prototype of the Sigmoid curve function can be represented by the following equation:

$$y = \frac{1}{1+e^{-t}} \tag{1}$$

Then the displacement Y of the stepper motor in 0.2 s can be expressed by the following equation:

$$Y = \int_0^{0.2} \frac{1}{1+e^{-t}} dt \tag{2}$$

Then the average speed of the stepper motor during the acceleration process can be expressed by the following equation:

$$v = \frac{Y}{t} \tag{3}$$

The speed of the stepper motor was 0.147 m/s at constant speed. In view of the fact that the adjustment speed of the furrow opener during the acceleration of the motor was much lower than the normal adjustment speed, which will delay the adjustment agility of the furrow opener, the furrow opener lifting response test was conducted to investigate its specific effect.

Design of human-computer interaction interface design

Figure 7 shows the human-computer interaction interface, which was designed by the HMI touch screen produced by Shenzhen Tao Jingchi Company. The display interface includes system switches, real-time display of the tip of furrow opener pressure curve, real-time display the tip of furrow opener Pressure data, appropriate pressure detection before operation, appropriate operation pressure data input, system settings, and other functions.

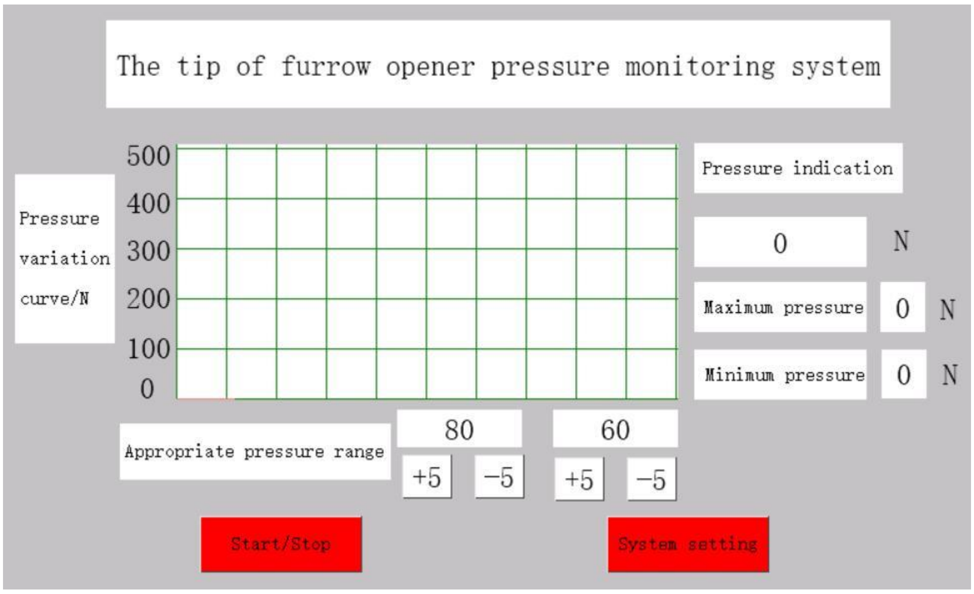

Fig. 7 – Human-computer interaction interface

Among them, the system switch button was responsible for the system start and the reset of the furrow opener after stopping work, the real-time display function of the tip of furrow opener pressure curve can display the force changes of the tip of furrow opener in real time and convert the pressure data into curve display, the tip of furrow opener real-time force display function can turn the pressure signal into a digital real-time display, the pre-operation suitable pressure detection function detects the maximum and minimum pressure for the plot to work at the right seeding depth before the official work, the suitable operating pressure input function can input the suitable pressure value obtained according to the suitable pressure detection function before the operation to change the working conditions of different plots, the system setting is mainly to adjust the brightness of the display screen.

Design of System circuit

The system mainly includes signal processing module, stepper motor driving module, Arduino control module, display screen and SD card recording module, which can realize the monitoring of real-time force of the tip of furrow opener in soil and real-time adjustment function of seeding depth. Through the design of each module and the selection of key components, the overall circuit of the seeding depth control system with the tip of furrow opener force measurement is shown in Figure 8.

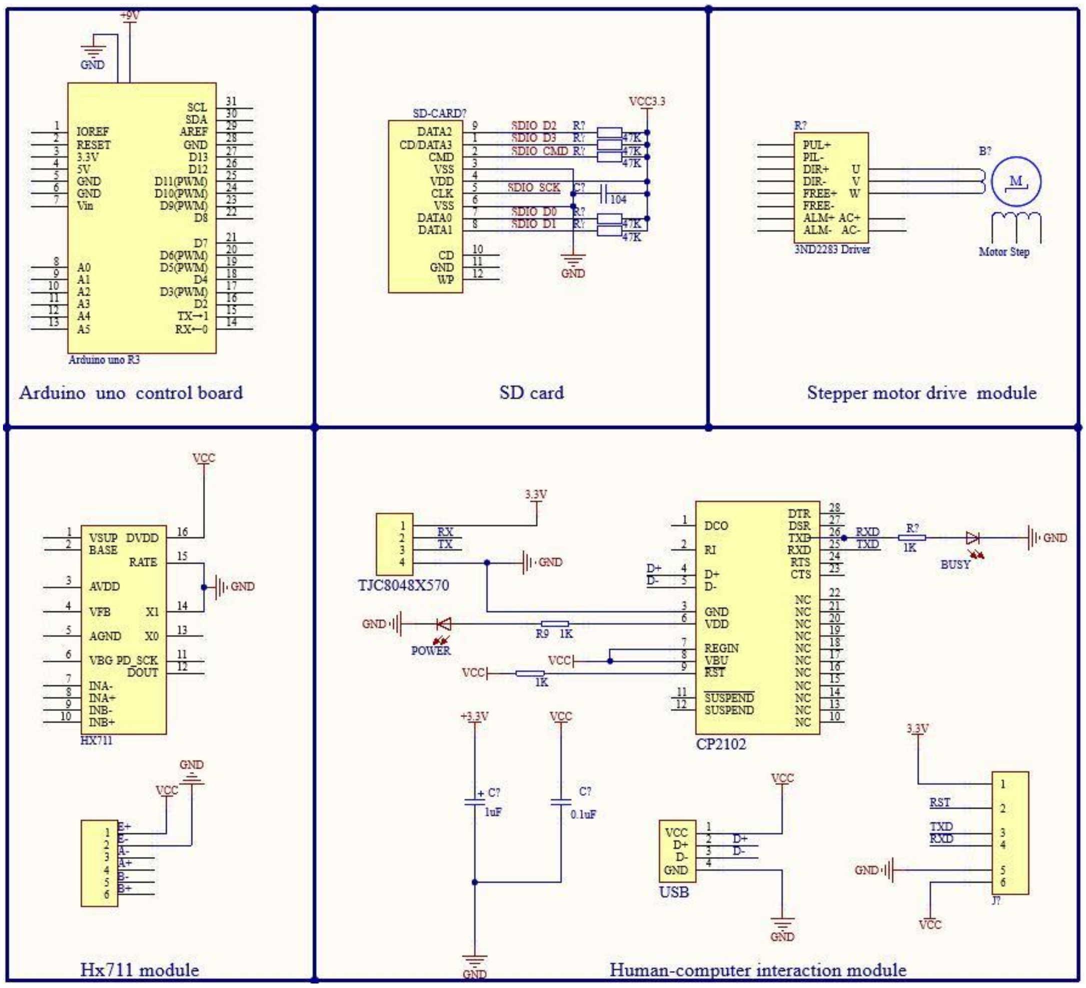

Fig. 8 – System circuit diagram

Design of system program

The system program control flow is shown in Figure 9, which mainly includes parameter setting, signal acquisition, data transmission, and system operation. At the beginning of the program, it was necessary to initialize the entire system, including a strain type pressure sensor, HX711 A/D conversion module, and the initialization of the corresponding I/O of the microcontroller. Set the program cycle to 50 ms, which means the sampling frequency was 200 HZ, after setting the tip of furrow opener force range and seeding depth, press the switch to start the official operation of the system.

When the pressure signal was generated, compare with the suitable pressure range N~M set in the microcontroller, if the force F on the tip of furrow opener was greater than N and less than M, the control circuit will not issue a signal, the motor will not rotate and the seeding depth will not change.

If the tip of furrow opener force F was less than N and greater than S (the value of the tip of furrow opener when it was nearly unstressed), the control circuit sends a low-level signal, at which time the motor counterclockwise rotation and the seeding depth begins to increase until the tip of furrow opener force was between N and M and the motor stops rotating.

If the tip of furrow opener force F was greater than M and less than B (the tip of furrow opener in the soil when encountering stones and other hard objects generated far beyond the pressure range of the value), the control circuit issued a high level signal, at which time the motor was clockwise rotation, seeding depth began to reduce, until the tip of furrow opener force between N to M motor stopped rotating.

If the force F on the tip of furrow opener was greater than B (when the tip of furrow opener encounters stones or higher hardness soil blocks in the soil) or less than S (when the tip of furrow opener encounters small pits in the soil causing suspension), the control circuit also does not issue a control signal and the seeding depth remains unchanged. At the same time, the operation information (real-time pressure value and pressure change curve of the tip of furrow opener) will be displayed on the human-computer interaction interface.

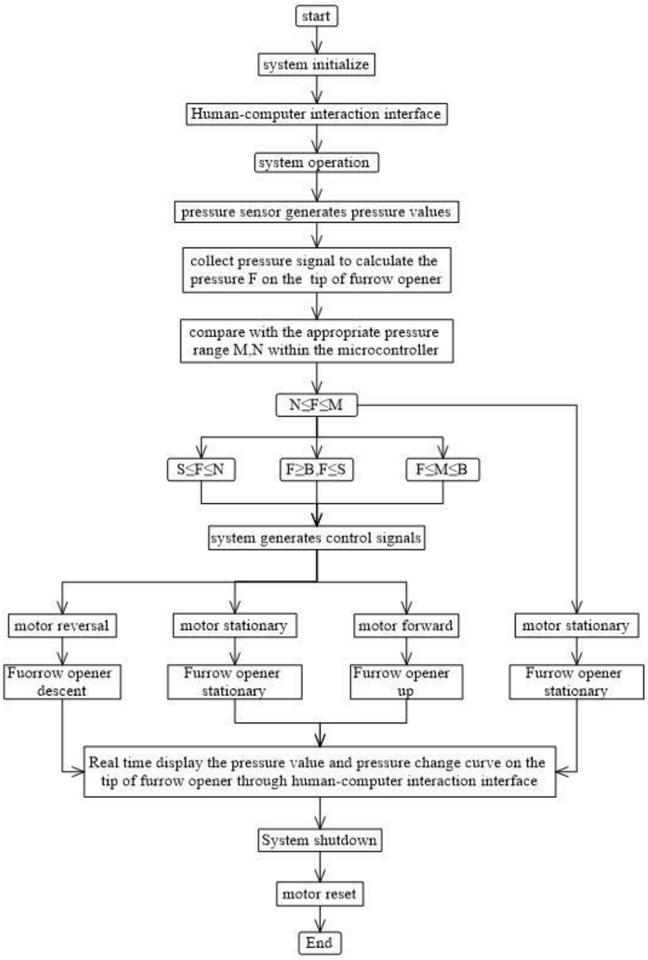

Fig. 9 – System workflow diagram

Soil trough test

To test the performance of the system in controlling seeding depth at different operating speeds and depths, a test was conducted in a soil bin at the Agricultural Machinery Equipment Laboratory of Shandong University of Technology in March 2023. The selected soil trough was 40 meters long and 2.5 meters wide, with a hauling vehicle as the traction power source. The test setup is shown in Figure 10.

Fig. 10 – Seeding depth stability test

1 – Tractor control console; 2 – The hauling vehicle; 3 – Stepper motor; 4 – Motor driver; 5 – furrow opener

The working object of the furrow opener is field soil, but due to the complex working conditions in the field, the soil conditions are difficult to control, and the difficulty of the experiment is high. Therefore, an indoor soil bin was selected for the experiment. The soil bin was sprinkled with water five days before the test, and the soil was tested for water content, soil firmness, and the percentage of 5 mm particles on the test day.

A number of 50 uniformly distributed measurement points within 25 m of the middle of the soil bin test bench were selected, J-K750-I soil compactness meter of Beijing Jinkelida Electronic Technology Co., Ltd. and JK-500 high-frequency moisture detector of Jiangsu Youke Instrument Co., Ltd. were selected for measurement, and the average soil density and soil moisture content obtained from the measurement are shown in Table 2.

Table 2

Soil mechanical and physical parameter

Soil depth mm	Soil density kPa%	Soil moisture content %	Proportion of soil particles/%(≥ 5 mm)
30	60.16	9.13	12.57
50	61.58	10.52	10.13
70	61.74	12.61	9.76

According to the operating depth of the seeder and the seeding depth requirements of different crops *(Yao et al., 2007; Yao et al., 2007; Zhang et al., 2010; Chen et al., 2009)*, the selected seeding depths were 30, 50, and 70 mm, respectively, and the tests were conducted under the conditions of 3, 5, and 7 km/h of the forward speed of the hauling vehicle. In order to simplify the test, no seeding operation was carried out to evaluate the seeding depth control effect by furrow depth etc. In order to reduce the measurement error caused by the difference in height of the ground surface on both sides of the seeding furrow, the height from the center of the seeding furrow to the ground surface was selected as the seeding depth measurement method as shown in Figure 11. In the whole test process, first of all, calibration tests should be carried out, and the seeding depths of 30, 50 and 70 mm should be selected respectively, and the working speeds of 3, 5 and 7 km/h. Without the participation of the motor lifting control system, the force of the tip of the furrow opener in the plot should be determined by the tip of furrow opener force measurement system, and then the suitable force range of the tip of furrow opener in the plot under different seeding depth conditions should be determined, and the test data should be recorded by SD card. Subsequently, in the seeding depth control test of the furrow opener, in order to avoid the influence of the acceleration and deceleration process of the hauling vehicle on the seeding depth, points were selected in the middle 25m area of the soil trough test stand, and one measurement point was selected every two theoretical seed distances, and a total of 100 measurement points were selected. According to the judgment standard of qualified seeding depth (H±10) mm in the agricultural industry standard NY/T 1768-2009 "Technical specification for quality evaluation of no-till seeders", the qualified seeding depths were 20-40 mm, 40-60 mm, and 60-80 mm under the target seeding depths of 30, 50, and 70 mm, respectively *(Fu et al., 2018; Gao et al., 2019).*

The calculation formula for each parameter is as follows:

$$\begin{cases} \eta=\frac{n}{N}\times 100\% \\ h_p=\frac{\sum h_i}{N} \\ S_h=\sqrt{\frac{\sum (h_i-h_p)^2}{N}} \\ V_h=\frac{S_h}{h_p}\times 100\% \end{cases} \tag{4}$$

In the formula: η is the seeding depth qualification rate, the unit is %; n is the number of qualified seeding depth; *N* is the total number of measuring points for seeding depth; h_p is the average seeding depth, the unit is mm; h_i is measurement of seeding depth, the unit is mm; S_h is the Standard deviation of seeding depth, the unit is mm; V_h is the coefficient of variation of seeding depth, the unit is %.

Fig. 11 – Measurement methods for seeding depth

RESULTS

Without the participation of the motor lifting control system, the force acting on the tip of furrow opener was measured using the tip of furrow opener force measurement system at depths of 30, 50, and 70 mm, and at speeds of 3, 5, and 7 km/h. The test results are shown in Table 3. The selection criteria for the appropriate pressure range of the tip of furrow opener when the seeding depth is 30, 50, or 70 mm are as follows.

$$\begin{cases} F_3=\frac{F_{max}+F_{min}}{2}\pm 10 \\ F_5=\frac{F_{max}+F_{min}}{2}\pm 20 \\ F_7=\frac{F_{max}+F_{min}}{2}\pm 30 \end{cases} \tag{5}$$

Table 3

Calibration test results

Speed(km/h)	Seeding depth/mm	Minimum pressure/N	Maximum pressure/N	Suitable pressure range/N
3	30	97	135	110—130
3	50	219	283	230—270
3	70	368	442	375—435
5	30	117	143	120—140
5	50	238	312	255—295
5	70	391	467	400—460
7	30	103	152	115—135
7	50	251	331	270—310
7	70	407	493	420—480

By summarizing the seeding depth data of measurement points, the variation curve of seeding depth is obtained as shown in Figure 12. (a), (b), (c), (d), (e), (f), (g), (h), and (I) are the variation curves of seeding depth under the conditions of target seeding depth of 30 mm, 50 mm, 70 mm, and working speed of 3, 5, and 7 km/h.

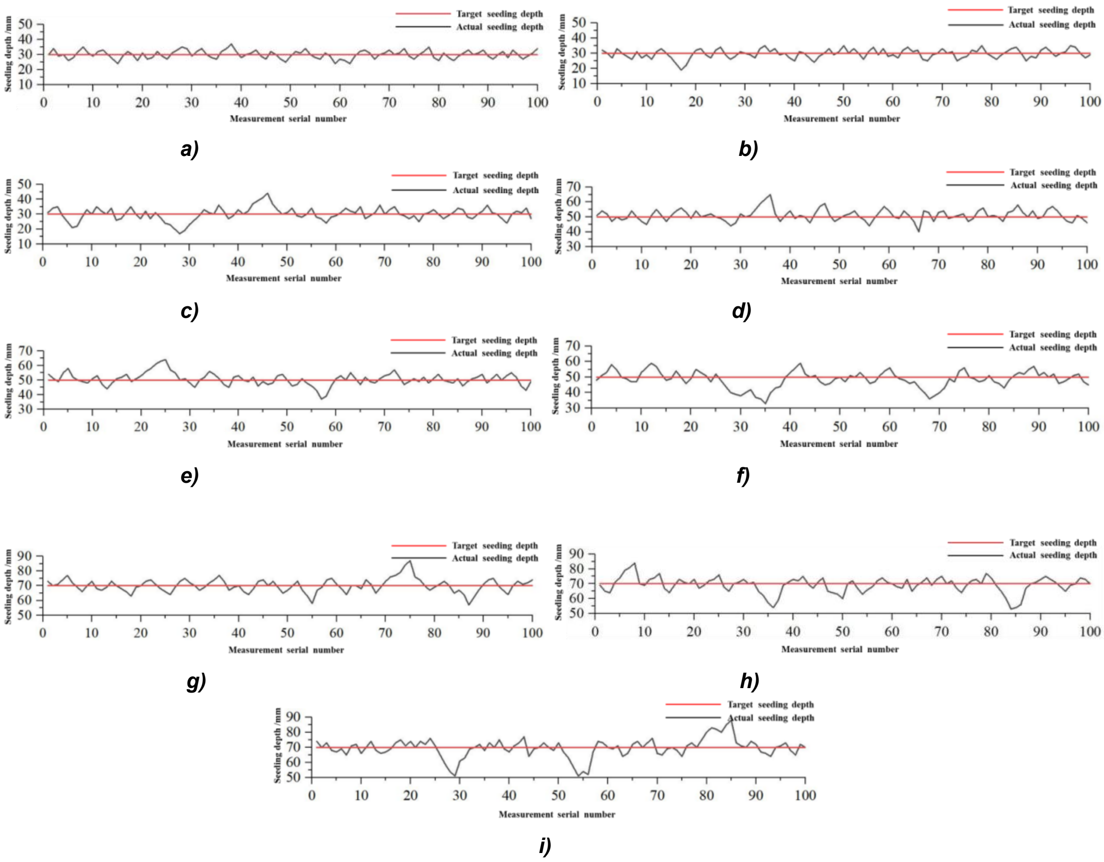

Fig. 12 – Variation curve of seeding depth

Figure 12 shows the measurement data of seeding depth under three different seeding speeds and three different set seeding depths. From the variation curve of seeding depth, it can be seen that the seeding depth under the active adjustment method fluctuates in a small range at the set value, with a few discontinuous and unqualified seeding depth data. This demonstrates the advantage of fast motor adjustment response.

Table 4

Test results of soil tank test

Speed (km/h)	Set broadcast depth / mm	Average seeding depth / mm	Seeding depth qualification rate / %	Standard deviation of seeding depth	Coefficient of variation of seeding depth / %
3	30	30.03	100	2.71	8.94
3	50	50.12	98	3.82	7.47
3	70	70.15	96	4.53	6.46
5	30	29.63	97	3.04	10.26
5	50	50.63	95	4.20	8.29
5	70	69.24	92	5.36	7.74
7	30	30.11	95	4.36	14.48
7	50	48.53	91	5.34	11.01
7	70	69.57	87	6.26	9.00

The results of the analysis by extracting the data in the graph are shown in Table 4. The analysis of the average value of the seeding depth shows that the maximum error of the average value of the seeding depth was 1.12 mm under this active adjustment method, and the maximum error of the seeding depth value was 9 mm when the depth of the furrow was 70 mm at the working speed of 7 km/h, and the overall seeding depth value was slightly less than the set seeding depth value. Through the analysis of the seeding depth qualification rate, it can be seen that different seeding depths and different seeding speeds had a certain degree of influence on the active adjustment method, with the same working speed, as the seeding depth increases, the soil conditions become more complex, and the seeding depth qualification rate was gradually decreasing.

With increasing seeding speed at the same seeding depth, the seeding depth qualification rate also shows a gradually decreasing trend, the highest seeding depth qualification rate reaches 100% when the working speed was 3 km/h and the seeding depth was 30 mm, and the lowest seeding depth qualification rate was only 87% when the working speed was 7 km/h and the seeding depth was 70 mm. Through the analysis of the standard deviation and coefficient of variation of seeding depth, it can be seen that the variation of seeding depth standard deviation was relatively small whether it was the case of gradually increasing seeding depth at the same working speed or the case of gradually increasing working speed at the same seeding depth. However, the coefficient of variation of seeding depth shows a gradual increasing trend in both cases, that is, the consistency of seeding depth decreases with the increase of seeding depth and working speed. In the data obtained from the soil trough test, it can be seen that the maximum seeding depth qualification rate was 100%, the minimum was 87%, and the average value was 94.56%, and the maximum coefficient of variation of seeding depth was 14.48%, the minimum was 6.46%, and the average value was 9.29%. From the above data, it can be seen that the seeding depth adjustment device based on the tip of furrow opener force measurement can fully meet the operational requirements.

CONCLUSIONS

From the perspective of monitoring the force on the tip of furrow opener, a seeding depth control device based on the force measurement of the tip of furrow opener was designed. By monitoring the signal of the change in force on the tip of furrow opener, the Arduino microcontroller was used to control the stepper motor to rotate and drive the handle of furrow opener to vertical movement, thereby achieving the goal of adjusting the depth of seeding. Realizing closed-loop control of seeding depth and the tip of furrow opener force provides a new approach for the design and research of automatic control devices for seeding depth.

The seeding depth adjustment device based on the tip of furrow opener force measurement has the characteristics of short response time, high sensitivity and accurate control. The average speed of the acceleration stage was 55 mm/s and the working speed of the stepper motor was 60 r/min (147 mm/s), which greatly ensures the sensitivity of the device and realizes the accurate control of seeding depth.

The soil trough test shows that the seeding depth adjustment device based on the tip of furrow opener force measurement has stable and reliable control performance when the depth of seeding was 30-70 mm and the working speed was 3-7 km/h. The qualified seeding depth was as high as 94.56%. Although the coefficient of variation of seeding depth increases with the increase of seeding depth and working speed, the average remains at 9.29%, and the consistency of seeding depth was relatively stable.

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