DESIGN AND PERFORMANCE TEST OF REMOTE CONTROL SYSTEM FOR SMALL VEGETABLE PLANTER BASED ON ARDUINO

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基于 Arduino 的小型蔬菜播种机远程控制系统设计与性能试验

Yinping ZHANG[1)], Bin WANG[1)], Xin LI[1)], Hua ZHOU[1,*)], Fangyuan LU[1)], Jiasheng WANG[2)]
[1)]School of Agricultural and Food Science, Shandong University of Technology, Zibo (255000), China;
[2)]School of Mechanical and Electrical Engineering, Qingdao Agricultural University, Qingdao (266109), China;
Tel: +86-15071259850; E-mail: zhouhua688@163.com
Corresponding author: Hua Zhou

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ABSTRACT

Facilities greenhouses are relatively narrow and airtight, and the machine operation turns frequently. The existing vegetable seeders is supported by manual hand, and the straightness of operation is poor, Turning around is time-consuming and laborious. This paper designs a remote control system of small vegetable seeder based on Arduino microcontroller, the Arduino single-chip microcomputer remote control technology, multi-motor synchronous drive technology, differential-electric push rod combined with lifting and steering control and other methods are adopted. Through remote control, the forward, speed regulation, lifting of the whole machine and field line change and steering of the seeder during vegetable sowing are realized. The differential steering model and brushless motor speed control model are established, and the android human-computer interaction APP is designed to realize the remote precise control of vegetable seeder. The performance test of the accuracy of the control system was carried out with the accuracy and steering accuracy of the seeder. The results showed that: under the condition of medium speed and medium and low speed operation, the seeding level of vegetable seeder is the most stable and reliable, the speed deviation rate of the seeder is 1.59 %, after starting the drive motor for 2s, the actual speed is close to the target speed, differential steering is relatively accurate, the qualified rate of steering is more than 89.8 %, the synchronous speed error of the lifting mechanism tends to be stable. This study can provide reference for the development of intelligent equipment for facility agriculture.

摘要

设施大棚空间相对狭小、密闭，机器作业掉头转弯频繁，现有的蔬菜播种机多由人工手扶，作业直线性差，掉头费时费力，本文基于 Arduino 单片机微控制器设计了小型蔬菜播种机远程控制系统，采用了 Arduino 单片机远程控制技术、多电机同步驱动技术、差速-电动推杆结合的升降转向控制等方法，通过远程遥控的方式来实现蔬菜播种时播种机前进、调速、整机升降和田间换行转向等作业。建立了差速转向模型与无刷电机调速模型，设计了 android 端人机交互 APP，实现对蔬菜播种机的远程精确控制。以播种机的作业行走准确度和转向准确度为指标进行对控制系统运行的准确性的性能测试，结果表明：在中速及低速运行状态下，蔬菜播种机的播种水平最为稳定可靠，播种机行驶速度偏差率为 1.59%，启动驱动电机 2s 后实际转速接近目标转速，差速转向相对准确，转向合格率大于 89.8%，升降机构同步速度误差变化趋于稳定。本研究可为设施农业智能装备的发展提供参考。

INTRODUCTION

China ranks first in vegetable production and consumption in the world, and is the world's largest vegetable exporter (*Qi et al, 2020*). However, there is still a big gap in the level of comprehensive mechanization compared with developed countries (*Li et al,2019;Richard, 2005; Xiao et al, 2017*), especially in facilities greenhouses vegetables sowing, the space is narrow, the working distance is short and the manual dependence is strong (*Narang et al, 2012; EL-Ghobashy et al, 2016; Du et al, 2017; Jin et al, 2019*), with the shortage of rural labor force, the problem of expensive labor and difficult labor in vegetable production is becoming more and more prominent. Therefore, it is of great significance to study efficient intelligent equipment to improve the production efficiency of facilities greenhouses vegetables, reduce manual dependence and improve the mechanization level of vegetable production.

The research on sowing technology and equipment in developed countries such as Europe and America is relatively mature, with high sowing quality, fast operation speed and simple control (*Zhang et al, 2022; Mei et al, 2016; Zhang et al, 2022*). For example, the automatic seeding and weeding robot for vegetables produced by FarmDroid Company in Denmark, which is driven by solar energy and based on high-precision GPS positioning system, realizes automatic seeding and weeding in the field. The Omnipower seeding platform produced by Raven Company in the United States realizes autonomous operation through remote control of farmers' handheld tablet computers (*Raven, 2021*). In China, the intelligent control of seeder is still in the research stage and has not been widely used. Yuan Yongwei et al. applied laser collimation technology and PLC control system to vegetable seeder to realize linear walking and flexible steering of vegetable seeder (*Yuan et al, 2014*). Xu Qimeng et al. from the College of Engineering of China Agricultural University designed a self-propelled agricultural mobile seeding platform. GNSS positioning and speed measurement technology is used to realize automatic seeding, and multi-motor synchronous drive, electric push rod and differential speed are used to realize the walking and steering of the platform (Xu *et al, 2021*). A plot seeder row control system was designed by Cheng Xiupei et al., the STM32 microcontroller as the main control center, and the Android terminal was used for human-computer interaction (C*heng et al, 2019)*. The solenoid valve was used to control the lifting of the seed tube, the stepper motor was used to drive the cone grille, and the DC brushless motor was used to drive the seeder, the problems of difficult adjustment of seeding operation parameters and poor seeding accuracy were solved. Ding et al. developed an electric drive corn precision seeder control system based on GPS speed measurement. The system also uses STM32 as the main controller and Android mobile phone as the control terminal to set the operating parameters such as planting spacing. The GPS receiver is used to collect the forward speed of the tractor, and the speed of the metering device is adjusted in real time according to the speed information provided by GPS, so as to realize the real-time matching of the speed of the metering device and the forward speed of the tractor (*Ding et al, 2018*). The above examples have good effects on wheat and corn sowing operations, but they do not meet the agronomic requirements of narrow space in facilities greenhouses and vegetable sowing.

Based on the current situation of vegetable sowing in facilities greenhouses, this study designed a remote control system for vegetable seeder. The Arduino single-chip microcomputer was used as the main control core, and the human-computer interaction was carried out through Bluetooth communication and Android terminal, remote control of vegetable seeder walking, speed regulation and lifting steering operations, to achieve long-distance remote control of vegetable seeder operations, reduce labor intensity, improve vegetable seeding efficiency, and provide technical reference for the intelligent development of facility agricultural equipment.

MATERIALS AND METHODS

The structure and working principle of the whole machine

The whole structure of the small vegetable seeder is shown in Fig. 1, which is mainly composed of frame, seeding unit, front and rear pressing device, lift steering mechanism, transmission system, battery and remote control system.

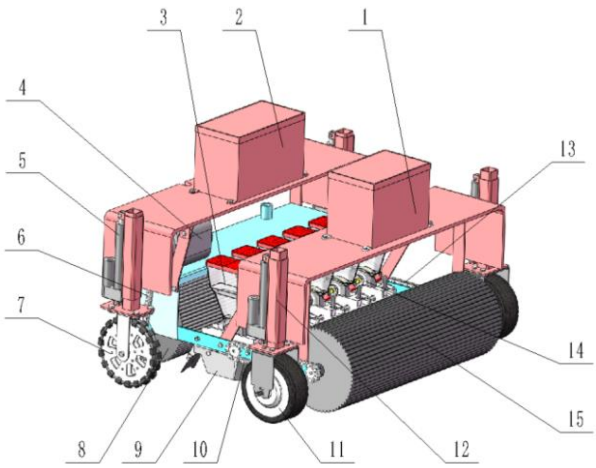


Fig. 1 - Small electric remote control vegetable seeder machine structure diagram

1 – Electric control box; 2 – Battery box; 3 – Seed box; 4 – Travel drive motor; 5 – Electric push rod; 6 – 1st drive chain; 7 – Driven wheel; 8 – Rear press wheel; 9 – Trenching device; 10 – 3rd drive chain; 11 – Drive steering wheel; 12– Front lifting frame; 13 – 2nd drive chain; 14 – Seed rower; 15 – Front press wheel

During the operation, the electric push rod of the lifting steering device is in a low position, and the front and rear press wheels contact the ground. The power is driven by the first-stage chain drive to drive the rear press wheel, and the rear press wheel drives the whole machine forward; the front press wheel obtains power through the second-stage chain drive, and then drives the metering device through the third-stage chain drive to realize the seeding operation. During the steering, the seeding operation mode is switched to the steering mode, the seeding drive motor stops, the seed metering device stops rotating, the lifting drive motor starts, the electric push rod of the lifting mechanism elongates, the steering drive wheel and the driven wheel drop, the whole machine is lifted, the front and rear pressing wheels leave the ground, the steering drive motor starts, and the left and right produce differential speed to achieve steering. The main parameters of the whole machine are shown in Table 1.

Table 1

Main parameters of remote control vegetable seeder

Projects	Parameter
Overall dimensions L×W×H (mm)	1000×900×600
Weight of the whole machine (kg)	102
Number of seeding rows	6
Row spacing (mm)	18-25 Adjustable
Type of seed metering device	Nest round wheel
The whole machine lifting height range/mm	0-150
Drive power (W)	576
Operating voltage (V)	48

The overall design of the remote control system

The composition of the remote control system is shown in Fig. 2, which mainly consists of three parts: control unit, interaction unit and execution unit. The interaction unit consists of Android terminal and Bluetooth module; the control unit consists of Arduino microcontroller, data transmission module, motor driver and relay; the execution unit mainly consists of motor driver, DC brushless motor, relay and electric push rod.

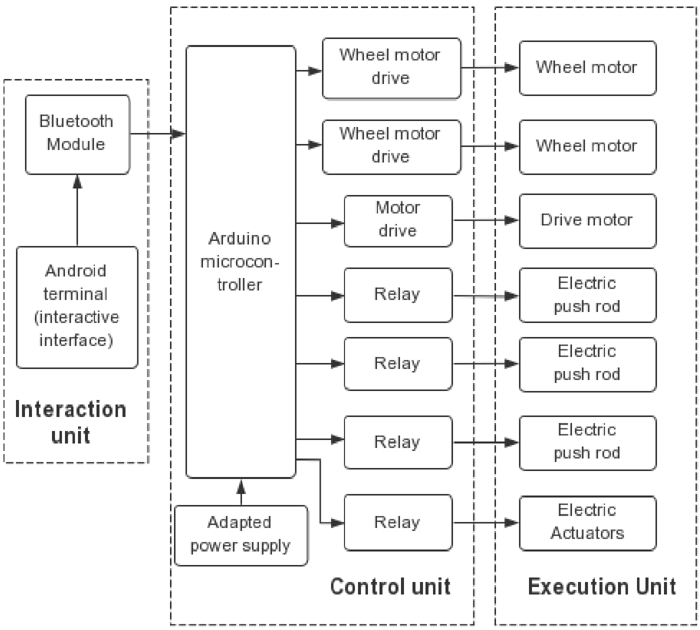


Fig. 2 - Structure diagram of control system

When working, the resetting button is selected in the Android terminal, the Android terminal transmits the status signal to the Arduino microcontroller through the Bluetooth module, the status signal is converted to low level, the relay is disconnected, the electric pusher is reset, and the front and rear press wheels touch the ground; select the sowing button in the Android terminal, the Android terminal transmits the seeding command to the Arduino microcontroller through the Bluetooth module, the Arduino microcontroller outputs the PWM signal to the drive motor driver, and controls the speed of the drive motor by changing the duty cycle of the PWM control signal, thus controlling the operating speed of the seeder. When road walking or steering change, select the lift button in the Android terminal, which is converted into a high level signal by Arduino microcontroller to control the relay suction, the electric pusher extends, the whole machine leaves the ground, select the in/out or steering button, the Arduino microcontroller transmits the road walking or steering command to the front-end steering wheel driver, and the wheel drive wheel starts or generates differential speed to realize road walking or steering change. When changing the sowing site and needing to modify parameters such as turning radius and operating speed, the operating parameters can be set directly through the PC upper computer on the Arduino IDE platform, solving the problem that the traditional vegetable seeder operating mode changes require manual adjustment of the mechanical structure, which is time-consuming and laborious, and can adapt to the sowing needs of different seeds, different plant spacing and different monopoly heights according to the agronomic requirements.

Hardware design

The remote control system of vegetable seeder is based on Arduino microcontroller as the main control core, Bluetooth communication as the data transmission method, and Android platform as the control terminal to complete the operation speed adjustment lift and steering control of the seeder, and the hardware composition of the system is shown in Fig. 3.

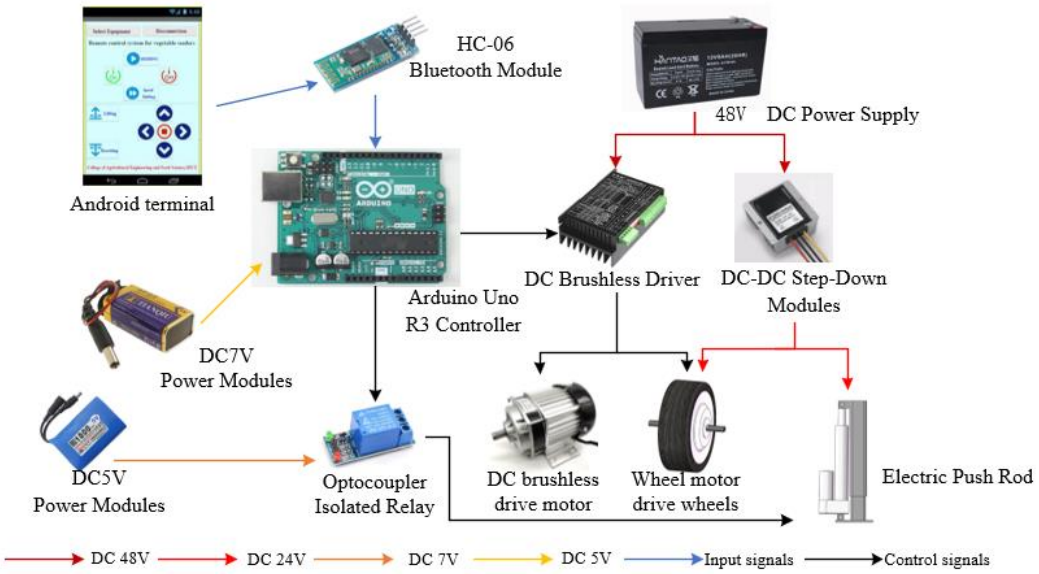


Fig. 3 - Hardware composition

As the core of the control system, the main role of the Arduino microcontroller is to accept the command signals from the host computer and make feedback to control the speed of the drive motor, the wheel motor and the state of the electric push rod. The model Uno R3 Arduino microcontroller with ATmega 328P as the main chip, operating voltage of DC 5V and current of 50mA, has the advantages of high performance, rapid response to real-time communication, low cost and low power consumption, with 6 analog input interfaces and 14 digital input and output interfaces (*Xu et al, 2021*), to meet the system building requirements for multi-target precise control of vegetable seeders.

The communication interface circuit of the system is shown in Fig. 4, where port IN1 on the driver is the input of PWM1 and PWM2 that control the rotational speed of the left and right hub motors, and is connected to ports 5 and 6 of the Arduino main controller; IN2 is the forward and reverse rotational control of the hub motors, and will be connected to ports 7 and 8 of the Arduino main controller; Hall signal ports 5V0, HU, HW, HV, COM are connected to the hub motor Hall signal port; the controller controls the speed and forward and reverse rotation of the two hub motors to achieve the purpose of precise control of the motor working state;

port 9 is the generation port of the PWM3 pulse signal that controls the speed of the DC brushless motor, which also uses the way of changing the duty cycle to drive the motor speed; D2 and D3 are the control ports of the relays, which control four groups of eight D2 and D3 are relay control ports, which control the suction and disconnection of relays by controlling the high and low level conversion of 4 groups of 8 relays, so as to precisely control the state of the electric push rod, and finally realize the lifting and resetting of the whole machine with the lifting device. It is equipped with RS485 communication module, which can be connected to the host computer, and the operating parameters such as turning radius can be adjusted by the host computer terminal to adapt to the changing operating environment; after connecting to the host computer, the speed of the drive motor, the received PWM duty cycle and the high and low potentials can be displayed in detail, which is convenient for system debugging and data collection of the test (*Jiang et al, 2016*).

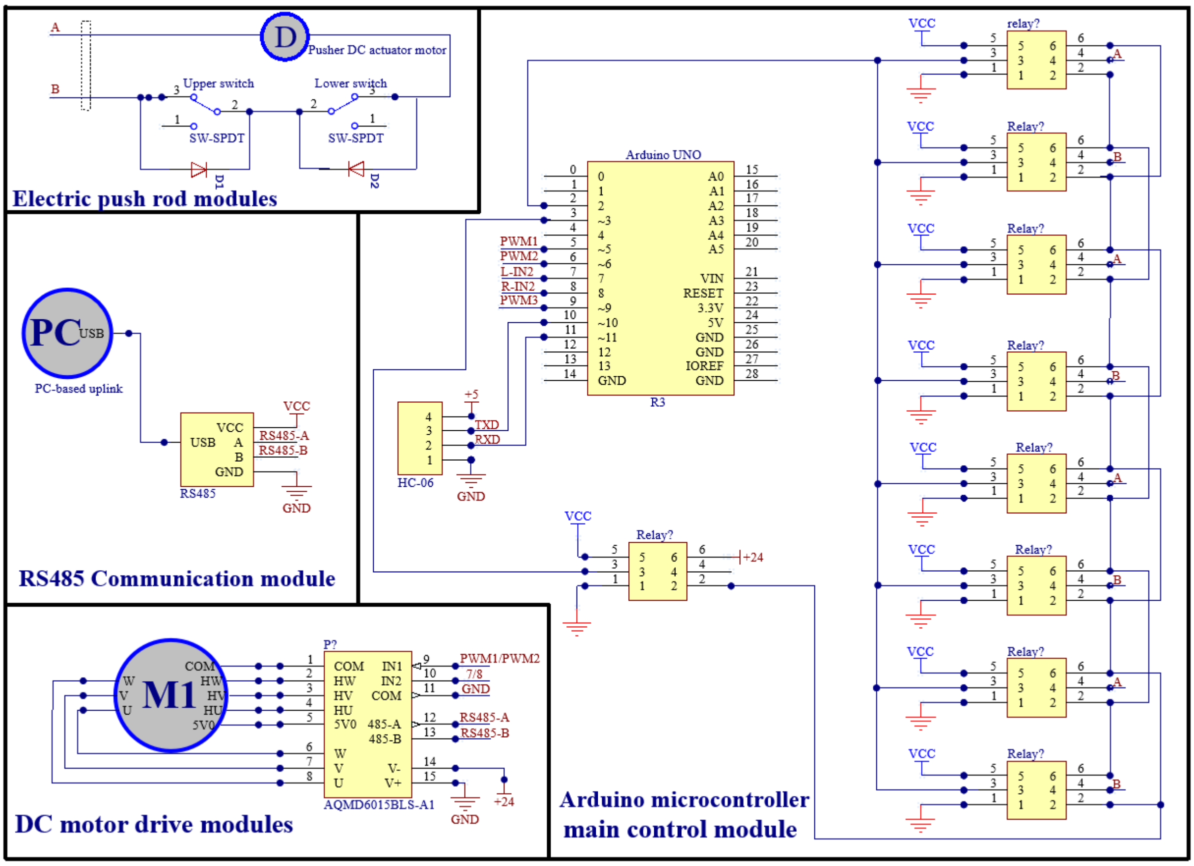
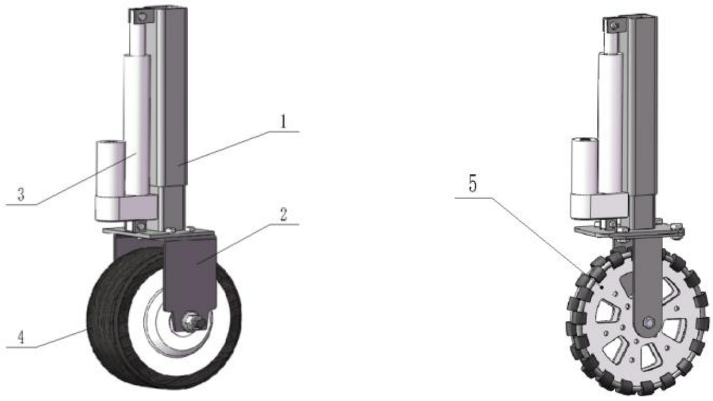


Fig. 4 - Design of communication interface circuit of the system

The data transmission between Android terminal and Arduino microcontroller uses wireless Bluetooth communication, and HC-06 Bluetooth serial module is selected. The principle is shown in Fig. 4 Bluetooth communication circuit part. The module is compatible with a variety of different voltage microcontroller motherboard, comes with 5V to 3.3V circuit, the maximum transmit power is 4dBm, the reception sensitivity is -85dBm (*Chao et al, 2013*), comes with LED lights, can judge whether the Bluetooth is successfully connected through the LED light off, comes with the transmission function, can be connected with cell phones, computers and other kinds of upper computer to communicate with each other, pairing quickly, simple operation, relatively stable.

Description of lifting and steering mechanism

The lifting and steering control mechanism consists of lifting sleeve, supporting frame and electric actuator, driving wheel and universal driven wheel, etc., as shown in Fig. 5. The bottom end of the electric actuator is fixed on the support frame, and the upper end is fixed on the lifting sleeve. The built-in motor drives the actuator to do vertical telescopic movement, and drives the whole machine to lift and reset through the lifting sleeve. The front lifting mechanism is the driving steering mechanism, the walking wheel is the wheel motor, the rear lifting mechanism is the driven steering mechanism, the walking wheel is the universal wheel.



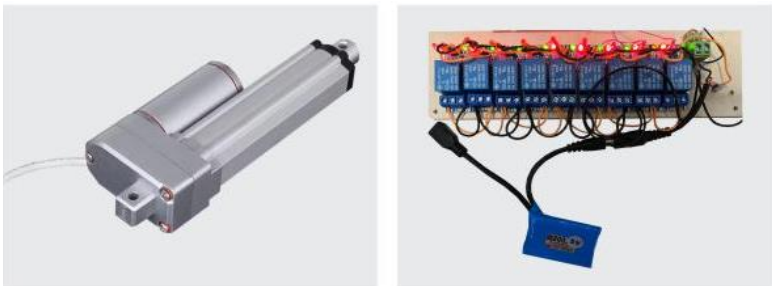
(a) Front lift drive steering device (b) Rear lift slave steering device

Fig. 5 - Lifting and steering mechanism

1 – Lifting sleeve; 2 – Wheel support frame; 3 – Electric push rod;
4 – Wheel motor drive wheel; 5 – Slave universal wheel

Electric push rods should be selected based on parameters such as thrust, stroke and push rod speed. When the vegetable seeder road travel, the press wheels, openers, etc. should be completely off the ground, and the minimum ground clearance should be more than 110 mm (Xu *et al, 2021*), considering the requirement of working monopoly height and the minimum stroke that does not interfere with the sowing operation, the stroke of the push rod is determined to be 150 mm. Select the small silent electric push rod from Dongguan Yiheng Electronics Co., Ltd. as shown in Fig. 6(a). The built-in motor torque of the push rod is 105kg·cm, the reduction ratio is 46.8, the thrust force of the push rod is 900N, the linear speed is 12mm/s, the total thrust force of the four push rods is 3600N, which meets the thrust force requirement of lifting the whole machine. The working voltage of the electric push rod is 24V DC, and the main power supply converts 48V DC to 24V through the step-down module for the use of the push rod.

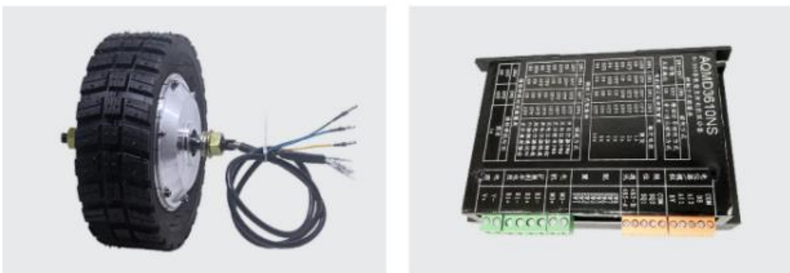
The positive and negative terminals of the electric push rod are connected to the relay, and the Arduino microcontroller controls the switch of the relay by outputting high and low level signals to control the forward and reverse rotation of the built-in motor of the push rod, so as to control the lift of the electric push rod. The relay itself operates at 5V, which requires an additional power supply or a step-down module. In this study, a DC 5V power supply module is used to power the relay, as shown in Fig. 6(b).



(a) Electric push rod (b) Relay modules

Fig. 6 - Electric push rod and relay modules

The driving steering wheel is a wheel motor of type HB-200 with embedded DC brushless motor, DC power supply 24V, rated power 250W, no-load speed 125r/min, and built-in reduction gear with a reduction ratio of 1:5, as shown in Fig. 7(a).



(a) Wheel drive steering wheel (b) Motor drive

Fig. 7 - Drive motor wheels and their drives

Steering control test method

Using the turning radius as the test factor, the Arduino controller sends PWM pulse signals to the driver of the steering drive wheel to control the speed of the drive wheel, and the speed ratio of the two wheels is calculated by equation (2) to adjust the turning radius of the seeder.

The actual turning radius of the planter was tested to ensure the accuracy of the row effect and turning radius when the planter was actually sown, and to verify the accuracy of the differential steering of the planter based on this control system. Set the target steering angle of the planter to 180°, set the theoretical turning radius of the test to 0, 400mm, 500mm, 600mm, 700mm, 800m, and measure the actual turning radius corresponding to the different theoretical turning radii of the planter, each group of turning radius is tested once clockwise and once counterclockwise, and each test is repeated three times to measure the actual turning radius and take the average value to analyze the control accuracy of the seeder steering system. The steering passing rate is calculated as:

$$E = 1 - \frac{|R - R_0|}{R_0} \times 100\% \qquad (2)$$

where:

R is actual measurement of turning radius, mm; R_0 is theoretical turning radius, mm; E is steering pass rate, %.

Software design

Arduino control program design

During sowing operation, enter commands on the interactive interface of the Android terminal, the command information is transmitted to the Arduino microcontroller through the Bluetooth serial port, and the Arduino microcontroller parses the protocol and obtains different control commands to complete the control of the seeder actuator. Under normal operating conditions, the Arduino microcontroller can output PWM signals and high and low level signals to each driver and relay to control the forward and reverse rotation and speed of the drive wheel, the speed of the drive motor and the expansion and retraction of the electric push rod separately, and the different commands are not affected by each other; in addition, an emergency stop button is set up to directly override the three-way control signal and emergency stop in case of emergency to avoid accidents. The workflow of the control system is shown in Fig. 8.

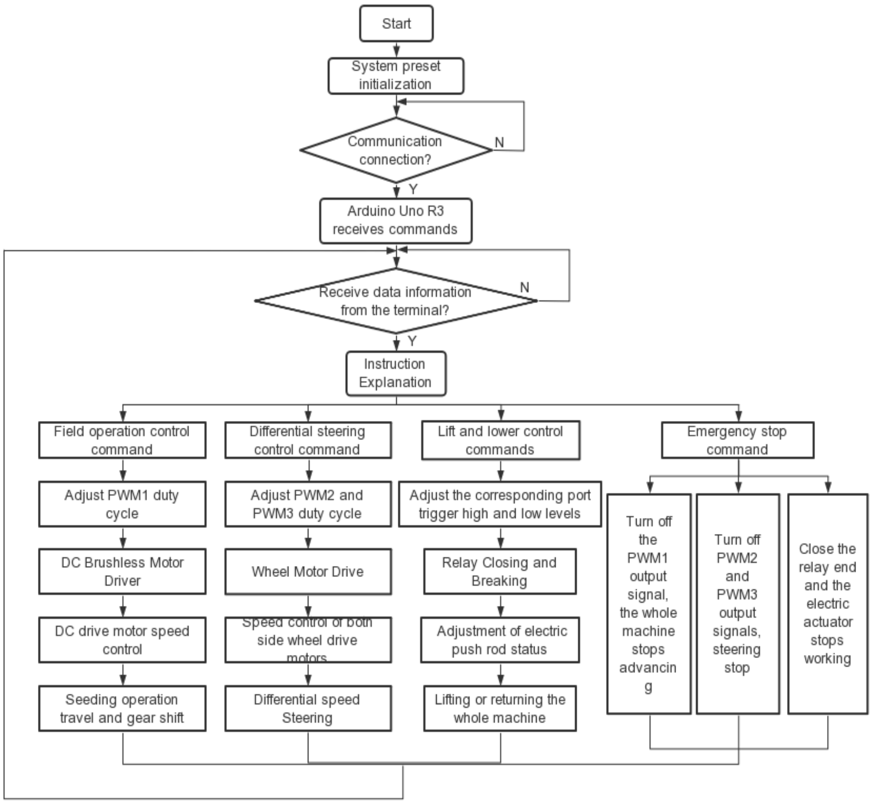


Fig. 8 - Control system workflow

Design of differential steering control model

Differential steering is used to control the planter for steering and row change operation (*Yang et al, 2013*). The Arduino main controller sends PWM duty cycle to regulate the speed of the drive wheels on both sides respectively, and the drive wheels on both sides form a differential speed so as to complete the steering and row change, and the differential steering model, as shown in Figure 9.

It is assumed that the body of the seeder is rigid and the wheels are purely rolling with the ground, without considering the relative sliding of the driving wheels.

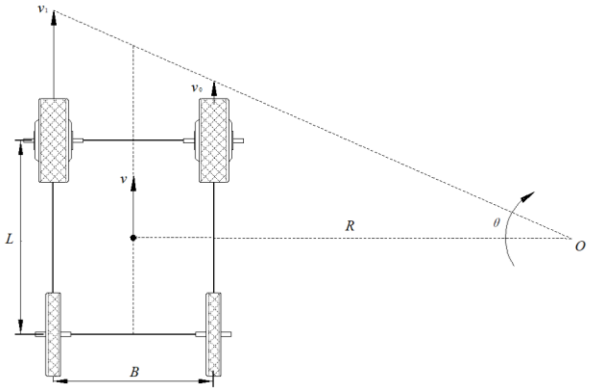


Fig. 9 - Differential steering model

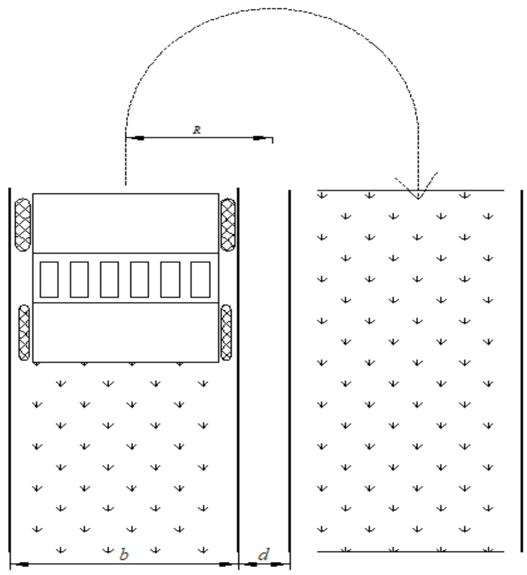


Fig. 10 - Steering diagram

From Fig. 9, it can be seen that the speed ratio of the two driving wheels during the turn is

$$\frac{v_1}{v_0} = \frac{R + B/2}{R - B/2} \tag{1}$$

where:

v_0 is the inside wheel speed, m/s; v_1 is the outside wheel speed, m/s; B is the wheelbase of two driving wheels, mm, here 990 cm is taken; R is the turning radius when steering, mm.

From the above equation, it can be seen that by adjusting the ratio of the speed of the two driving wheels, the demand for different turning radii can be met. When the turning space is narrow, the turning radius R<B/2 can be achieved when R=0. At this time, the speed of the two driving wheels is the same size and the direction is opposite; when the sowing operation changes rows and turns, R≥B/2 is required in order not to reseed, as shown in Fig.10, the width of the monopoly is b and the distance between the monopoly is d. At this time, the turning radius R=(b+d)/2. The turning radius is determined according to the agronomic requirements, and the speed ratio of the two driving wheels is adjusted by PWM duty cycle signals.

Design of Android Remote Control Terminal

The system program is written in Arduino IDE, and the parameters such as communication connection, steering motor speed, drive motor speed, state of electric push rod and emergency stop switch are bound to the keys of Android terminal interaction interface respectively, and the control interaction interface is shown in Fig. 11. During operation, open the Android terminal APP, connect to the control system, click the On button to turn on the power, through the Resetting button, the whole machine descends, the front and rear suppression wheels touch the operating ground, the four steering wheels of the lifting and steering mechanism do not touch the ground, select the Sowing operation button, the sower carries out sowing operation, adjust the operating speed through the Gear shifting button, the gear speed is set according to the actual sowing agronomic requirements, from low speed to high speed cycle change gear; at the end of sowing, the whole machine is lifted off the ground by the Lifting button, and the 4 directional buttons of the lower lift and steering mechanism control the road walking or turning to change rows and turn around in place; after the sowing operation is finished, click the off button to turn Off the power and end the sowing operation. In case of emergency, click the emergency stop button below, the command can override all the commands and realize emergency stop.

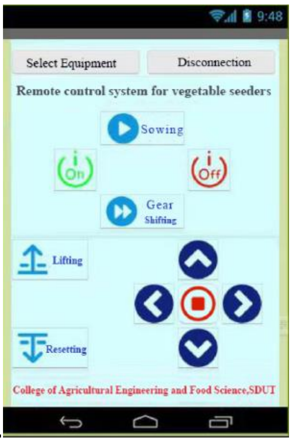


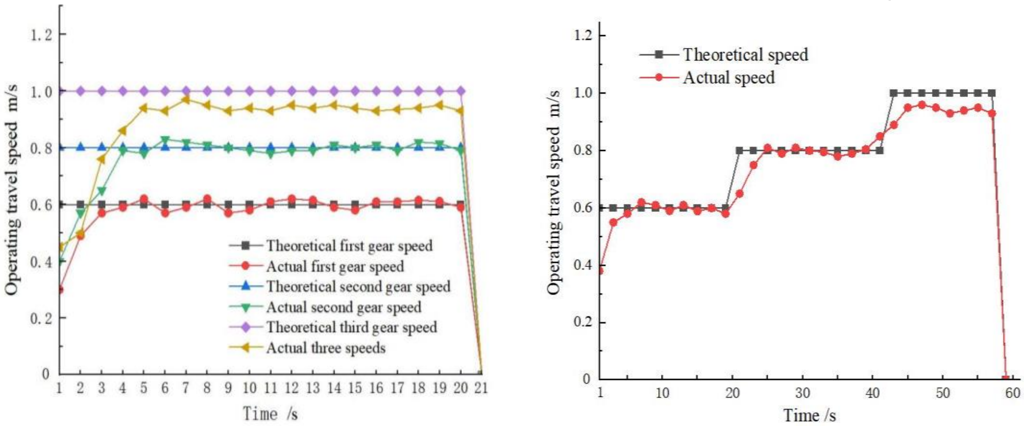
Fig. 11 - Android terminal human-machine interaction interface

RESULTS AND ANALYSIS

The test design of system control accuracy and results analysis

In order to ensure that the vegetable seeder travels smoothly and smoothly during the working process, the reliability and stability of the control system are verified, and the parameters of the drive motor speed are optimized, and the no-load driving test based on this control system is carried out.

According to the literature (*Li et al, 2022; Wang et al, 2022*), the reference of the no-load pre-test results of the drive motor, it is found that the operation driving speed of vegetable sowing is generally in 0.6~1.0m/s when the effect of sowing is more ideal, that is, the operation driving speed of the sower is set to three gears of 0.6m/s, 0.8m/s and 1.0m/s respectively, and the operation parameters are set through Arduino IDE. During the test, the driving speed of the seeder was measured in real time by the tachometer. During the test, the control accuracy of the seeder control system was measured under various driving conditions such as three gear speeds and random acceleration and deceleration, and the test data is shown in Fig.12.



(a) Different gears driving status (b) Random acceleration and deceleration driving status

Fig. 12 - Variation curves of some operating speed parameters under different states

After the system is in stable state, the measured actual speed is compared with the theoretical speed of driving, and the data is shown in Table 2.

Table 2

Deviation of theoretical speed and actual speed under different driving conditions

Driving status	Maximum deviation rate (%)	Minimum deviation rate (%)	Average deviation rate (%)
First gear	6.57	0.93	3.57
Second gear	2.54	0.75	1.59
Third gear	7.16	3.06	5.06
Random gears	6.83	4.57	5.89

From the speed change curve in Fig. 12, it can be seen that the drive motor running start time is about 2s, and the seeder is more unstable in this time period, and the speed deviation rate is larger. After the control system is stabilized, the actual speed of the planter is close to the theoretical speed, and there is no stuck phenomenon; when the driving speed is 0.8m/s, the driving state of the planter under the control system is most stable based on the control system, and the average value of deviation rate is 1.59% at this time, and the control accuracy is higher and the stability is better to meet the control accuracy requirement of the control system.

The test design of steering control and result analysis

In order to ensure the accuracy of the seeder's actual seeding to the row effect and turning radius, to verify the accuracy of differential steering of the planter based on this control system, the actual turning radius of the planter is tested.

Table 3

Steering control test results

Target theoretical turning radius(mm)	Average actual turning radius (mm)	Standard deviation (mm)	Steering pass rate (%)
0	87	31	93.42
400	369	33	94.50
500	547	45	94.10
600	679	86	92.10
700	909	114	91.25
800	941	137	89.80

During the different turning radius tests, the planter was kept driving smoothly, the steering inner measuring wheel speed was kept constant, and the outer wheel speed was changed to vary the actual turning radius. From the analysis of the data in Table 3, it can be seen that the maximum standard deviation is 137 mm, the minimum steering pass rate is 89.8%, and the error value of the turning radius basically meets the target control requirement of the steering system during the test to ensure the planter achieves 180° steering. The error value of turning radius basically meets the target control requirement of steering system. However, as the turning radius becomes larger, the turning radius error gradually increases and the steering qualification rate gradually becomes smaller, which is caused by the vibration of the machine body and the unevenness of the seeding operation road during the seeding process. The larger the turning radius is, the more obvious the above problem is.

CONCLUSIONS

The remote control system of small vegetable seeder was designed with Arduino microcontroller as the control core. Through remote control, the planter can move forward, adjust speed, change line and turn in the field. Through the lifting device and the differential steering device, the vegetable seeding operation is separated from the three modes of road walking and lane changing, it solves the problem of seed waste caused by the fact that the seeding operation of the traditional vegetable seeder is not independent of the mode of road walking and lane changing, and the seed metering device is still rotating during road walking and steering. The Android terminal remote control APP is designed, and the Android terminal is connected through Bluetooth for human-computer interaction.

The operation is simple and the operation parameter setting is convenient, the precision control of vegetable sowing in facilities greenhouse was realized, the quality of vegetable sowing was improved, and the greenhouse vegetable sowing with high precision, high strength and strong repeatability could be completed.

The accuracy of the control system and the qualified rate of steering were tested. The test shows: the control system is stable and reliable, the speed deviation rate of the seeder is 1.59 %, the differential steering is relatively accurate, the qualified rate of steering is more than 89.8 %, and the synchronous speed error of the lifting mechanism tends to be stable, which meets the accuracy requirements of the control system. The designed remote control system is stable, reliable and has good adaptability.

ACKNOWLEDGEMENTS

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