DESIGN AND RESEARCH OF AUTOMATIC ALIGNMENT TEST DEVICE OF SEMI-FEEDING PEANUT COMBINE HARVESTER
/
半喂入式花生联合收获机自动对行试验装置的设计与研究

Prof. Ph.D. Eng. Lv X.L.[1, 3], R. Ph.D. Eng. Hu Z.L.*[2], R.A.M.S. Eng. Wang S.Y.[2], R.A.M.S. Eng. Yu Z.Y.[2]
[1] Ministry of Agriculture, Key Laboratory of Modern Agricultural Equipment/China
[2] Ministry of Agriculture, Nanjing Research Institute for Agricultural Mechanization /China
[3] Chuzhou University, College of Machinery and Automotive Engineering/China
Tel: 862584346246; E-mail: nfzhongzi@163.com

Keywords: *Peanut harvester; Automatic alignment; Detection mechanism; Control system; Performance test*

ABSTRACT

For the caused harvesting loss problem by inaccurate alignment of the semi-feeding peanut harvester, an automatic alignment system on the control core of the single chip microcomputer μPD78F0525 was designed. The system adopts a four-bar detection mechanism to transmit the offset to the controller through the sensor and to adjust the excavator in time. On this basis, a peanut automatic alignment test device is developed, which is composed of conveying platform, ridge ditch, hydraulic execution system, signal detection mechanism, signal processing and control system, etc. The influence effect of the main factors of the system is tested through the test bench. The results show: the reaction time increases with the increase of spring preload and deviation distance, gradually decreases and tends to remain unchanged with the increase of forward speed, and first decreases and then increases with the increase of hydraulic flow. The unqualified rate first decreases and then increases with the increase of spring preload, gradually increases with the increase of forward speed and deviation distance, and gradually decreases with the increase of hydraulic flow. The effectiveness and stability of the automatic alignment system can meet the operation requirements. It effectively solved the problem of automatic alignment of the semi-feeding peanut harvester and provided a technical reference for the research and development of the automatic alignment system for harvesting the fruits under the soil.

摘要

针对半喂入式花生收获机对行不准确造成收获损失的问题，设计了一种基于单片机μp78f0525为控制核心的自动对行系统。系统采用四杆检测机构，通过传感器将补偿量传递给控制器，并及时调整挖掘铲。在此基础上，研制了由输送平台、垄沟、液压执行系统、信号检测机构、信号处理与控制系统等组成的花生自动对行试验装置。对该系统主要因素的影响效果进行了测试，结果表明：随着弹簧预紧力和偏位距离的增大，自动对齐反应时间增大，随着前进速度的增加，反应时间逐渐减小，并趋于不变，随着液压流量的增加，反应时间先减小后增大；不合格率随弹簧预紧力的增加先减小后增大，随着前进速度和偏离距离的增加而逐渐增大，随着液压流量的增加而逐渐减小；自动对行系统的有效性和稳定性均能够满足作业要求。该系统有效解决了半喂入式花生收获机的自动对行问题，为土下果实收获自动对行系统的研制提供了技术参考。

INTRODUCTION

In China, peanut is an important oil crop and high-quality protein resource; it is also the most competitive crop at international level. The overall level of peanut mechanized harvesting in our country is low. How to improve the level of peanut mechanized harvesting is a major problem (*Lv X L et al, 2012*). The ridge cultivation is the main method of peanut planting in China. Because the digging shovel cannot align with the peanut under soil, it will cause large loss and low efficiency. In order to improve the harvesting quality, it is necessary to adjust the digging shovel during operation, so the operator labour intensity is high and the accuracy of the alignment is greatly affected by man-made factors. At present, a great deal of research has been done on the agricultural machinery automatic operation in the country and abroad. The great progress has been obtained in the automatic control system of agricultural machinery (*Fernando A Auat Cheein et al, 2016; Perez-Ruiz Manuel et al, 2014; Ji Changying et al, 2014; Saeys W et al, 2008; Chen Man et al, 2016*), but little research has been done on the automatic alignment of the fruit under the soil. The research on automatic alignment of harvesting fruit under the soil in China is still in the initial stage. Qingdao Agricultural

University has made a preliminary study on the automatic alignment device of peanut combine harvester (*Yang Ranbing et al, 2011*), which adopted the structure of the moving chassis and moving shovel as a whole, and the research is still in the experimental stage. The automatic alignment system of beet harvester is studied by the Nanjing Research Institute for Agricultural Mechanization of the Agriculture Ministry (*Wang Shenying et al, 2014; Wu Huichang et al, 2013*) and the automatic alignment hydraulic rectification system of beet harvester is designed, which is in the experimental stage at present. This paper studies and designs the automatic alignment test device. It can effectively solve the existing technology problems in the automatic alignment of the semi-feeding peanut harvester in China and provide the technical conditions for promoting the development of the automation and intellectualization of peanut industry.

MATERIALS AND METHODS

- **Overall scheme and working principle**

As shown in Fig. 1, the designed automatic alignment test bench mainly includes: deviation detection mechanism, signal processing and control system, rectifying mechanism, signal feedback system, conveying platform, longmen rack and ridge ditch, etc.

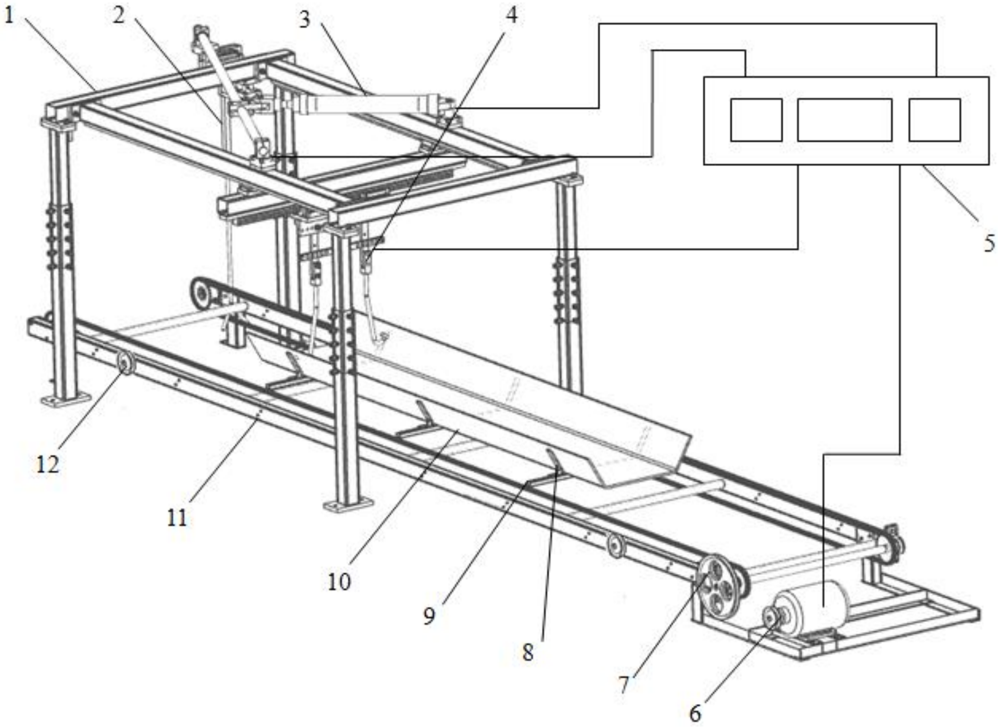


Fig. 1 - Structure diagram of automatic alignment test device

1- Longmen rack; 2- Rectifying rod; 3- Cylinder; 4- Detection mechanism; 5- Controller; 6- Motor; 7- Transmission system; 8- Clamping plate; 9- Adjusting slot; 10- Ridge ditch; 11- Conveying platform; 12- Control switch;

When the test bench is working, the motor drives the ridge ditch movement to imitate the machine driving in the field, and the moving direction and distance of the ridge ditch are controlled by the adjusting switch on the conveying platform. When the roller of the deviation detection mechanism contacted with the ridge ditch, the roller drives the detection rod to swing. The displacement signal is transformed into angle signal by the angle sensor and transmitted to the single chip microcomputer for calculation and processing. The hydraulic system of the rectifying mechanism adjusts the position of the rectifying rod to imitate the adjustment of the digging shovel during the machine working and, at the same time, the rotation angle of the pull rod on the cylinder is monitored in time. The rectifying situation is fed back to the signal processing and control system in time and the timely rectification is finished.

- **Design of automatic alignment system**

Deviation detection mechanism

As shown in Fig. 2, the deviation detection mechanism is mainly composed of the fixed frame, detection rod, roller, sensor and reset spring.

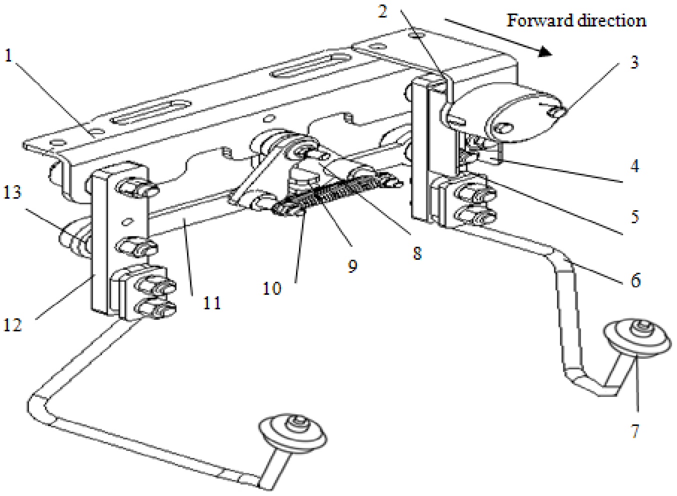


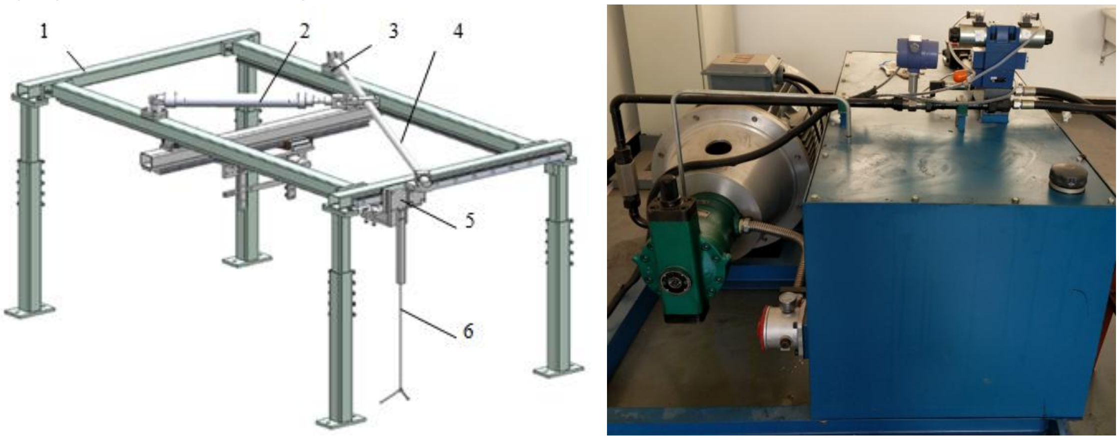
Fig. 2 - Structure diagram of detection mechanism

1- Fixing frame; 2- Mounting plate; 3- Sensor; 4- Connecting shaft; 5- Support plate; 6- Detection rod; 7- Roller; 8- Spring limit plate; 9- Block; 10- Replacing spring; 11- Connecting rod; 12- Swing arm; 13- Bearing

It is composed of the swing arm, connecting rod and frame formed four link mechanisms. The deviation situation of the digging shovel was detected by the roller on the detection rod. The connecting shaft of the sensor is connected with the supporting plate, which can drive the connecting shaft of the sensor to rotate, and the displacement signal is transformed into angle signal by the sensor and transmitted to the controller. The controller controls the rectifying mechanism to finish automatic alignment. The replacing device is composed of the spring limit plate, replacing spring and block. The two spring limit plates are located separately to the two sides of the block and the blade on the connecting rod, and are connected with the replacing spring. When the detection rod is forced to swing, the blade on the connecting rod pushes the spring limit plate on the opposite side to swing. When the force is greater than the spring preload, it drives the rotating shaft of the sensor to rotate. When the detection rod is not forced, it will be replaced in time under the combined action of spring preload and the block. According to experience and experimental measurement, the minimum preload of the replacing spring cannot be less than 30N. According to the requirement of the detection mechanism, the angle sensor selects the photoelectric incremental encoder VLH11 with three-phase square wave output of EPC Company in USA, its maximum revolution is 7500r/min, the starting torque is 1.5×10^{-5}N·m, the response frequency is 100kHz and the resolution ratio is 1024P/R. The angle sensor has the direction indication of angle change, the pulse output of the angle sensor are connected to the external interrupt input of the microprocessor, and the interrupt of the way touch edge is used to count pulse and determine direction.

- ***Rectifying execution system***

The system is mainly composed of hydraulic control system, cylinder, pull rod, signal feedback device and rectifying rod, as shown in Fig. 3.



(a) Rectifying mechanism (b) Hydraulic control system

Fig. 3 - The rectifying execution system

1- Longmen rack; 2- Cylinder; 3- Signal feedback device; 4 - Pull rod; 5- Bracket; 6- Rectifying rod

The rectifying rod is connected with the longmen rack by the bracket and can move to the left and right along the beam by the pull rod driving. The signal feedback device mainly includes angle sensor and sensor mounting bracket. The actual rotation angle of the pull rod is transmitted to the control system by the angle sensor and the adjustment of the digging shovel is imitated by the cylinder adjusting the rectifying rod. As shown in Fig. 4, according to the processing result of the detection signal (*Zhang Hui et al, 2010; Chen Yazhou et al, 2012; Yu Yang et al, 2011*), the 2-position, 3-way solenoid valve *4* is first controlled by the controller, the high-pressure oil enters into the oil circuit and then the movement direction and flex value of the hydraulic cylinder are controlled by the 3-position, 4-way solenoid valve *8*. The high-pressure oil can be conveyed to the 3-position, 4-way solenoid valve *8* by controlling the 2-position 3-way solenoid valve *6* and adjusting throttle valve *7*, so that the hydraulic cylinder *9* moves smoothly and accurately.

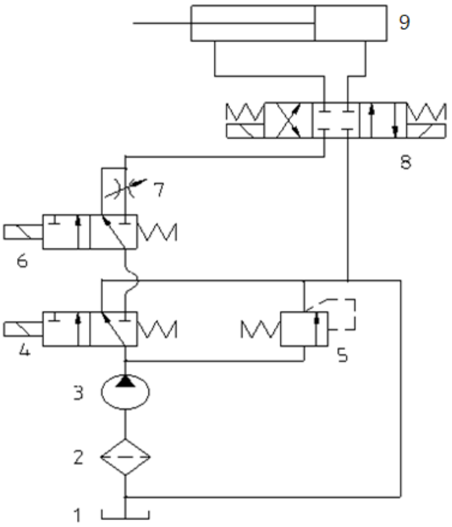


Fig. 4 - Schematic diagram of hydraulic system

1- Fuel tank; 2- Filter; 3- Hydraulic pump; 4, 6- 2-position, 3-way solenoid valve; 5- Relief valve; 7- Adjustable throttle valve; 8- 3-position, 4-way solenoid valve; 9- Cylinder

- ***Signal processing and control system***

The system mainly processes the detection information in time, and controls the execution parts to complete the rectification (*Feng Huimin et al, 2018; Wei Xinhua et al, 2009*). As shown in Fig. 5, the system takes the single-chip microcomputer as the control core, converts the offset into electrical signal by the angle sensor and transmits it to the controller. The speed sensor transmits the forward speed of the harvester to the controller. The controller judges rectifying value according to the angle sensor transmitted signal and finishes the rectification in time by controlling the hydraulic valve to adjust the flex value of the cylinder. The controller determines the adjusting time according to the speed sensor signal. The signal feedback sensor monitors the angle change of the pull rod in time and transmits to the controller to adjust the output control signal in time. The closed-loop control system is formed. According to the requirement, the speed sensor adopts KJT-J18GW-ZK proximity sensor of Nanjing kaijite Electric Co., Ltd, and the angle sensor uses the three-phase square wave output photoelectric incremental encoder VLH11 of USA EPC Co., Ltd.

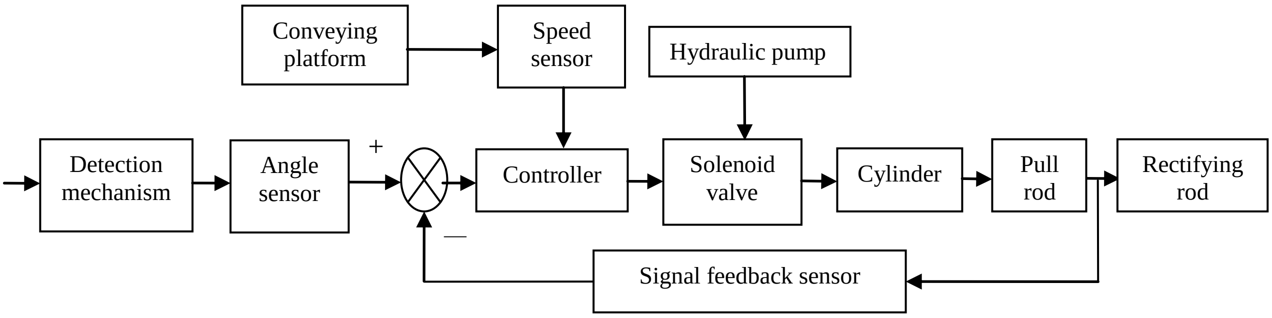


Fig. 5 - The schematic diagram of signal processing and control system

The system needs to finish complex logic judgment, so the digital-analog hybrid circuit is adopted on the single chip microcomputer. The overall structure is mainly composed of the smallest processor system, data storage, power supply, solenoid valve drive and clamp-limiting filtering circuit. The single chip microcomputer adopts μPD78F0525 (*Cai Guohua et al, 2011; Hu Lian et al, 2009*). As shown in Fig. 6, the minimal system mainly includes single chip microcomputer, crystal oscillator circuit and reset circuit. It mainly finishes the scanning and identification of the input information of angle sensor and speed sensor and processing of the internal program, and outputs the control signal of the electromagnetic valve driving circuit. As shown in Fig. 7, in order to improve the anti-interference ability of the interface, the clamp-limiting filtering circuit is added in the interface between the angle (speed) sensor and the single chip computer. As shown in Fig. 8, the drive circuit of solenoid valve is mainly composed of the opto coupler TLP817 and the field effect Transistor 2SK2931. In order to eliminate the reverse flow of solenoid valve coil, a diode stack 10GL2CZ47A is added.

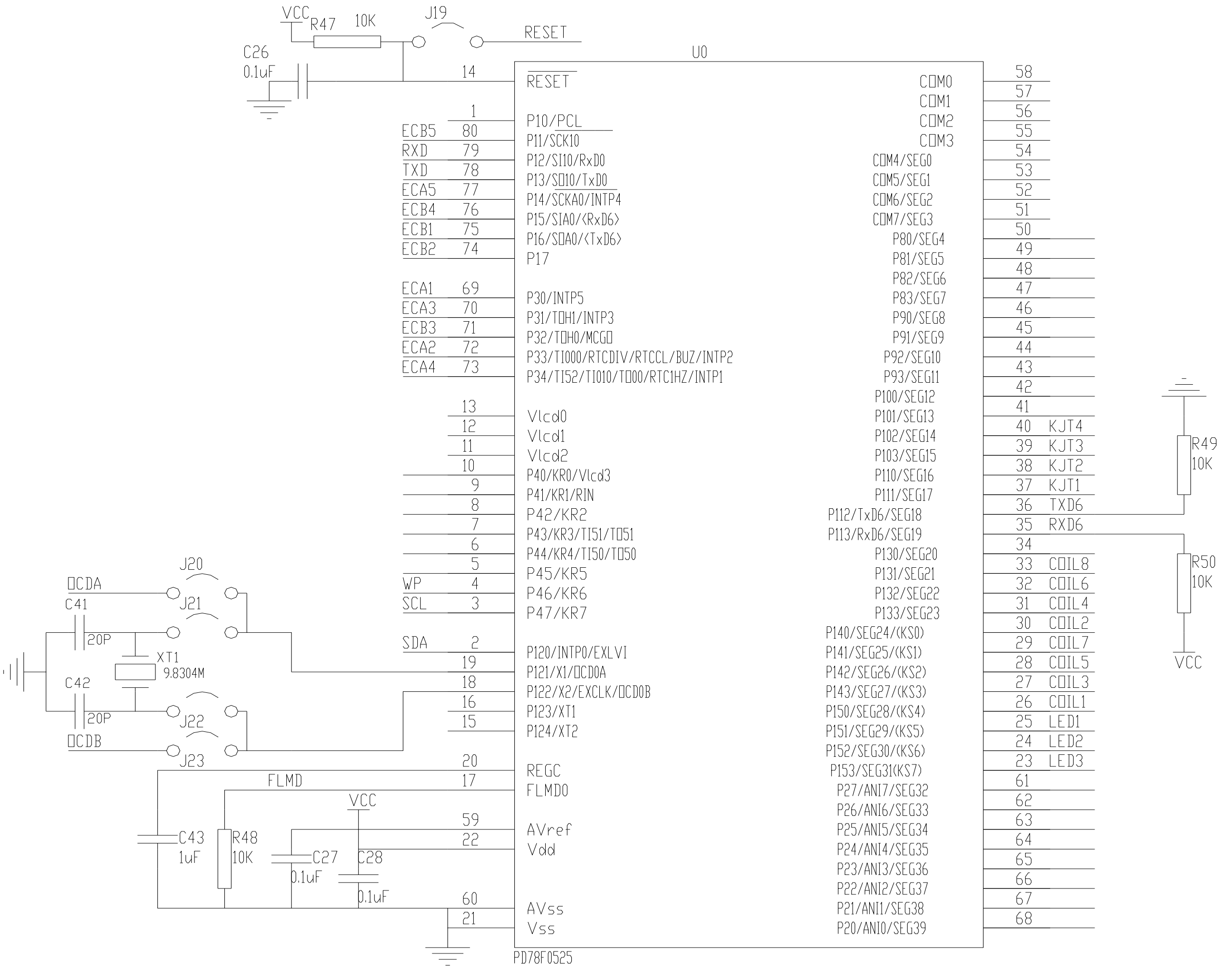
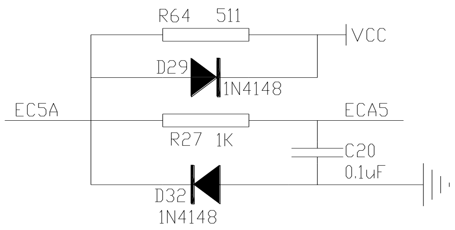


Fig. 6 - Minimum system circuit diagram of the single chip microcomputer



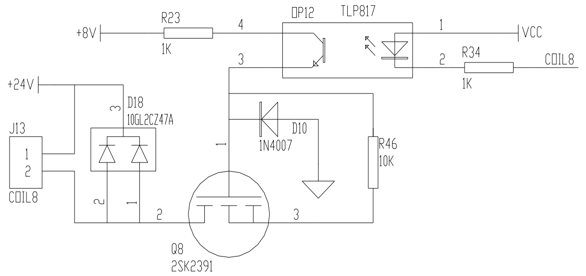


Fig. 7 - Diagram of clamp-limiting filtering circuit **Fig. 8 - Driving circuit diagram of the solenoid valve**

The main program flow chart of the detection and control system of the automatic alignment is shown in Fig. 9.

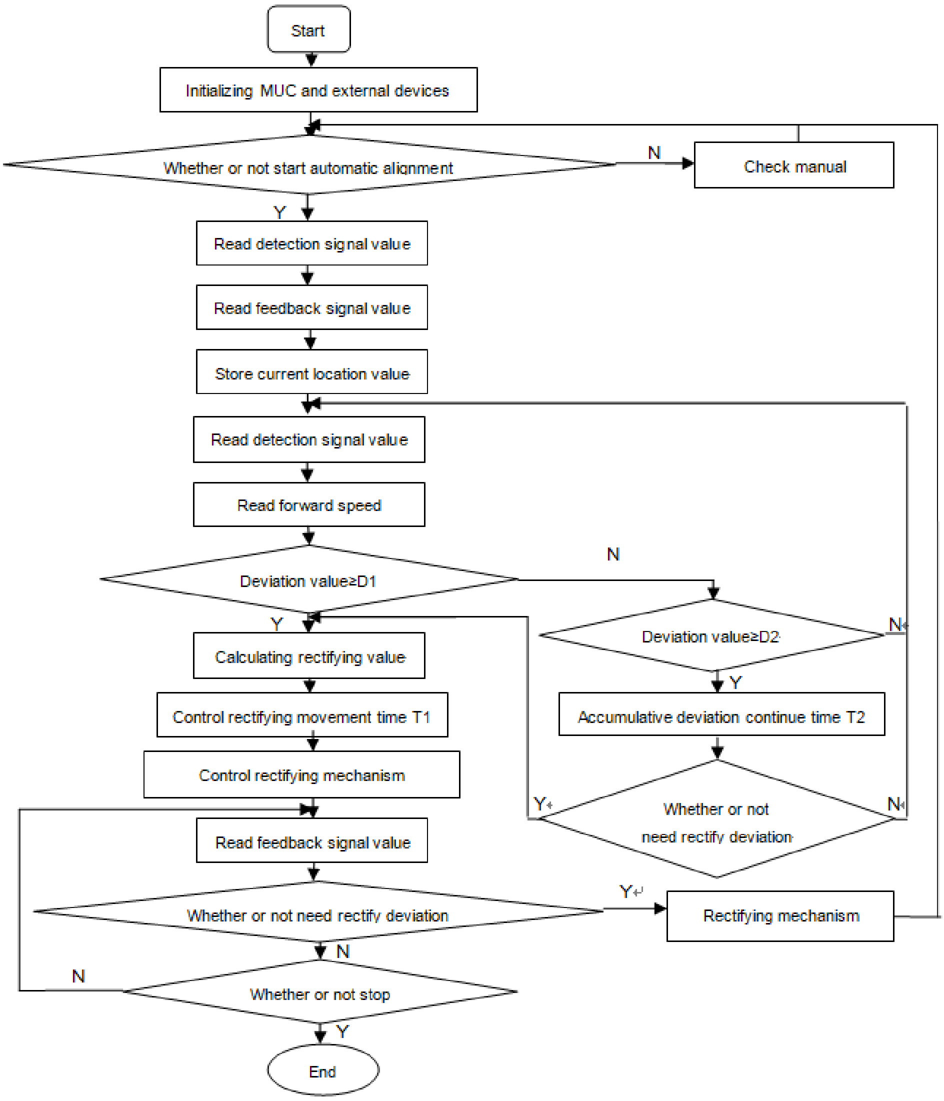


Fig. 9 - Flow chart of main program

The program first initializes and then processes the detection signal of the sensor in time. The main program first reads the angle values of the detection mechanism and the feedback mechanism, and stores the values in current position. Then, it extracts the forward speed of the harvester and the angle value of the detection mechanism and judges whether the angle value exceeds the range of the allowed value. When it does not exceed the allowed range, the controller will not send out the control signal, carrying on the trimming after the corresponding time according to the forward speed of the harvester. When it does exceed the allowed range, the controller calculates the rectifying value according to the deflection angle and calculates the rectifying adjustment time according to the harvester forward speed to adjust the flex value of the cylinder in time, then adjusts it properly according to the feedback signal. Until the rectification meets the requirements, the rectification mechanism replaces it and the system enters into the next adjustment or meets the stop conditions to stop work. In order to reduce the inertia of the hydraulic rectifying mechanism and improve the stability and accuracy of the adjustment, the throttle valve was started to carry on the trimming before the beginning and ending adjustment of the cylinder.

- **Performance test**

Test equipment and instruments

The automatic alignment test bench of semi-feeding peanut harvesting (As shown in Fig. 10), tape (range is 5m, accuracy is 1mm), tachometer (range is 1-19999r/min, accuracy is ± 0.02%), scientific calculator, oscilloscope (2 channels, bandwidth is 100MHz, vertical resolution is 8bit, maximum real-time sampling rate 1.25GS/s, recording length of the per channel is 27500 points)), BM902 multimeter.

Fig. 10 - The automatic alignment test bench of semi-feeding peanut combine harvester

Contents and methods of the test

The influence of the main factors on performance of the automatic alignment system are tested (*Zhai Changyuan et al, 2009; Zuo Xingjian et al, 2016*) and the influence law is analyzed. The spring preload, forward speed, deviation distance and flow were selected as the test factors, and the rectifying unqualified rate and system reaction time were selected as the test indexes. The levels of each factor were as shown in Table 1. In the test, the moving speed of conveyor platform is used to imitate the forward speed of the harvester. The moving speed of the test bench is adjusted by the frequency converter, and the speed is measured by the tachometer. The position status of the digging shovel is imitated by the moving track of the rectifying rod at the bottom of the ridge ditch. The value of the rectifying rod deviating from centreline of ditch bottom is selected as the deviation value of the digging shovel. When the value exceeds the deviation range, it is unqualified. In order to measure the reaction time of the system, the detection sensor and the feedback sensor are connected to the oscilloscope respectively to measure the reaction time of the automatic alignment system. In the test, single factor test was done. Each factor level was repeated three times and the average value was taken as the test result.

Table 1

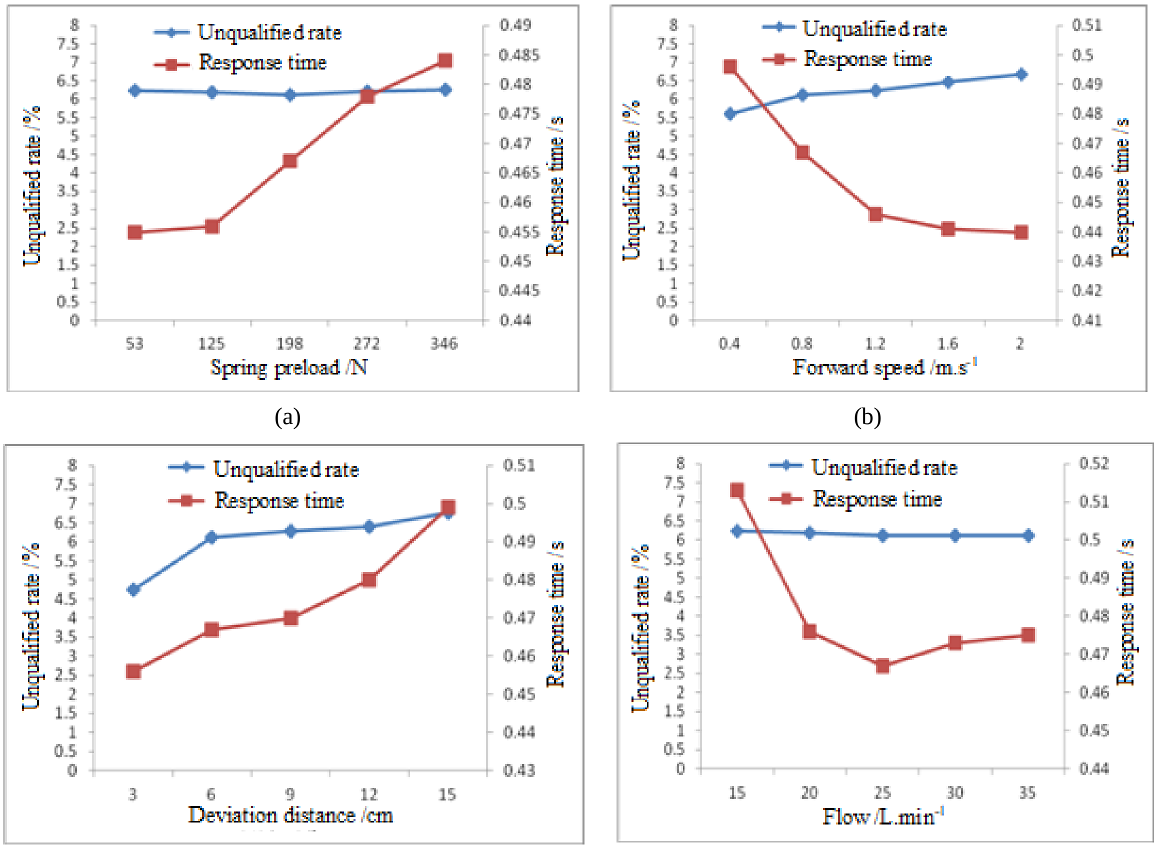
Factor and level table

Levels	**Factors**			
	Spring preload /N	**Forward speed /m.s^{-1}**	**Deviation distance /cm**	**Flow /L.min^{-1}**
1	53	0.4	3	15
2	125	0.8	6	20
3	198	1.2	9	25
4	272	1.6	12	30
5	346	2.0	15	35

RESULTS

As shown in Fig. 11, the test results and analysis illustrate that: (1) the preload of the spring has greater effect to the reaction time, but smaller effect to the unqualified rate. With the increase of spring preload, the reaction time increases, while the unqualified rate first decreases and then increases. The preload force of the replaced spring increases, the swing resistance force of the detection rod increases, so that the signal extracting time of the detection system increases. (2) The forward speed has much great effect to the reaction time and the unqualified rate. With the increase of the forward speed, the reaction time gradually decreases and tends to remain unchanged, and the unqualified rate gradually increases. With the increase of the forward speed, the signal extraction time of the detection system decreases. When the speed is greater than a certain value, the reaction time of each link of the system reaches "saturation" state, and the reaction time does not change. With the increase of the forward speed, the reaction time of the system decreases, so that the digging shovel cannot be adjusted to location in reaction time. It makes the unqualified rate improve. (3)

The departure distance has greater effect on the reaction time and the unqualified rate. With the increase of the departure distance, the reaction time and unqualified rate increase gradually. The longer the deviation distance is, the larger the swing angle of the detection rod is and the longer the signal extraction time of the detection system is. It makes the adjustment quantity of the hydraulic cylinder increases, so that the action time of the rectification execution system increases. The longer the deviation distance, the longer the rectification time, so that the digging shovel cannot be adjusted to location in time. It makes the unqualified rate improve. (4) The flow has greater effect on the reaction time, but smaller effect on the unqualified rate. With the increase of the flow, the reaction time decreases first and then increases, and the unqualified rate gradually decreases. With the increase of the flow, the movement time of hydraulic cylinder decreases, so that the automatic alignment speed increases and the reaction time and the unqualified rate decrease. When the flow exceeds the demand value, the too fast hydraulic cylinder movement causes the overshoot of the rectification execution mechanism. It causes reciprocating vibration of the rectification execution mechanism, and the reaction time decreases first and then increases.



(a) (b)

(c) (d)

Fig. 11 - The influence of the factors to automatic alignment performance

CONCLUSIONS

The automatic alignment system of the semi-feeding peanut harvester was designed. The system is mainly composed of the deviation detection mechanism, signal processing and control system, rectifying execution mechanism, signal feedback system, etc. The core of the signal processing and control system adopts the single chip microcomputerμPD78F0525. By the angle sensor, the deviation signal is transformed into an angle signal and processed in time. On this basis, the test bench of the automatic alignment system of the peanut harvester is designed. The test bench is mainly composed of the conveying platform, ridge ditch, hydraulic execution system, signal detection mechanism, signal processing and control system. The working performance of the automatic alignment system and the influence effect of the main factors are tested. The test results show that: the spring preload, forward speed of the peanut harvester, deviation distance of the digging shovel and flow of the hydraulic system rate have significant effects on the response time of the system. With the increase of the spring preload and deviation distance, the reaction time increases. With the increase of the forward speed, the reaction time gradually decreases and tends to remain unchanged. With the increase of the flow, the reaction time decreases first and then increases. The spring preload and flow of the hydraulic system have smaller effects on the unqualified rate. The forward speed of the peanut harvester and deviation distance of the digging shovel have greater effects on the unqualified rate. With the increase of the spring preload, the unqualified rate decreases first and then increases. With the increase of the forward speed and deviation distance, the unqualified rate gradually increases. With the increase of the flow, the unqualified rate gradually decreases. The system has good real-time performance, stable operation performance and can better meet the requirement of the automatic alignment operation of the peanut harvester.

ACKNOWLEDGEMENT

The study was supported by the Key Laboratory of Modern Agricultural Equipment, Ministry of Agriculture, P.R. China (201602002), and the Natural Science Foundation for colleges and universities in Anhui Province of China (KJ2018A0423).

REFERENCES

[1] Cai Guohua, Li Hui, Li Hongwen et al, (2011), Design of test-bed for automatic depth of furrow opening control system based on ATmega128 single chip microcomputer, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.27, Issue 10, pp.11-16, Beijing/ China;

[2] Chen Man, LU Wei, Wang Xiaochan et al, (2016), Design and experiment of optimization control system for variable fertilization in winter wheat field based on fuzzy PID, *Transactions of the Chinese Society for Agricultural Machinery*, Vol.47, Issue 2, pp.71-76, Beijing/ China;

[3] Chen Yazhou, Pi Jun, Zheng Tianyi, (2012), Electro-hydraulic proportional manipulation system of land leveller based on pilot oil distribution method, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.28, Issue 2, pp.7-12, Beijing/ China;

[4] Feng Huimin, Gao Na'na, Meng Zhijun et al, (2018), Design and Experiment of Deep Fertilizer Applicator Based on Autonomous Navigation for Precise Row-following, *Transactions of the Chinese Society for Agricultural Machinery*, Vol.49, Issue 4, pp.60-67, Beijing/ China;

[5] Fernando A Auat Cheein, Gustavo Scaglia, Miguel Torres-Torriti et al, (2016), Algebraic path tracking to aid the manual harvesting of olives using an automated service unit, *Biosystems Engineering*, Vol.142, pp.117-132, England/ UK;

[6] Hu Lian, Luo Xiwen, Zhao Zuoxi et al, (2009), Design of electronic control device and control algorithm for rice transplanter, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.25, Issue 4, pp.118-122, Beijing/ China;

[7] Ji Changying, Zhou Jun, (2014), Current situation of navigation technologies for agricultural machinery, *Transactions of the Chinese Society for Agricultural Machinery*, Vol.45, Issue 9, pp.44-54, Beijing/ China;

[8] Lv X.L., Wang H.O., Zhang H.J. et al, (2012), Present Situation and Analysis on Peanut Picking Technology and Equipment, Hubei Agricultural Sciences, Vol.51, Issue 18, pp.4116-4118, Wuhan/ China;

[9] Perez-Ruiz Manuel, Slaughter David C, Fathallah Fadi A, et al, (2014), Co-robotic intra -row weed control system, *Biosystems Engineering*, Vol.128, pp.45-55, England/ UK;

[10] Saeys W, Wallays C, Engelen K, et al, (2008), An automatic depth control system for shallow slurry injection, part 2: Control design and field validation, *Biosystems Engineering*, Vol.99, Issue 2, pp.161-170, England/ UK;

[11] Yang Ranbing, Shang Shuqi et al, (2011), Research on automatic alignment technology for harvesting machinery of rootstalk crops, *CSAE 2011*, pp.1-5, Beijing/ China;

[12] Yu Yang, Shi Boqiang, Hou Youshan, (2011), Analysis on stability of hydraulic servo systems affected by structure stiffness, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.27, Issue Supp.2, pp.32-35, Beijing/ China;

[13] Wang Shenying, Hu Zhichao, Wu Huichang et al, (2014), Design simulation and test of auto-follow row control system employed in beet harvester based on Proteus, *Journal of Chinese Agricultural Mechanization*, Vol.35, Issue 3, pp.35-40, Beijing/ China;

[14] Wei Xinhua, Li Yaoming, Chen Jin et al, (2009), System integration of working process intelligent monitoring and controlling devices for combine harvester, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.25, Issue Supp.2, pp.56-60, Beijing/ China;

[15] Wu Huichang, Hu Zhichao, Peng Baoliang et al, (2013), Development of auto-follow row system employed in pull-type beet combine harvester, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.29, Issue 12, pp.17-24, Beijing/ China;

[16] Zhai Changyuan, Zhu Ruixiang, Sui Shuntao et al, (2009), Design and experiment of control system of variable pesticide application machine hauled by tractor, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.25, Issue 8, pp.105-109, Beijing/ China;

[17] Zhang Hui, Li Shujun, Zhang Xiaochao et al, (2010), Development and performance of electro-hydraulic proportion control system of variable rate fertilizer, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.26, Issue Supp.2, pp.218-222, Beijing/ China;

[18] Zuo Xingjian, Wu Guangweiu Weiqiang et al, (2016), Design and experiment on air-blast rice side deep precision fertilization device, *Transactions of the Chinese Society of Agricultural Engineering*, Vol.32, Issue 3, pp.14-21, Beijing/ China.