

Experimental Study of Intelligent Precision Cotton Topping Machine

Qiangji Peng, Jianming Kang*, Qinghai He, Hui Yue, Guojian Wei, Shichun Jian

Shandong Academy of Agricultural Machinery Sciences, Jinan, 250100, China

pengqiangji1984@126.com

Abstract: Existing problems in operation of cotton topping machines include poor performance in actual height measurement of the cotton plant, omission of topping, severe over topping, low level of intelligence, and etc. To solve these problems, a scheme of separating the detection device from the topping device and separating the lifting drive from the topping drive is proposed herein, and an intelligent precision cotton topping machine is designed based on the Field-Programmable Gate Array (FPGA) technology. During the topping practice, the detection device precisely detects the height of the cotton plant, while the topping device controlled by the control system carries out accurate quantitative topping. The touch screen control system, which displays the operating speed, work area in real time and monitors the process of cotton topping, significantly increases the level of intelligence. Field tests show that the whole structure of the machine is stable, the machine operation speed is within $3.24\text{km}\cdot\text{h}^{-1}$, the topping rate is about 90%, and the topping quantity is close to the set value, so it is possible to realize quantitative topping and this research provides technical support for cotton topping mechanization.

1. Introduction

Cotton is an important commercial crop in China, the planting area of which reaches about 2.92 million hectares ^[1]. Cotton is a kind of plant that will grow to an infinite height or span, but such unlimited growth will decrease the number of fruit-bearing branches and undermine the quality of cotton, thereby reducing cotton production. Cotton topping is the key to increasing cotton production, and timely topping which can avoid preferred transmission of nutrition to the top branches ensures transportation of most nutrients to fruit-bearing branches, reduce abscission and rotting of cotton bolls, and promote cracking of bolls, so it will help reach the goals of early maturity, high and stable yield of cotton ^[2].

Timing for topping is particularly important. To carry out topping too early will cut down the number of fruit-bearing branches, but to do it too late will increase invalid fruit-bearing branches and turn it to an effort in futility as it no longer plays a role in nutrition regulation ^[3]. At present, there are three ways of topping. The first is manual topping, which is time-consuming, laborious and causes delays in other farming activities ^[4]. The second is chemical control, which is highly technical and subject to such factors as the cotton species and weather conditions; besides, repeated spraying of chemicals may cause environmental pollution and harm human health, so large-area promotion of this way remains controversial ^[5-6]. The third is mechanical and automatic topping, which is becoming a hot research topic in the field of precision agriculture science. To solve the existing problems in the design of cotton topping machine, many domestic academies and related companies have done research from different aspects like the ultrasonic sensor, laser sensor and image recognition



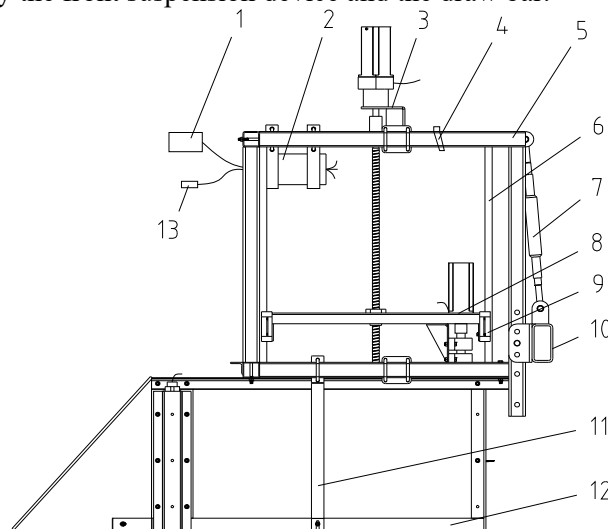
technology, and have made some achievements [7-10]. Due to the problems in precise detection of the cotton plant's height, quantitative topping and intelligent control, the topping rate and the level of intelligence are still to be improved. Now intelligent topping technologies are still under testing, and no mature products are available on the market.

To solve the above-mentioned problems, an intelligent precision topping machine with the FPGA control system as its core is developed herein. By separating the detection device from the topping device and the lifting drive from the topping drive, this machine realizes quantitative topping, avoids favored nutrition supply to top branches, increases cotton yield and quality, saves time and labor. Moreover, the intelligent touch screen control system realizes one-key control, which greatly improves the intelligent level of mechanical cotton topping. The research hereof provides a theoretical basis for the popularization and application of mechanical cotton topping technology.

2. Structure and Working Principle

2.1 Machine Structure

The machine is mainly composed of a touch screen, a control cabinet, a lifting device, a digital camera, a frame, guiding rails, a topping device, a slider, a front suspension device, a reinforcement device, a detection device, an encoder, etc., as shown in Fig.1. The whole structure is based on the frame, with the control cabinet fixed on the top of the front frame to realize intelligent control of the whole machine. The touch screen is installed in the cab and connected to the control cabinet through the cable to realize one-key control. The lifting device fixed in the middle of the frame by a U-typed bolt is connected with the topping device through the bolt to provide lifting power for the topping device and realize accurate displacement according to the controller. The topping device is fixed by the bolt and the slider, and the slider collaborates with the guiding rail; the guiding rail fixed on the frame by bolts ensures the vertical movement and completes the topping cutting process. The detecting device is fixed on the lower part of the machine frame by bolts and is installed in a bilaterally symmetrical manner to complete the cotton height detection process. The encoder connected to the wheel shaft gives real-time feedback of the machine's speed to the controller. The whole machine is fixed on the front part of the tractor by the front suspension device and the draw bar.



1.Touch screen 2. Control cabinet 3. Lifting device 4. Digital camera 5.Frame 6.Guiding rail 7.Draw bar 8.Topping device 9.Slider 10.Front suspension device 11.Reinforcement device 12.Detection device 13.Encoder

Fig.1 Structure of the intelligent precision cotton topping machine

The control system, with the FPGA controller as its core, mainly consists of a speed detection encoder, a detection light curtain, a digital camera, a servo motor, communication circuits, a power

switch and a FPGA controller. The sensor circuit acquires signals of detection indices; the digital camera realizes real-time acquisition of digital signals; the servo motor drives the circuits to control the lifting movements and the rotating speed of the cutter mandrel; the touch screen composed of input, output and display circuits realizes human-computer interaction, display of real-time index information and real-time monitoring; the power supply is from the tractor's built-in batteries.

2.2 Working Principles

Before the topping practice, the machine's frame shall be adjusted to a reasonable position according to the cotton plants' height, and the mechanical structure and wiring of the machine shall be checked. Then after all parts are ensured for normal operation, the switch is turned on to boot the touch screen and the parameters for the topping machine's control system are set; the topping servo motor starts to work after the start button is pressed. During the topping practice, the detection device detects the actual height of the cotton plant and sends the height signal to the controller; the encoder collects signals of the machine's advancing speed and transmits the signals to the controller. Then, the controller, after processing of the received signals, presents the information of the speed and working area on the touch screen. Meanwhile, the controller, which can judge the response time according to the machine's advancing speed, sends the driving signal to the driver and, through the driver, controls the lifting servo motor to realize the forward and reverse rotation, that is, upward or downward movements, to complete the topping operation.

The controller controls the motor's rotation laps through the frequency of the pulse signals, and by controlling the number of the screw rod's rotation laps when the screw rod's lead stays at a certain level, it realizes quantitative displacement and hence quantitative topping. A safety limit point is set on the lifting device, so when the topping device moves beyond the prescribed moving range, the lifting servo motor will immediately stop running and send out alarm signals. The digital camera records the topping process and then directly delivers the digital signals to the touch screen for display. The topping range of the topping device is fixed, and the starting point can be set either by default or through the manual button.

3. Main Technical Parameters

Main design parameters of the intelligent precision cotton topping machine are shown in Tab.1.

Tab.1 Main design parameters of intelligent precise cotton topping machine

parameter	value
Length × width × height / mm	1300×1000×1300
total weight / kg	70
topping rate / %	≥88
operating speed / km·h ⁻¹	2~4
topping height / mm	550~900
work breadth / line	single line
spindle speed / r·min ⁻¹	0~3000
lifting type	motor drive
mount type	front suspension

4. Experimental Research

4.1 Experimental Condition

1) Basic Situation of the Experimental Field

Cotton plants in the topping period at the mechanical cotton picking base in Wudi County of Binzhou City are used as the experiment sample. The variety of the cotton is *Gossypium arboreum* 915, the previous crop of the field is cotton, and the cropping pattern is the one-film six-ridge mechanical cotton picking pattern; the pilot field covers 684m² (6.84 m×100 m), the cotton planting density is 1.2×10⁵ plants / hm⁻², and the land surface of the pilot field is relatively flat.

2) Experiment Apparatus

Apparatus used in the experiment include meter rules (0~2 m), tape measures (0~50 m), stopwatches (0.0001~9999 s) and digital cameras as well as a Foton Lovol M1000H.D high-arch tractor with a wheel tread of 2250mm and a minimum clearance from the ground at 900 mm. It is required that the tractor is in good condition and that the driver is proficient and knows how to operate a topping machine. The cotton intelligent precision topping machine used is the self-designed 3MDZJ-1 prototype machine, and it shall be ensured that the machine is well structured with firm linking parts, a reliable and safe power transmission system and is in good condition.

4.2 Experimental Method

Three testing areas A, B and C are set for the experiment, each area covering 228 m² (2.28 m×100 m). Each area that stretches 100 m long is divided into three zones according to the machine's advancing speed: Fast I Zone, Fast II Zone and Fast III Zone, and a 20m-long belt of land is reserved at both ends of the field for turning of the machine. Six processing blocks measured at 0.76 m×3 m are randomly arranged between the ridges of each testing area, with a plate to mark each block and record the number of cotton plants within the block. The height of the cotton plant is the vertical distance from the plant's top to the ground measured manually. The specific measurement method is prescribed in "Manual for Crop Field Experiment".

4.3 Experiment and Evaluation

Reliability and working condition of each part of the prototype machine are verified in the experiment. The actual height of cotton plants before topping, the height after topping, the topping rate and the amount of topping under different operating speed conditions are recorded to analyze the relationship between the machine speed and the work quality. The experiment also aims to observe problems in order to improve the design.

Topping rate: the ratio of the number of cotton plants that had been topped against the total of valid cotton plants in the area, expressed in%.

$$\eta = \frac{n_s}{n} \times 100\% \quad (1)$$

where η stands for the topping rate, n_s for the number of cotton plants being topped, and n for the total of valid cotton plants.

Topping quantity: the difference between the heights of plants before topping and after topping in the same experiment area.

$$\Delta h = L_q - L_h \quad (2)$$

where Δh represents the topping quantity, L_q the valid height of cotton plants before topping, and L_h the valid height after topping (unit: cm). The topping operation is required to cut one leaf and one core from the top of the cotton plant, and as measured by field survey, the height of the "one leaf and one core" at the top is 4-8cm, so the topping quantity is set at 7cm according to the range of topping quantity [12].

Operating speed: the average speed of the machine for two round trips in the experiment area.



Fig.2 Experimental prototype

5. Experiment Results and Analysis

The experiment was carried out on August 7th, 2017, and the selected cotton samples are those in good growth condition and meet the agronomic requirements for topping, that is, the sample cotton plants have above 7 fruit-bearing branches. Specific performance indicators are shown in Table.2.

Tab.2 The field operation performance index

Average speed /km·h ⁻¹	Label	Set the topping amount/ cm	number of cotton plants /plant	Before topping		After topping		Topping rate /%
				the average plant height /cm	standard deviation	the average plant height /cm	Topping the amount /cm	
2.88	1	7	17	83.1	3.9	76.6	6.5	88.2
	2		20	79.5	4.5	72.1	7.4	90.0
	3		20	80.0	6.0	74.0	6.0	90.0
3.24	1	7	19	77.0	5.3	71.0	6.0	89.5
	2		20	82.0	6.2	75.5	6.5	90.0
	3		19	83.4	4.7	77.0	6.4	89.5
3.52	1	7	17	79.0	4.6	71.0	8.0	76.5
	2		18	75.9	6.5	70.9	5.0	66.7
	3		21	80.0	5.2	72.5	7.5	71.4

Part of the data of the field experiment are listed in Table 1. In order to make intuitive analysis of experiment results, the statistical software Minitab is used for graphical description^[13], and the effect diagram is shown in Fig.3.

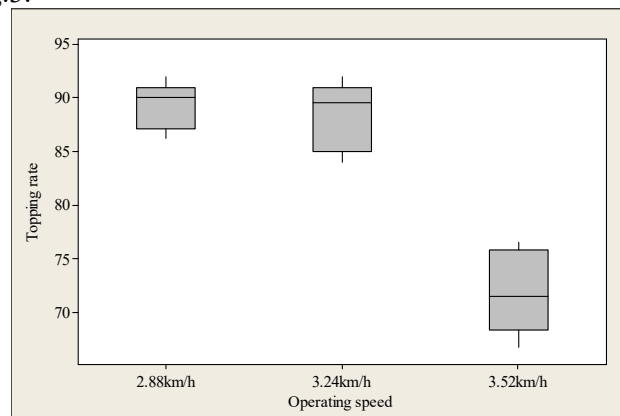


Fig.3 The boxplot of topping rate under different speeds

As shown in Fig.3, the topping rate differs with the speed. When the operation speed is at $2.88\text{ km} \cdot \text{h}^{-1}$ and $3.24\text{ km} \cdot \text{h}^{-1}$, the topping rate remains the same at about 90%. Within this speed range, the correlation analysis of the relationship between pre-topping standard deviation and the topping rate shows that the Pearson correlation coefficient between the standard deviation and the absolute value of error is 0.3, which is below 0.8, so there is no significant linear correlation. The topping quantity is close to the set value. The machine is a FPAG control system-based intelligent precision topping machine, and after the detection device detects the height of cotton plants, the topping device automatically adjusts the response time and the lifting height according to the machine's advancing speed. Thus when the operation speed is within $3.24\text{ km} \cdot \text{h}^{-1}$, the machine achieves the optimal performance and fulfills the topping task well.

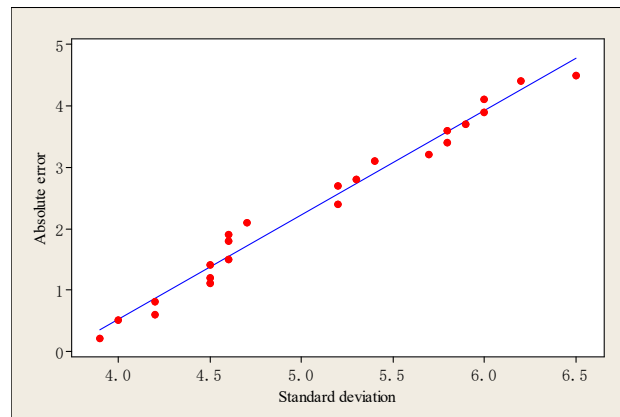


Fig.4 Cotton high standard deviation and topping error correlation diagram

When the operation speed reaches $3.52\text{km}\cdot\text{h}^{-1}$, the topping rate shows obvious difference, dropping to about 70%, which means that at this speed, the topping device cannot reach the corresponding position at the predetermined response time after the detection device detects the cotton plant's height, so the lifting speed should be improved. By comparing the topping rate and the standard deviation before topping at this speed, it is found that when the standard deviation of the cotton plant's height before topping is small, the topping rate was significantly higher than that when the standard deviation is large. Correlation analysis of the relationship between the pre-topping standard deviation of height and the topping quantity shows that the Pearson correlation coefficient between the standard deviation and the absolute value of error is 0.989, greater than 0.8, which means there is a significant linear correlation, as shown in Fig.4. At this speed, the topping rate and the topping quantity are obviously affected by the standard deviation of the cotton plant's height before topping.

6. Conclusions

1) As verified by the experiment, the scheme proposed herein – separating the detection device from the topping device and separating the lifting drive from the topping drive, is feasible, which provides theoretical and practical basis for the application and promotion of mechanical cotton topping technology.

2) The machine's control system can adjust the topping response time in real time according to the advancing speed and realize accurate quantitative topping; the touch screen control system can display in real time the operating speed, working area and monitor the operation process, which improves the intelligent level of cotton topping.

3) The machine's performance is obviously influenced by the operating speed. When the operating speed is within $3.24\text{km}\cdot\text{h}^{-1}$, the topping rate reaches about 90%, the topping quantity is close to the set value, and the topping effect is good. When the operating speed is increased to $3.52\text{ km}\cdot\text{h}^{-1}$, the topping rate decreases significantly, the topping quantity error fluctuates significantly, and the impact of the degree of dispersion of cotton plants' height increases.

4) The single-row cotton intelligent precision topping machine can be assembled to a multi-row topping machine by increasing the width of its frame and revamping the overall structure to improve operating efficiency.

5) The operating speed is a key factor of operating efficiency, and further experiments are needed to optimize the overall structure to increase the operating speed.

Acknowledgment

Foundation item: Shandong science and technology development plan project (GG201703240040)

Biography: Qiangji Peng (1984-), Male, Engineer, major in agricultural mechanization engineering, Shandong Academy of Agricultural Machinery Sciences, Jinan, 250100, Email: pengqiangji1984@126.com.

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