Development of an Automatic Testing System for Corn

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Abstract: Currently, the mainly used methods for corn parameters are traditional artificial method and semi-automatic method based on machine vision technology, which restrict the efficiency of multiple date acquisition during corn breeding. To solve this problem, an automatic testing system for corn was developed. This system is consist of corn ear testing unit, automatic threshing unit, corn kernels testing unit, post-processing unit and system control unit. Corn ear testing unit contains four cameras as well as a weighting sensor, which can measure corn ear parameters such as ear weight, ear length, ear width, ear row number, grains per row, bare tip size, et al. automatically. Corn kernels testing unit measures corn kernels parameters including kernel color, kernel width, kernel length, kernel shape, kernel number, et al. based on computer vision technology after kernels were spreading out by a vibrating mechanism. Post-processing unit can lift kernels to a fixed height, packaging the kernels and print a label contains corn ear and corn kernel parameters. An industrial control tablet combined with I/O module were chosen for the system control unit, receiving sensing information and feedback to control the device. Results of experiment showed that the prototype can realize the whole testing process for corn, includes ear parameters measuring, ear threshing, kernel parameters measuring, kernel lifting, kernel packaging and label printing automatically. The average efficiency of the prototype was up to 4 ear/minute, the average measurement accuracy for ear length and ear width is up to 98.93% and 97.71%, the average accuracy of kernel number is up to 99.11%, which can improve the efficiency of corn breeding obviously.

1 INTRODUCTION

Corn breeding affects the quality and yield of corn. Therefore, measurements of corn parameters determine directly the quality evaluation and selection of breeding materials (LIU Guanyi, 2013). These parameters include ear weight, length, and thickness; ear row number; row kernel grain number; and corn kernel number, length, width, type, color, moisture, and volume weight (Cao Jinghua, 2011). Parameters that measure efficiency and accuracy are key factors restricting breeding efficiency.

With the development of information technology, machine vision and digital image processing technologies have been used in the detection and classification of agricultural products on a large scale (WANG Qiao, 2017; Nayak R K, 2015; C.Igathinathane, 2009; Cao Weishi, 2012). An increasing number of scholars have studied the parameter extraction method of corn ears or corn kernels (Liu Changqing, 2014; Ma Qin, 2012; Wang Chuanyu, 2013; Zhang Fan, 2015; Zhou Jinhui, 2015; Wang Huihui, 2010; Lü Yongchun,2010), but only a few have studied the design and realization of the automatic testing system. Wang et al.(2015) developed a maize kernel trait extraction system to realize the measurement of total kernel number, long and short axes, and length-width ratio through a line-scan camera. The average measured efficiency of the system is 12 s per ear. Xiao et al. (2015) designed an automatic assembly line organization to measure corn parameters and performed virtual modeling and simulation to discuss the feasibility of the assembly line processing for corn ear measuring. Wu et al. (2016) designed an automatic corn ear testing system to realize the automatic corn ear feeding, sorting, image collection and analysis and automatic weighing.

Existing corn testing devices and methods measure corn ears and kernels separately rather than simultaneously, thereby slowing down the process of testing a large amount of breeding materials. The high-throughput automatic corn measuring device designed in the study realizes the rapid,

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comprehensive, and automatic acquisition of testing parameters from corn ears to kernels, greatly reducing the human cost for testing and improving breeding efficiency. Thus, this system is of great significance in enhancement of breeding efficiency.

2 OVERALL SCHEME DESIGN OF THE SYSTEM

An automatic corn testing system was designed to realize the composite measurement of the parameters of corn ears and kernels. The modular design is adopted to divide the automatic measuring device into five parts according to their function, namely, corn ear testing unit, ear threshing unit, corn kernel testing unit, kernel post-processing unit, and system control unit. The ear testing unit uses weighing sensor to measure ear weight, uses multiple cameras to take corn ear images for analysis and acquire the main parameters of corn ear, including ear weight, ear length, ear width, ear row number, row kernel number, bare tip size. The ear threshing unit enables automatic ear threshing and impurity removal after ear testing. The kernel testing unit vibrates the threshed kernels to avoid large-area adhesion and accumulation. It also analyzes kernel images and acquires kernel number, length, width, type, and color. The kernel post-processing unit includes pneumatic hoisting mechanism, automatic packaging mechanism, and 2D code label printing system. This unit prints 2D code labels first before ascending corn kernels to a certain height and encapsulating them. The 2D code labels contain all measured information of the corresponding ear. The system control unit ensures that the entire system is running orderly, stably, and automatically. The Principle of the automatic testing system for corn is shown in Fig. 1.

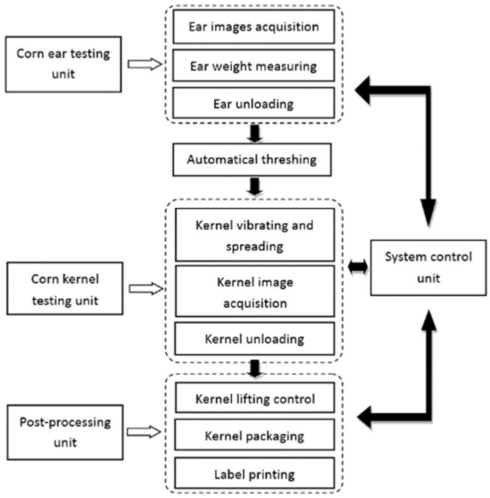


Fig.1 Principle of automatic testing system for corn

3 KEY UNIT DESIGN

The automatic testing system is mainly composed of corn ear testing unit, automatic threshing unit, corn kernel testing unit, post-processing unit and system control unit. A thresher for single ear from Canada is chosen for the core of automatic threshing unit, threshing efficiency can up to 3~5 s/ear, with low breakage. For post-processing unit, a vacuum suction machine was used to lifting kernels, which can ensure the lifting process without mixture between neighboring corn. Thus, the key elements of the system include core ear testing unit, corn kernel testing unit and system control unit.

3.1 Corn Ear Testing Unit

Corn ear parameters include ear weight, ear length, ear width, ear row number, row kernel number, bare tip size, average kernel thickness, and ear color. To ensure that the ear testing unit can adapt to the detection requirements of various forms of corn ears and provide consideration to the precision and speed of ear testing in the automatic testing process, the ear testing unit structure is designed, as shown in Fig. 2.

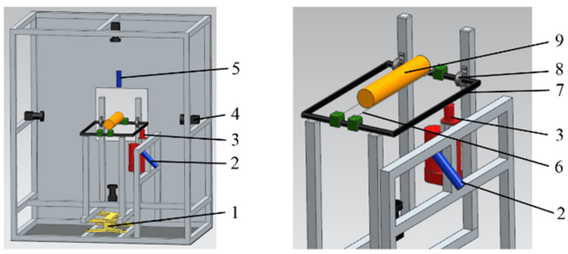


Fig.2 Structure of corn ear testing unit

1.Weighing sensor 2.Ear loading sensor 3.Ear unloading motor 4.Cameras for ear images 5.Ear unloading sensor 6. Load bearing steel wire 7. Corn ear carrying device 8.bearing bracket 9.Sample under test

Ear testing unit mainly includes weighing sensor, cameras, and ear bearing mechanism, the ear bearing mechanism consists of a bearing bracket and an ear bearing device. The whole ear bearing mechanism is placed above the weighing senor with a range of 0~10 kg and a precision of 0.1 g. The ear bearing device adopts two Tungsten wires with high hardness and a diameter of 1.5 mm. Those two wires are installed in parallel with adjustable space. During work, the sample ear is placed above two wires. Four high-resolution color cameras are evenly distributed around the ear with an interval of 90° to acquire corn ear images in four directions. In this study, ear images are taken using a high-resolution color CMOS industrial digital camera and the lens with a focal length of 5 mm. In addition, four 12 V bar LED white light sources are distributed in the middle of the adjacent cameras to guarantee uniform illumination. Ear loading sensor detects ear feeding, which triggers four cameras to acquire ear images and record ear weights simultaneously. Then, ear unloading motor drives the ear carrying device to revolve round the axis. The ears slide down to the threshing unit under the effect of gravity, which resets both the unloading motor and the bearing device, waiting for the feeding of the next ear. The ear unloading sensor is installed at the discharge outlet to detect whether the corn ear is successfully discharged to the kernel threshing unit.

3.2 Kernel Testing Unit

When the testing system works, corn kernels after being threshed and cleaned are randomly scattered in the kernel testing unit under the effect of gravity. At this time, the industrial camera is used to acquire kernel images and then obtain the kernel parameters, including kernel number, kernel shape, length, width, and color. Corn kernels, which are scattered in the kernel testing unit after being threshed and cleaned, are easily adhered and accumulated. Thus, guaranteeing the accuracy of the kernel parameters is difficult if the images to process are directly acquired. To solve the problem, the kernel testing unit consists of three parts: (1) image acquisition device for collecting kernel images; (2) automatic spreading mechanism for reducing kernel adhesion and accumulation and obtaining high-quality kernel images; and (3) kernel discharging mechanism for ensuring the smooth implementation of high-throughput assembly line operation and allowing the discharge of kernels whose test parameters have been measured into the next link. The structure of the kernel testing unit is shown in Fig. 3.

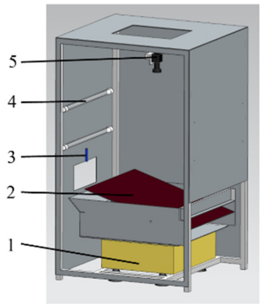


Fig.3 Structure of corn kernels testing unit

1. Vibration platform 2. Kernel layer board 3. Threshing unload sensor 4. Strip source 5. Camera for kernels image

The camera of the kernel image acquisition device adopts a high-resolution color CMOS industrial digital camera. The CMOS size of the camera is 1/2.5 inch with an imaging resolution of 2592 × 1944 pixels. After the test, the corn kernel distribution area is designed to 50 cm × 40 cm to improve the pixel utilization rate of the camera and meet the testing demands of single-corn ear kernels of different specifications.

The automatic spreading mechanism vibrates the plate containing corn kernels under the drive of the vibrating platform before the acquisition of corn kernel images to avoid corn kernel accumulation. After spreading, it triggers the camera to acquire kernel images. The kernel discharging mechanism uses the linear motor to drive the kernel plate to form a certain angle and make the kernels slide down under the effect of gravity.

3.3 System Control Unit

The Kunluntongtai TPC7062K industrial control tablet and the Modbus input–output module comprise the control system. The Modbus module uses the RS485/RS232-based Modbus RTU standard communication protocol with 16 photoelectric isolating switch input channels and 16 photoelectric isolating relay output channels.

After corn ear feeding, the ear loading and unloading sensors are installed at the ear processing unit, the kernel threshing detection senor at the outlet of the threshing unit, and the kernel discharging sensor at the outlet of the kernel testing unit. This procedure realizes the automation of ear image acquisition and analysis, discharging, kernel threshing and spreading, kernel image acquisition and analysis, as well as lifting, packaging and label printing. The output signals of the sensors are all switch quantities, which are taken as the input signals to control the testing system according to the designed logic and time sequence. The overall design of the control system is shown in Fig. 4.

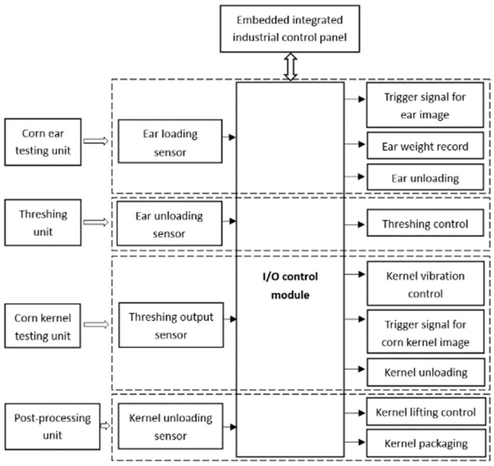


Fig.4 Overall design of control system

The system uses four input signal terminals and 12 output signal terminals. In addition, it is comprised of three sets of mechanical switches, namely, system power-on, control system start/stop, and power system emergency shutdown. The input-output signal terminal configuration of the control module is shown in Table 1.

Table 1 I/O ports configuration of control module

Name	Port channel	Signal connected
Input port	10001	Ear loading sensor
	10002	Ear unloading sensor
	10003	Threshing output sensor
	10004	Kernel unloading sensor
Output port	00001	Motor for ear unloading(extending)
	00002	Motor for ear unloading(restoration)
	00003	Signal for ear image acquisition
	00004	Start stop signal of threshing
	00005	Signal of kernel vibration platform
	00006	Motor for kernel unloading(extending)
	00007	Motor for kernel unloading (restoration)
	00008	Signal for kernel image acquisition
	00009	Start stop signal of lifting device
	00010	Kernel unloading signal after lifting
	00011	Packaging signal
	00012	Barcode printing signal

When the power is turned on, the control system starts and the device completes initialization to wait for ear feeding. Ear loading sensor detects the ear information and then judges the kernel discharging state of the last ear. If the last ear's kernel is discharging or already discharged successfully, the ear weight is read from the weighing sensor. At the same time, four cameras are triggered to collect the ear images from four angles. If the last ear's kernel has not discharged kernels yet, the mechanism waits. The kernel process of the last ear must be completed when the current ear threshes kernels to avoid the mixture of kernels on adjacent ears during measuring. The acquired ear images are processed to extract ear parameters. On the contrary, the ears are discharged to reset the weighing sensor. When the ear discharging sensor detects the entry of ears into the thresher, the thresher starts to thresh corn kernels. At this time, the threshed kernels are scattered in the kernel testing unit. When detecting the scattering of kernels at the outlet of the thresher, the vibration spreading mechanism vibrates until the threshing is completed to avoid large-area kernel adhesion and accumulation. The camera of the kernel testing unit is triggered to collect kernel images, which are then processed. At the same time, the kernels are discharged and the fan of the pneumatic lifting device starts to lift the kernels to the specified height and package them. After processing the kernel images and obtaining the kernel test information, the ear test 2D code is automatically printed and the test parameters of the corresponding ears and kernels are written into the 2D code. The system control process is shown in the figure below.

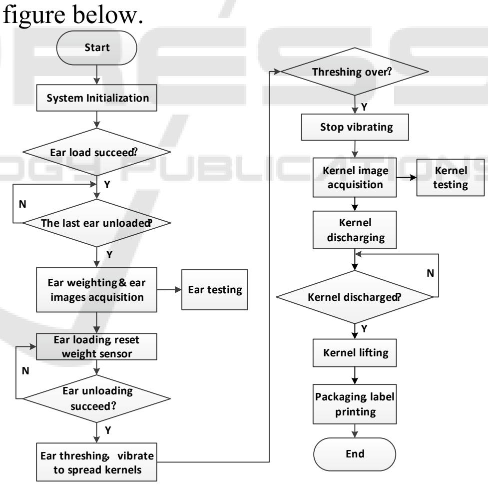


Fig.5 The flow chart of system control

4 EXPERIMENT AND ANALYSIS

The automatic testing system for corn was built according to the design shown in Fig. 6. Then, the corn testing experiment was carried out. Test samples were composed of the corns harvested in Hainan breeding base of Liaoning Dongya Seed Industry Co., Ltd.

Fig.6 The prototype

4.1 System Operation Test

During the test, the total time consumed for a single corn ear from artificial feeding to kernel packaging was recorded. Twenty ears were randomly selected. Statistical results showed that the average time was 27.2 s per ear.

On this basis, 50, 100, and 150 corn ears were randomly selected for the experiments. Three runs of experiments were conducted to verify the stability and operation speed of the system. In each group of test, the ears were fed continuously. In other words, when the last corn ear was discharged automatically and the ear bearing mechanism was reset, the next one was fed rapidly. The total time from feeding the first ear to packaging the last one in each group of samples was recorded.

Then, the average time consumed for single corn ear test during the continuous operation of the system was

$t = (T - \Delta t) / (N - 1)$, where T is the total time consumed for the test of each group of samples; Δt is the whole process time consumed by a single ear, having a constant of 27.2;
and N is the total number of samples.

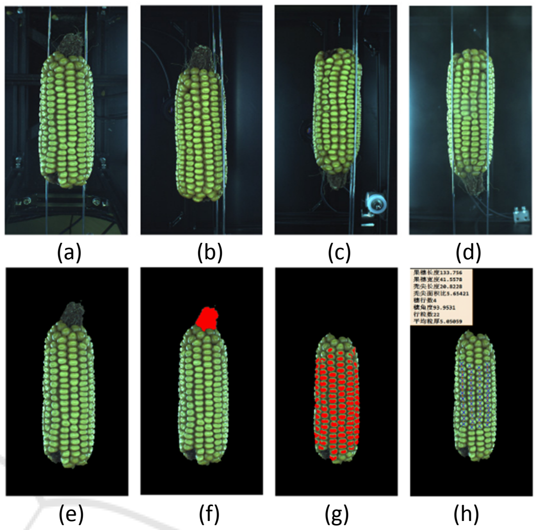
Table 2 Processing efficiency at continuous mode

No.	Sample number	Total time consuming/s	Processing effiency/(Ear·min^{-1})
1	50	759.5	4
2	100	1490.4	4
3	150	2231.3	4

The results show that the average efficiency of the prototype was up to 4 ear/minute, which can improve the efficiency of corn breeding obviously.

4.2 Ear Testing Experiment

Among ear testing parameters, except the ear weight that was acquired by the weighing sensor, other parameters such as ear length, ear diameter, bare tip size, ear row number, row kernel number, kernel thickness, and ear color were obtained by four cameras from four angles. The ears were placed between two high-strength steel wires. Thus, four original ear images were obtained by four cameras of the system, which are shown below.



(a)Original image of Cam. 1 (b)Original image of Cam. 2 (c)Original image of Cam. 3 (d)Original image of Cam. 4 (e)Background removal for Fig.8(a) (f)bare tip extract for Fig.7(a) (g)kernel extract for Fig.7(a) (h)kernel track for Fig.7(a)

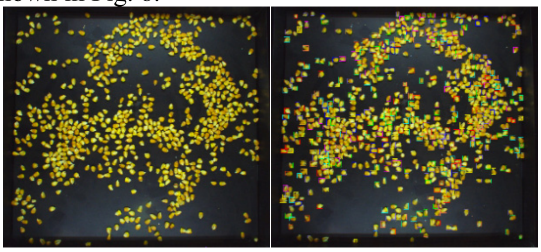
Fig.7 Images of corn ear and the processing results

Table 3 Results for corn ear testing

Sample No.	Ear length			Ear width			Ear rows	
	Measu-red manual-ly/mm	Measu-red by system/ mm	Accu-racy/ %	Measu-red manual ly/mm	Measu-red by system/ mm	Accu-racy/ %	Measu-red manually /mm	Measu-red by system/ mm
1	131.68	133.76	98.44	40.36	40.48	99.70	14	14
2	121.02	122.97	98.41	38.52	39.49	97.54	14	12
3	95.74	96.85	98.85	35.42	36.88	96.04	16	16
4	108.32	109.26	99.14	41.86	43.07	97.19	16	16
5	117.36	119.39	98.30	45.26	46.52	97.29	16	16
6	145.62	147.08	99.01	40.78	41.52	98.22	16	16
7	168.34	169.97	99.04	49.70	51.34	96.81	18	18
8	108.94	109.56	99.43	42.68	43.53	98.05	14	14
9	73.48	73.92	99.40	31.26	31.48	99.30	12	12
10	97.88	98.24	99.63	41.28	42.36	97.45	14	14
Average	1168.38	1181	98.93	407.12	416.67	97.71	150	148

4.3 Kernel Testing Experiment

After background removal and separation of adhered kernels, the original images obtained in the corn kernel testing unit were analyzed. Single kernels were studied to measure kernel number, kernel type, kernel length, kernel width, and other testing parameters. The original kernel images obtained by the automatic testing device and the kernel separation results are shown in Fig. 8.



(a)Original kernel image (b) Segment result

Fig. 8 Image of corn kernels and the processing result

Table 4 Results of maize kernel number measuring

No.	Measured manually	Measured by system	Accuracy/%
1	351	344	98.01
2	424	419	98.82
3	505	499	98.81
4	318	316	99.37
5	492	487	98.98
6	276	276	100.00
7	532	530	99.62
8	582	577	99.14
9	429	428	99.77
10	367	362	98.64
Average	4276	4238	99.11

5 CONCLUSIONS

An automatic testing system for corn was designed in this study to realize corn ear testing, automatic threshing, kernel testing, automatic packaging, 2D code generation and printing. On this basis, a prototype machine was developed to test the stability and efficiency of the system. Experimental results showed that the automatic testing system could automatically acquire various parameters involved in the corn ear and kernel testing process. The average efficiency of the prototype was up to 4 ear/minute. The average measurement accuracy for ear length and ear width is up to 98.93% and 97.71%. The average accuracy of kernel number is up to 99.11%.These results indicate that the system can greatly improve the corn breeding efficiency.

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