Design and experiment of high-throughput maize ear analysis platform

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Abstract: At present, the most maize ear analysis platforms usually acquire the holographic images of ear by maize rotation shot, image mosaic or 3D reconstruction. There are problems such as high cost, complex computation, long time consuming about the above ear analysis platforms. Aiming at the above problems, the high-throughput maize ear analysis platform was constructed in this paper. The pipelining platform was composed of ear separation module (structure large batch ears to single ear vertically aligned), first level measurement module (acquire two-dimensional image and measure), second level measurement module (acquire multi-angle snap shot on freely falling ear and 3D measure) and recycling screening module (recover and screen ears). The 2D phenotypic traits (ear length, ear diameter, etc.) computed from the first level module were combined with the 3D visual measurement (ear row number, row grains, lack of grain yield, etc.) to restructure the 3D trait information of the ear in the second level measurement module. In the second level measurement module, drop snap shot method is used to acquire all-dimensional information of maize ear. And the 3D depth information of maize ear was computed and computational complexity was reduced greatly under the absence of additional fixed points. Finally, taking the hybrid maize as test object, the pipelining platform didn't need to carry out multiple images continuous scanning and stitching and reduced the computational complexity greatly. And the single channel measurement speed can reach 40 spike per minute. The accuracy of 2D parameters is more than 97.5%. The accuracy of 3D parameters, such as row number, the error is less two grains. This platform provides the basic data for the automated, high-throughput pipelines for maize ear analysis.

Keywords: maize ear, analysis platform, high throughput, holographic phenotypic trait

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1 Introduction

Maize is one of the most important crops in the world (Huang, 2010) and its planting area is third only to the wheat and rice. A lot of researches show that the maize ear analysis has an important meaning for maize new variety breeding, genetic study, and cultivar identification (Chen, 2012; Li et al., 2010; Panigrahi et al., 1995). So maize variety test is the main means for acquiring the phenotypic traits (Yang et al., 2010). The traditional manual measurement is inefficient and restricts the development of maize seed industry for the complex phenotypic traits of maize (Ma et al., 2012; Zhou et al., 2015). In recent years, the automatic analysis platform of maize ear has played a huge role in modern seed industry (Bi et al., 2011). For the maize ear's irregular shape (space rotating body) and uneven growth, the phenotypic trait (ear row number, bare tip rate, lack of grain yield, ear length, etc.) acquisition device of ear needs to meet the high-throughput and all-dimensional requirements. In order to enhance the efficiency and accuracy of maize variety test, many scholars have researched the high-throughput method to acquire the all-dimensional phenotypic traits and achieved some research results (Liu,

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Niu, et al., 2013; Qi et al., 2011; Wiendahl and Rybarczyk, 2003; Chang, 2009; Hausmann et al., 2009).

Wang et al. (2013, 2015) proposed an automatic and rapid 3D reconstruction method of maize ear based on the computer vision. In this paper, the maize ear was rotated in a proper angle interval to acquire the images in different view. And the point cloud of maize ear surface with binocular stereovision was calculated. The final 3D shape of maize ear was reconstructed by the point cloud of different views after removing error treatment. He also used the panoramic photography to make image fusion and create the ear panoramas by rotating maize sequence images. But the processing time is longer. Li et al. (2014) used two uniformly rotating rollers and line scan camera to acquire all-dimensional information of maize ear. But the hardware equipment is complex and time-consuming. In addition, Liu, Yang, et al. (2013), and Liu and Chen (2014) have proposed an implementation of the maize rotation shot method. And flat mirror imaging method (Bi et al., 2011) and transparent partition method are used to automatically acquire the holographic images of ear program. In addition, some foreign researchers (Alley et al., 2012; Brumback et al., 2016; Davis, 2016) developed a number of high-throughput ear sorting device can provide reference for this article. Such as Davis et al. (2016) proposed an optical robotic sorting apparatus for identifying and ting the maize ear. And the robotic sorter sorts at a rate of approximately 90 picks per minute.

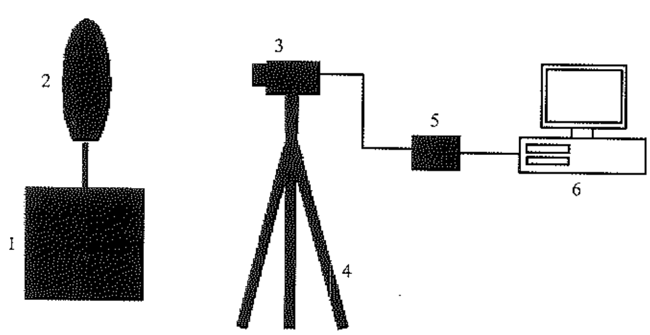
In conclusion, the most maize ear analysis platforms usually acquire the holographic images of ear by maize rotation shot, image mosaic or 3D reconstruction. There are problems such as high cost, complex hardware devices, complex computation, long time consuming about the above ear analysis platforms, which can't meet the requirements of high-throughput maize varieties test. In foreign countries, most of the corn ear images are acquired from the pipeline. Aiming at the above problems, the low-cost, high-throughput maize ear analysis platform with 2D and 3D phenotypic measurements was constructed for acquiring all-dimensional phenotypic traits and reducing complex computation in this paper. This platform was composed of ear separation module (structure large batch ears to single ear vertically aligned), first level measurement module (acquire two-dimensional image and measure), second level measurement module (acquire multi-angle snap shot on freely falling ear and 3D measure) and recycling screening module (recover and screen ears). The pipelining platform will play important significance for achieving high-throughput assessment and accuracy breeding.

2 Materials and method

2.1 Comparison of all-dimensional imaging method

In order to better meet the high-throughput and low-cost requirements of the maize ear analysis platform, this paper makes a comparative analysis of the following three kinds of commonly used maize ear all-dimensional imaging method.

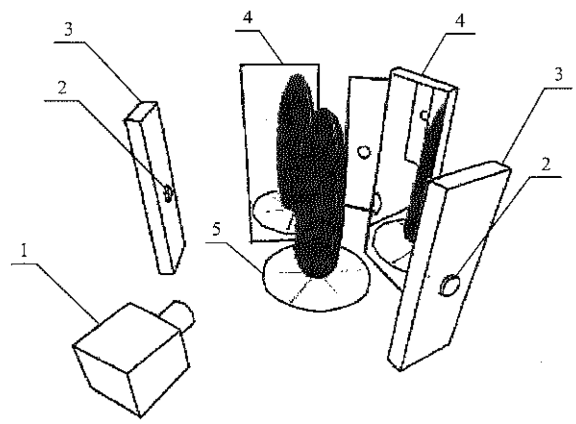
With regard to the maize rotation shot method, it can accurately collect the image of the all-dimensional information. And in the control of the rotational speed and scanning speed, the collected images can be ignored distortion. Then, the rotation shot takes a long time, resulting in an increase in the average measurement time of the ear. Such as the single ear measurement time in Liu, Yang, et al. (2013) is 30 seconds, and the time in Liu and Chen (2014) is 102 seconds, in Wang et al. (2013) is about 40 seconds. It can be seen that the use of this method can not meet the needs of high-throughput maize ear analysis measurement. The maize rotation shot method prototype is shown in Figure 1.



1. Rotating test platform 2. Sample maize ear 3. Binocular camera 4. Tripod 5. Image grabber 6. Computer

Figure 1 Prototype of the maize rotation shot method

With regard to the flat mirror imaging method, the size and location of the mirror is very important. In order to obtain the all-dimensional information, the ear can only take standing posture, which the ear need to be inserted in the fixed position of the thimble. As a result, the mechanical design complexity of the equipment is greatly improved and the degree of automation is low. Also, the maize ear is damaged. The flat mirror imaging method prototype is shown in Figure 2.



1. Image acquisition unit 2. Boundary light source 3. Boundary light source 4. The flat mirror 5. Tray

Figure 2 Prototype of the e flat mirror imaging method

For the transparent partition method, our paper has made the following analysis on the feasibility of this method.

First of all, the glass plate was selected as the transparent partition, and then made a measurement. In this device, the maize ear was placed on the transparent glass plate, and the upper and lower sides of the camera on both sides of the ear to collect the images. After the acquisition is complete, if the two sides of the information is not enough to reflect the 360° all-dimensional information, you can add the camera to two at the top, and the camera below the ear does not change. The three cameras are captured an image at an angle of 120° from three directions. After a large number of experimental analysis, the acquisition method has the following problems:

1. The environmental illumination arrangement is high, especially when multiple cameras are used for collection. If the location of the illumination is not appropriate, there will be a large area of light spot in the imaging results due to the specular reflection, which will affect the image processing result.

2. Durability is not good. After several maize ear measurements, it is easy to adhere to silk and dust on the glass plate. Or the ear may scratch the glass plate, causing a decrease in the transmittance of the glass plate. And this resulted in the accuracy of the measurement reduced.

3. A long time is needed to place the ear in stable state.

In order to improve the above scheme, prevent the occurrence of a large area of light spot and debris deposition, we used a 0.1 mm transparent organic nylon rope net to replace the transparent glass plate. The prototype of the transparent net test device picture is shown in Figure 3.

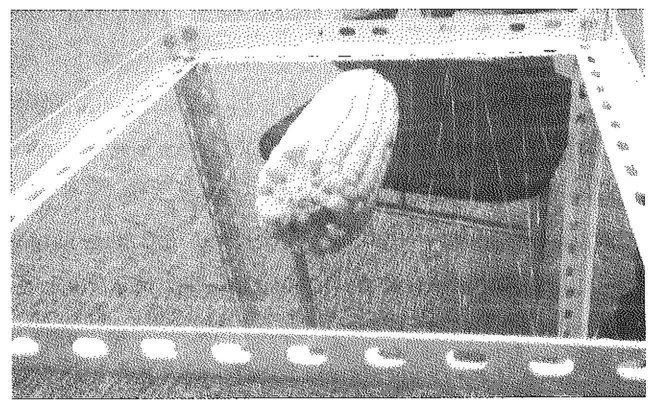


Figure 3 Prototype of the transparent net test device

With this method, the light layout requirement is lower, and there is no need to worry about the large area of light spot. And it doesn't pile up the silk and dust due to the long time use. However, depending on the tension and endurance of the silk thread, the different quality of the ear will cause different degrees of sedimentation. This resulted in the 2D calibration difficult to predict the error. And compared with the glass plate program, the assembly is more difficult. And this did not solve the complexity of the mechanical device and time-consuming issues. This can't meet the needs of high-throughput maize ear analysis accurately.

At present, the use of image processing methods have been able to achieve real-time processing requirements, such as Lie and Lei (2008) completed the automatic emerged corn plant spacing measurement of real-time crop row image reconstruction, Pearson (2009) completed a real-time detection and separation of grains with slight color differences or small defects. Besides, Xu and Zhao (2010) used machine-vision technology to grade strawberries, achieved the automation function. Therefore, the maize ear analysis platform should be able to meet the demands of disposable batch feeding and getting all-dimensional information of maize ear. In addition, it should be fast and accurate as possible. So the pipelining platform was composed of ear separation module (structure large batch ears to single ear vertically aligned), first level measurement module (acquire two-dimensional image and measure), second level measurement module (acquire multi-angle snap shot on freely falling ear and 3D measure) and recycling screening module (recover and screen maize ears). The design line diagram of entire platform is shown in Figure 4. The prototype of the entire test platform picture is shown in Figure 5.

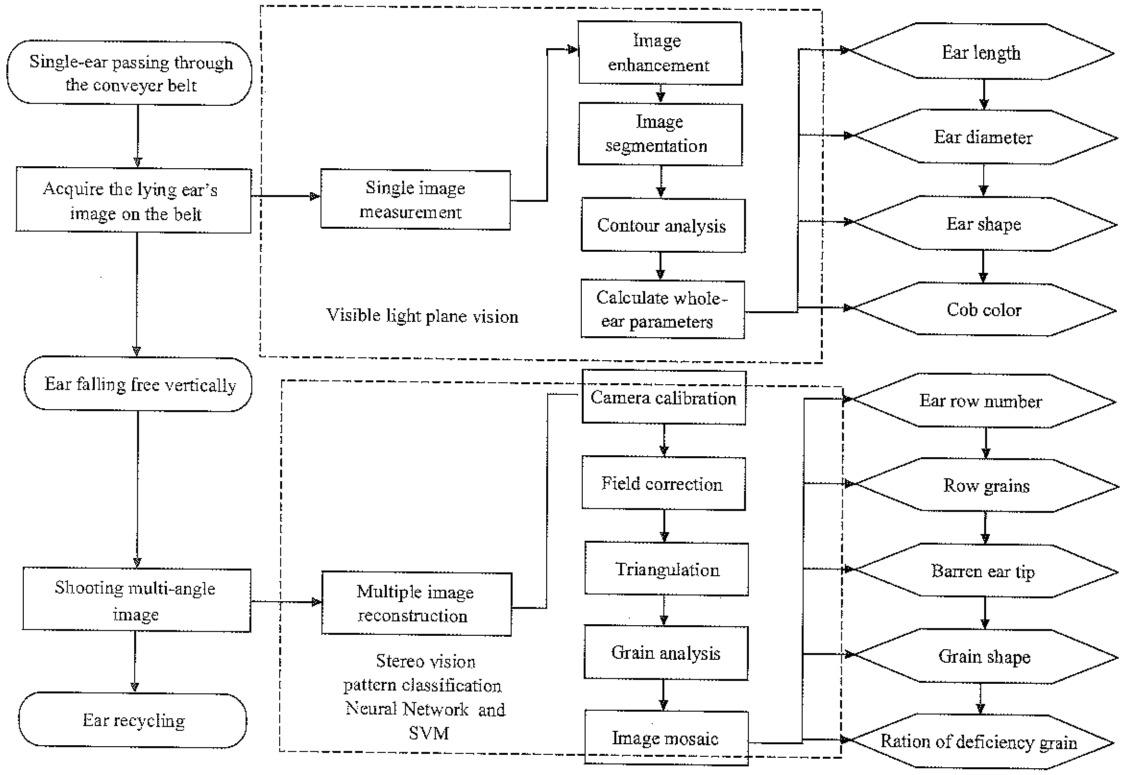


Figure 4 Design line diagram of high-throughput maize ear analysis platform

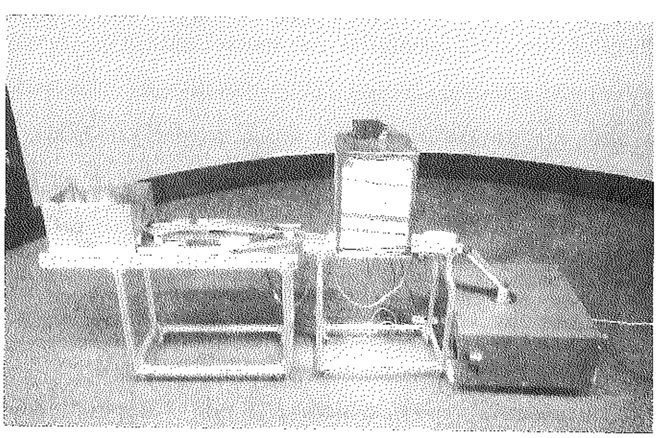
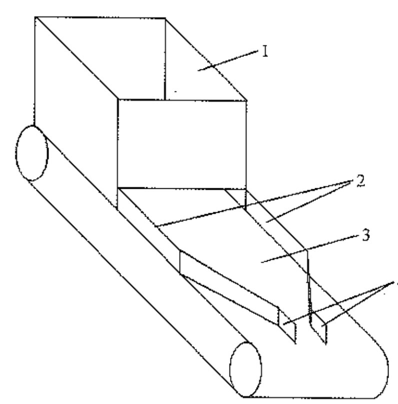


Figure 5 Prototype of high-throughput maize ear analysis platform



1. Feed inlet 2. Protecting sidewall 3. Wide conveyor belt 4. Folding sidewall

Figure 6 Design of ear separation module

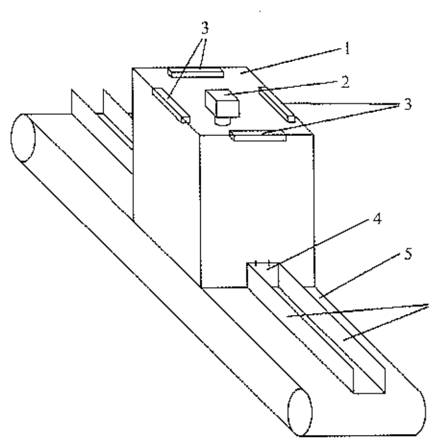
2.2 Ear separation module

Ear separation module is designed to implement the requirement of structuring large batch ears to single ear vertically aligned. When the whole bag maize ears are poured into feed inlet, the inlet of conveyor belt will stir maize ears into the vertical face one by one and enter next module automatically. The design of ear separation module is shown in Figure 6.

As shown in Figure 6, part 1 is the ear feed inlet with size of 700 mm × 420 mm × 350 mm. The whole bag ears are put into the part 1. And the height of transversal trough in front of feed inlet can only allow a lying ear to pass through. So the device can separate the overlapping ears. Part 2 in Figure 6 is the protecting sidewall, which can prevent the ears from dropping to outside of conveyor belt. Part 3 of figure 6 is the wide conveyor belt and the speed is adjustable, which is responsible for transmitting maize ears. Part 4 is the folding sidewall and its function is to arrange various directions ears to single ear vertically aligned. The width of folding sidewall is 80 mm that only allows one lying ear to pass through vertically. And its furling angle is small to prevent blockage caused by ears piles up here.

2.3 The first level measurement module

The first level measurement module is designed to measure the 2D characterization of the ear. It is composed of a narrow conveyor belt, which only allows single-ear pass vertically. There is a camera fixed above the narrow conveyor belt. Okopnik and Falate (2014) used the DFRobot RB-DFR-49 infrared sensor to detect the passage of corn seeds on the conveyor belt. Therefore, we use the photoelectric door sensor to detect the maize ear. When ear goes through the photoelectric door, the system will capture the 2D image of ear and calculate the essential parameters. And the capturing process is completed in the black box, which is filled light by the light source inside. Then use the color classification algorithm to extract the contours of maize ear, and the ear length and ear diameter are calculated by the minimum enclosing rectangle of the contour. And use the super blue feature extraction algorithm to extract the bare tip of maize ear. The 2D phenotypic traits (ear length, ear diameter, etc.) computed from the first level module were combined with the 3D visual measurement to restore the 3D trait information of the ear in the second level measurement module. The design of the first level measurement module is shown in Figure 7.



1. Collection black box 2. CCD camera 3. Strip light source 4. Mobile gate 5. Narrow conveyor belt 6. Protecting sidewall

Figure 7 Design of first level measurement module

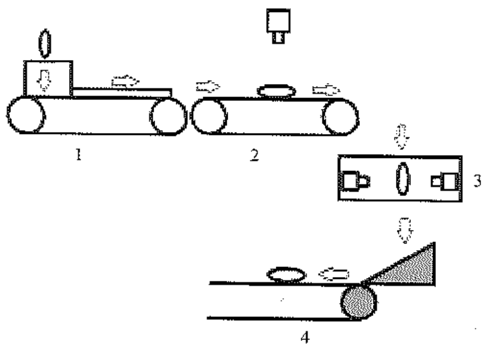
As is shown in Figure 7, the first level measurement module is composed of two parts: black box and conveyor belt. Part 1 of Figure 7 is the collection black box (460 mm × 420 mm × 670 mm). Part 2 is the charge coupled device (CCD) camera, which is used to acquire the maize ear passing through the black box. Part 3 is the strip light source installed at the top of the black box. In order to achieve no-shadow transparent, four sides of top surface are equipped one strip light source for each. Part 4 is the mobile gate (160 mm × 80 mm), and two sides of the black box are equipped one mobile gate for each. The maize ears pass in and out the black box by passing through mobile gate. The mobile gate is closed when the ear is located in the shotting center to prevent the shotting environment from suffering ambient light. Part 5 is the narrow conveyor belt and its speed is adjustable, which is responsible for transmitting maize ears. Part 6 is the protecting sidewall and its role is to control ears pass through the first level measurement module with vertically position.

2.4 The second level measurement module

After leaving the first level measurement module, the ears will free fall into the second level measurement module. Drop snap shot method is used to acquire all-dimensional information of maize ear. The three high-speed cameras crossed 120° mutually and triggered by photoelectric door will capture the three 2D images of dropping ear to acquire all-dimensional information of ear. The ear falls down very fast during the process, thus the high speed of camera's shutter is needed. In addition, enough supplemental lighting is essential because of the high speed of camera. So the 3D depth information of maize ear can be computed and the computational complexity can be reduced greatly under the absence of additional fixed points.

This paper selects the industrial camera model DH-SV2001GC network interface digital camera with a resolution of 200w pixels. Due to the high-speed industrial cameras installed in the middle of the black box, the movement speed of the corn ear is faster, and the shutter time needs to be adjusted to eliminate the smearing phenomenon. After the experiment to determine the shutter speed is 800 μs.

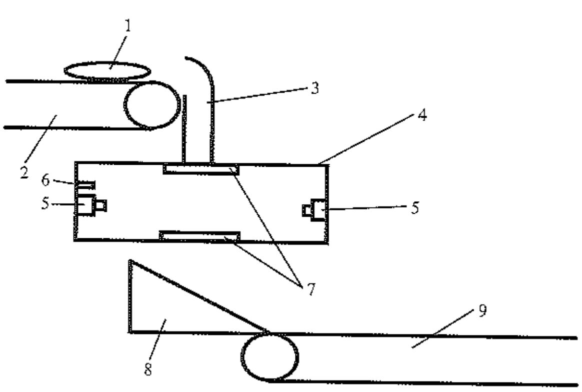
The first and second level measurement modules are the core parts to realize the main platform in the above design. The design of two-level measurement modules is shown in Figure 8.



1. Ear separation module 2. The first level measurement module 3. The second level measurement module 4. Recovery screening module

Figure 8 Design of two-level measurement modules

The design of second level measurement module and recovery screening module are shown in Figure 9. As shown in Figure 9, part 1 is the maize ear and part 2 is the cohesion part between the first level measurement module and the second level measurement module. Part 3 is one vertical cylindrical catheter with 75 mm diameter and 200 mm height, which is designed to adjust the direction of ear to make ear drop vertically. Part 4 is the collection black box of image acquisition. Part 5 is the high-speed CCD camera, and three cameras are in the same horizontal plane and the angle between adjacent cameras is 120°. Part 6 is the infrared obstacle avoidance flip-flop detector, which can transmit signal to the controlled camera for acquiring image while ears passing through. Part 7 is the ring high light led source, which is used to supplement light for the black box. Part 8 and 9 are parts of recovery screening module. Part 8 is sponge slope guideway, which is designed to buffer dropping ears and channel to conveyor belt 9.



1. Maize ear 2. Cohesion department between two-level device 3. Vertical cylindrical catheter 4. Collection black box 5. CCD camera 6. Infrared obstacle avoidance flip-flop detector 7. Ring high-light led source 8. Sponge slope guideway 9. conveyor belt

Figure 9 Design of the second level measurement module and recovery screening module

The detailed design of the second level measurement module is shown in Figure 10. In order to solve the problem that maize ear could stuck inside the catheter when passing through, the catheter is designed to slow down the degree of curve.

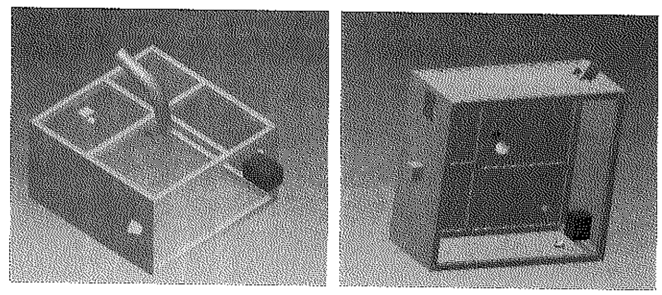


Figure 10 Detailed design of catheter

2.5 Recovery screening module

Ears will drop into recovery screening module after leaving the second level measurement module. Ears will be recovered or classified by parameters, which are calculated in previous modules.

In conclusion, the measurement module will receive the shape and size parameters of the conveyed ear when the second level device operates. And these parameters are transmitted from the first level measurement module. The detected ear will go into the cylindrical duct and finally leave from the catheter with vertical drop. When the infrared obstacle avoidance trigger of the black box detects the ear dropping, it will control three industrial high-speed CCD cameras to capture the images from three views at the same time. Then the computer will calculate the 3D parameters (ear row number, row grains, ration of deficiency grain, etc.) of maize ear according to parallax of three views and parameters obtained from the first level measurement module. The design in this paper has the following advantages:

1. High-speed and high-throughput.

2. The image calculation depth is 2.5D enough without 3D measurement.

3. Measure parameters are obtained from the three views. So it is unnecessary to use so much time to execute 3D reconstruction.

3 Results and discussion

3.1 Construction of experimental platform

In this section, taking the hybrid maize as test object, the high-throughput maize ear analysis platform is tested and evaluated. The most important parts of experimental platform are the camera and light sources.

The first level measurement device needs one camera and four light sources, and the four strip light sources are placed at the top of collection black box. The shooting height of CCD camera is about 450 mm .Under this height, the acquiring image is more accurate and the distortion is smaller. In addition, the conveyor belt is about 80 mm and just allows one single maize ear to pass through vertically. The physical map of first level measurement device is shown in Figure 11.

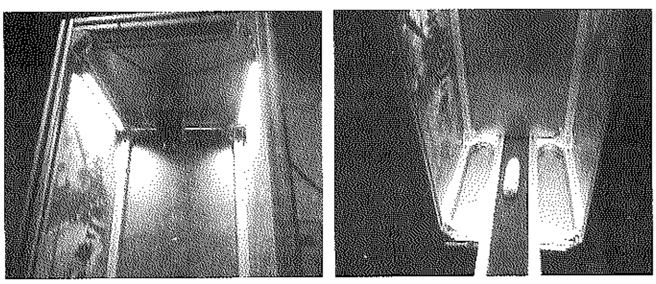


Figure 11 Physical map of the first level device

Then the second level measurement device needs three cameras and eight light sources. And eight strip light sources are placed in the black box, four sources arranged in a ring on the upper side, the others arranged in a ring on the lower side. The lighting directions should point to the intersection of three CCD cameras' measuring sight. The lighting strength of eight strip lights is so stronger to ensure the camera can get enough light to acquire the shape and texture features of maize ear during the short exposure time. Comparing the imaging effects of various conditions, the shooting distance of cameras is determined as 400 mm and the falling distance of maize ear is determined as 300 mm (leave the cylindrical catheter). Based on the above design, the physical map of second level detection module is shown in Figure 12.

After a lot of verification experiments, the pipelining platform can support high precise and efficient maize ear analysis as a practical tool and technical references. The images of maize ear acquired by the device are shown in Figure 13.

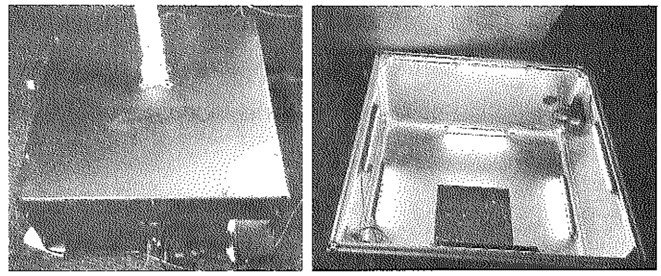


Figure 12 Physical map of second level device

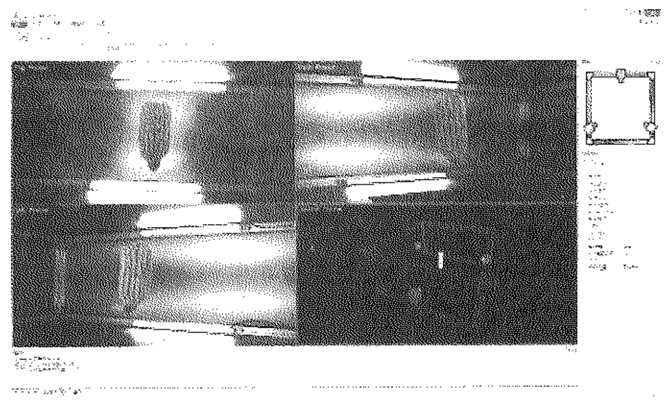


Figure 13 Images of maize ear acquired by the device

3.2 Experimental result analysis

In the stage of the two-dimensional characteristic measurement of the ear, it is mainly for the easy to extract on the single-sided image, and the measurement accuracy of the higher indicators. The parameters measured by the first level measurement module include ear length, ear dimeter, volume, and bare tip positioning and calculation. For the maize ear's irregular shape (space rotating body), some of the phenotypic parameters of the ear need to collect holographic images to calculate accurately. Therefore, it is necessary to measure the phenotype parameters in 3D mode. The parameters measured by the second level measurement module include ear row number, row grains, lack of grain yield and ration of deficiency grain.

In order to verify the measurement precision of length indicators calculated by the first level detection module, 50 maize ears are selected to do precision test with ear length and ear diameter. The test methods are as follows:

1. Randomly select 50 maize ears as the test samples.

2. Acquire image of every maize ear by the first level detection module.

3. Calculate the ear length and ear diameter by every ear image.

4. Measure actual ear length and diameter by vernier caliper.

5. Do data and error analysis.

The error analysis for ear length and ear diameter is shown in Table 1, Figure 14 and Figure 15.

Table 1 Error analysis for ear length and ear diameter

Test parameter	Average error	Maximum error	Minimum error	Standard deviation
Ear length	1.59%	5.77%	0.13%	0.0123
Ear diameter	2.45%	4.04%	0.41%	0.0105

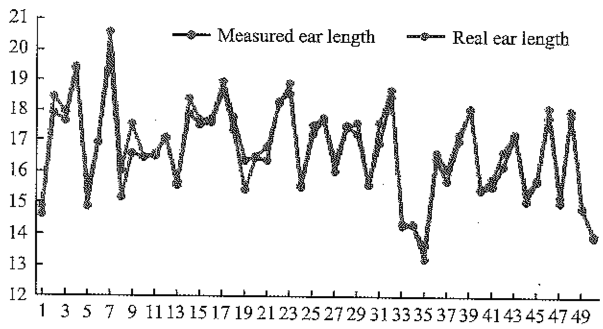


Figure 14 Error analysis for ear length

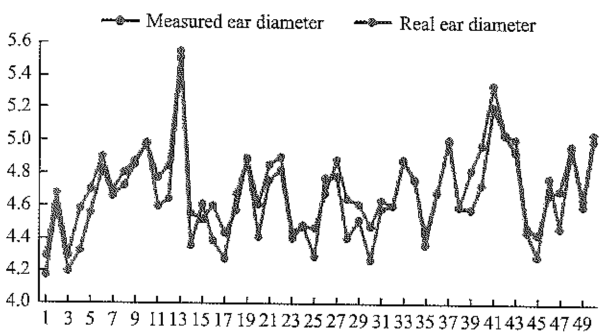


Figure 15 Error analysis for ear diameter

In order to verify the measurement precision of 3D phenotypic traits calculated by the second level detection module, 20 maize ears are selected to do precision test with ear row number and row grains. The test methods are as follows:

1. Randomly select 10 maize ears as the test samples.

2. Acquire images of three views at the same time and extract the ear center of gravity.

3. Substitute into the positive triangulation model to calculate the center of the ear from the three camera shooting center distance.

4. Measure real distance by tape measure.

5. Substitute into the calculation model of ear row number and row grains, and do error analysis.

The error analysis for ear row number and row grains is shown in Table 2, Figure 16 and Figure 17.

The measurement error of row number is multiple of 2 because row number is even. The true value of row number is accurate, so zero error rate should be used to measure accuracy error rate in place. After the test, the zero error rate of row number is 94%. And the grain number per row is less two grains. This pipelining platform can support high precise and efficient maize ear analysis as a practical tool.

Table 2 Error analysis for ear row number and row grains

Serial number	Measured ear row number	Real ear row number	Measured row grains	Real row grains
1	16	16	-28.56	27.67
2	18	18	27.44	28.33
3	18	18	33.13	31.67
4	14	14	31.76	30.33
5	16	16	30.99	29.00
6	16	16	28.38	30.33
7	18	18	32.54	33.33
8	16	16	29.17	30.67
9	18	18	28.66	29.33
10	16	16	31.73	30.00

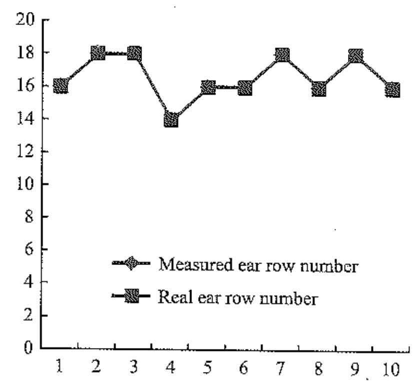


Figure 16 Error analysis for ear row number

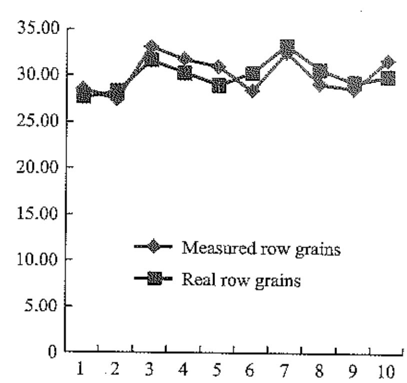


Figure 17 Error analysis for row grains

4 Conclusion

Aiming at these practical problems of high cost, complex computation, long time consuming in modern maize variety test, the high-throughput maize ear analysis platform was constructed in this paper. The pipelining platform realized structure large batch ears to single ear vertically aligned, the 2D phenotypic information (ear length, ear dimeter, bare tip, etc.) measurements and the 3D phenotypic information (ear row number, row grains, lack of grain yield, etc.) measurements. And on the basis of this, the feasibility of the design scheme of the high-throughput maize ear analysis platform was discussed by means of the prototype. In the experiment, the 2D phenotypic traits computed from the first level measurement module were brought into the second level measurement module as the prior knowledge parameters with the hybrid maize as the test object. So the 3D depth information of maize ear was computed under the absence of additional fixed points. The pipelining platform didn't need to carry out multiple images continuous scanning and stitching and reduced the computational complexity greatly. And the single channel measurement speed can reach 40 spike per minute, the accuracy of the two-dimensional measurement of the platform was above 97.5%, basically meet the expected requirements of this article. This pipelining platform provides a new method for realizing high-throughput maize ear analysis. And this paper provides a reference for the automatic, pipelined and intelligent maize ear analysis.

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[References]

[1] Alley, S. E., N. J. Hausmann, C. R. Homan, J. J. Kelsick, and M. L. Parlett. 2012. System and method for presentation of ears of corn for image acquisition and evaluation. US20120260618A1 (In USA).

[2] Bi, K., C. Wang., D. Zhu, J. Wang, and Y. Zhang. 2011. A corn testing device based on machine vision. CN101933417A (In China).

[3] Brumback, T. B., S. J. Corak, J. L. Hunter, and Y. G. Lee. 2016. System and method for sensor-based feedback control of a seed conditioning and production process. US9278377B2 (In USA).

[4] Chang, S. 2009. The design and research of automatic feeding device up and down. *Applied Computer Knowledge and Technology*, 5(28): 8076–8078.

[5] Chen, C. 2012. Effects of plant density on grain yield and relative physiological characteristics of maize elite inbred lines and its derived lines. M. S. thesis, Taian, Shandong: Shandong Agricultural University.

[6] Davis, C. M. 2016. Optical robotic sorting apparatus. US9492848B1 (In USA).

[7] Hausmann, N. J., T. E. Abadie, M. Cooper, H. R. Lafitte, and J. R. Schussler. 2009. Method and system for digital image analysis of maize. WO2009023110A1 (In USA).

[8] Huang, G. P. 2010. Identification of quantitative trait locus and heterosis analysis based on single segment substitution lines of yield trait in maize. M. A. thesis. Zhengzhou, Henan: Henan Agricultural University.

[9] Li, H., G. Liu, and P. Liu. 2014. A detection device of maize varieties test. CN103004322B (In China).

[10] Li, X., M. Cheng, Y. Wang and M. Guo. 2010. Study on maize yield and its ear characters under water-limited conditions. *Journal of China Agricultural University*, 15(4): 8–12.

[11] Lie, T., and F. T. Lei. 2008. Real-time crop row image reconstruction for automatic emerged corn plant spacing measurement. *Applied Transactions of the ASABE*, 51(3): 1079–1087.

[12] Liu, C., and B. Chen. 2014. Method of image detection for ear of corn based on computer vision. *Transactions of the Chinese Society of Agricultural Engineering*, 30(06): 131–138.

[13] Liu, G., X. Yang, M. Bai, W. Wei, S. Zhang, and H. Li. 2013. Detecting techniques of maize ear characters based on line scan image. *Transactions of the Chinese Society for Agricultural Machinery*, 44(11): 276–280.

[14] Liu, S, K. Niu, Q. Shi, S. Wang, Q. Yuan, and K. Zhang. 2013. Performance experiment of friction conveying device for maize ears. *Transactions of the Chinese Society of Agricultural Engineering*, 29(12): 9–16.

[15] Ma, Q., J. Jiang, D. Zhu, S. Li, S. Mei, and Y. Lv. 2012. Rapid measurement for 3D geometric features of maize ear based on image processing. *Transactions of the Chinese Society of Agricultural Engineering*, 28(1): 208–212.

[16] Okopnik, D. L., and R Falate. 2014. Usage of the DFRobot RB-DFR-49 infrared sensor to detect maize seed passage on a conveyor belt. *Applied Computers and Electronics in Agriculture*, 102(1): 106–111.

[17] Panigrahi. S., M. K. Misra, C. Bern, and S. Marley. 1995. Background segmentation and dimensional measurement of corn germ plasm. *Applied Transactions of the ASAE*, 38(1):

291–297.

[18] Pearson, T. 2009. Hardware-based image processing for high-speed inspection of grains. *Applied Computers and Electronics in Agriculture*, 69(1): 12–18.

[19] Qi, J., S. Zhang, X. Niu, W. Wang, and Y. Xu. 2011. Design and application of yield monitor system for corn ear. *Transactions of the Chinese Society for Agricultural Machinery*, 42(1): 181–185.

[20] Wang, C., X. Guo, S. Wu, B. Xiao, and J. Du. 2013. Investigate maize ear traits using machine vision with panoramic photography. *Transactions of the Chinese Society of Agricultural Engineering*, 29(24): 155–161.

[21] Wang, C., X. Guo, S. Wu, B. Xiao, and J. Du. 2015. Three dimensional reconstruction of maize ear based on computer vision. *Transactions of the Chinese Society for Agricultural Machinery*, 45(9): 274–279.

[22] Wiendahl, H. P., and A. Rybarczyk. 2003. Using air streams for part feeding systems—innovative and reliable solutions for orientation and transport. *Journal of Materials Processing Technology*, 138(1): 189–195.

[23] Xu, L., and Y. Zhao. 2010. Automated strawberry grading system based on image processing. *Applied Computers and Electronics in Agriculture*, 71(1): 32–39.

[24] Yang, J., H. Zhang, J. Hao, T. Du, F. Cui, N. Li, and G. Liang. 2010. Identifying maize cultivars by single characteristics of ears using image analysis. *Applied Transactions of the Chinese Society of Agricultural Engineering*, 27(1): 196–200.

[25] Zhou, J., Q. Ma, D. Zhu, H. Guo, Y. Wang, X. Zhang, S. Li, and Z. liu. 2015. Measurement method for yield component traits of maize based on machine vision. *Transactions of the Chinese Society of Agricultural Engineering*, 31(3): 221–227.