



Development of a whole-feeding and automatic rice thresher for single plant[☆]

Chenglong Huang, Lingfeng Duan, Qian Liu, Wanneng Yang*

Britton Chance Center for Biomedical Photonics, Wuhan National Laboratory for Optoelectronics–Huazhong University of Science and Technology, 1037 Luoyu Rd., Wuhan 430074, PR China

Key Laboratory of Biomedical Photonics of Ministry of Education, Huazhong University of Science and Technology, 1037 Luoyu Rd., Wuhan 430074, PR China

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ABSTRACT

Threshing is an essential pretreatment in rice yield-related traits evaluation and rice thresher is an important study of agricultural machinery automation. However, traditional threshers aim at threshing filled grains with simple function, which are inapplicable to high-precision and automatic yield-related traits evaluation of rice. And the conventional threshing method for the traits evaluation is still manual. To improve it, we developed a whole-feeding and automatic rice thresher for single plant. The thresher adopted a hierarchical multi-roller rolling method to thresh filled and unfilled grains respectively. A fish scale sieve plate was designed to separate the grains from the straw and the whole system was controlled by Programmable Logic Controller (PLC) automatically. To evaluate the threshing system, two batches of rice plants were tested, and the results showed that the thresher had the advantages of high precision, low breakage and no residue. Thus, the thresher provides strong support for high-precision and automatic yield-related traits evaluation of rice.

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1. Introduction

Rice is one of the staple foods in the world and approximately half of the world population feed on it [1]. The aim of rice breeding is always to increase rice yield [2]. Yield-related traits of rice, such as total spikelet number per plant, filled spikelet number per plant, seed-setting rate, thousand kernel weight, grain length and grain width, directly determine its production [3]. However, in order to evaluate the aforementioned traits, threshing is an essential pretreatment. Therefore, it is significant to study on the rice thresher.

Since the machine-vision technique is widely used in agriculture [4,5], more and more automated instruments are actualized for the traits evaluation with the rice samples threshed previously [6]. It is obvious that the procedure of threshing limits the automation and the efficiency of rice traits evaluation to a large degree. Therefore, in order to achieve the purpose, a type of rice thresher with the features of whole-feeding, no residue, and automation is really needed.

Existing paddy threshers for single plant were used to thresh filled grains, the function of which was too simple to serve the needs of high-precision and automatic traits evaluation. Due to the connectivity-force difference between grains and straw, most of the single plant threshers were half-feeding and semiautomatic [7]. Although a great deal of research was done to improve it, the threshing precision and automation were still the vital problems. In practice, the conventional threshing method for rice yield-related traits evaluation is still manual. Therefore, a single plant thresher designed for high-precision and automatic traits evaluation is really desirable.

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* Corresponding author at: Britton Chance Center for Biomedical Photonics, Wuhan National Laboratory for Optoelectronics–Huazhong University of Science and Technology, 1037 Luoyu Rd., Wuhan 430074, PR China. Tel.: +86 27 8779 2033; fax: +86 27 8779 2034.

E-mail address: wannengyang@126.com (W. Yang).

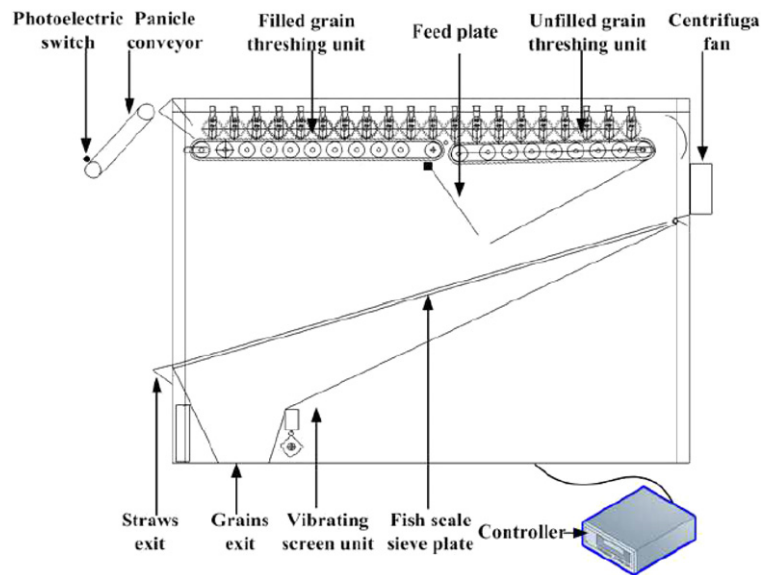


Fig. 1. The schematic drawing of whole-feeding and automatic rice thresher.

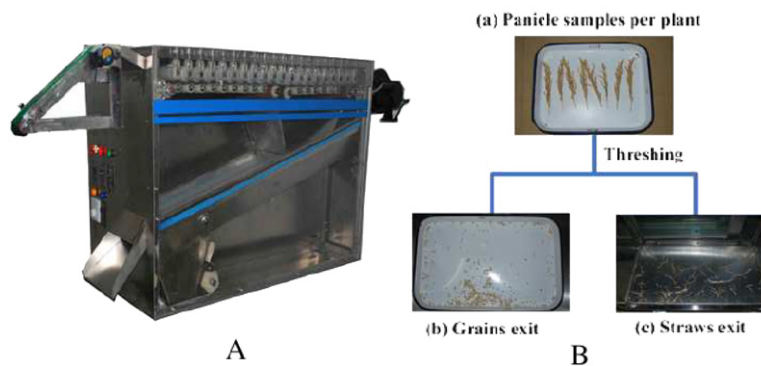


Fig. 2. The prototype (A) and the running results (B) of the whole-feeding and automatic rice thresher.

To achieve it, we designed a hierarchical multi-rollers threshing unit, which could detach filled and unfilled grains from straw with high-precision and this threshing method was applicable to different rice varieties. Moreover, fish scale sieve plate was firstly adopted in single plant thresher and was used to separate the grains from the straw effectively. In addition, the technology of industrial control was applied to realize paddy threshing automation. The objective of this work was to introduce a new kind of single plant rice thresher, which would be widely used in rice yield-related traits evaluation and greatly promote the evaluation efficiency.

2. Materials and methods

2.1. Whole-feeding and automatic rice thresher

The schematic drawing of the thresher is designed as Fig. 1, consisting of photoelectric switch, panicle conveyor, filled grain threshing unit, unfilled grain threshing unit, feed plate, centrifugal fan, fish scale sieve plate, vibrating screen unit and a programmable logic controller (PLC, CP1H-Y20DT-D, Omron, Japan).

The prototype of the whole-feeding and automatic thresher is shown in Fig. 2A and the running results of the thresher are shown in the Fig. 2B. The panicle samples [Fig. 2B(a)] were put on the conveyor in sequence, and the panicles were transmitted into the thresher. Then the filled grain threshing unit threshed the filled grains, which were sent to the fish scale sieve plate through the feed plate. And the unfilled threshing unit threshed unfilled grains. The unfilled grains and straw were transmitted to the fish scale sieve plate too. Next, the vibrating screen unit worked in collaboration with centrifugal fan to separate the straw and grains. Finally, the grains [Fig. 2B(b)] and straw [Fig. 2B(c)] exited at different places respectively.

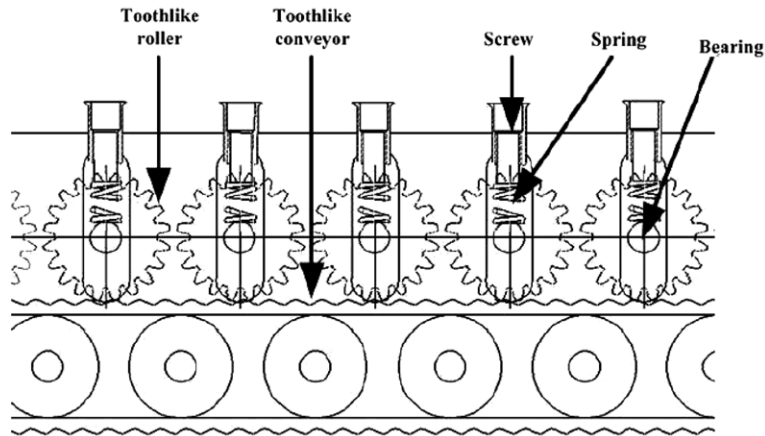


Fig. 3. Details of the threshing unit.

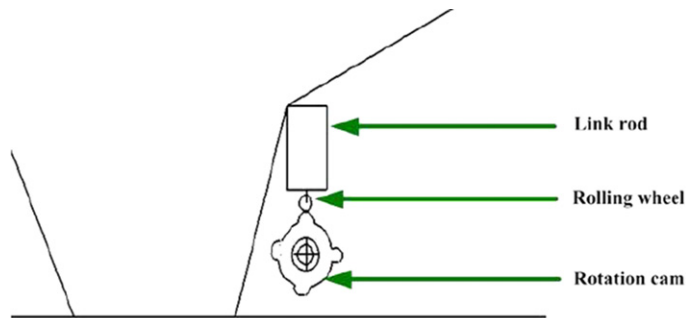


Fig. 4. The cam vibration mechanism.

2.2. Threshing unit

Although various threshing mechanisms were developed, such as axial flow rice thresher [8], and double roller rice thresher, the problem of breakage and separation are serious to satisfy high precision and automatic traits evaluation [9]. To improve it, we developed a new kind of threshing unit, the details of which are shown as Fig. 3. The dentate conveyor ran to drive the dentate roller, and they worked in collaboration to thresh grains. In addition, the pressure between the conveyor and the roller was able to be regulated by adjusting the screw. The threshing unit was generally divided into two stages: filled grain threshing unit and unfilled grain threshing unit. And the pressure in unfilled grain threshing unit was greater than that in filled grain threshing unit. Therefore, this method was able to thresh the grains with high precision and low breakage. Moreover, the thresher was applicable to various rice varieties by adjusting the screw properly.

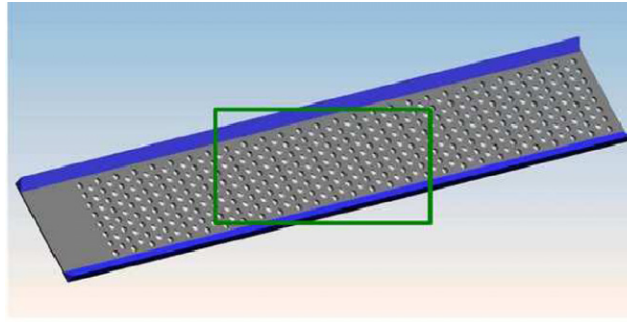
2.3. Sieving unit

The sieving unit in the thresher adopted a kind of cam vibration mechanism, which is shown in Fig. 4. The cam rotated to drive the sieve plate vibratory through the roller wheel and link rod. Besides, it was worth mentioning that the sieve plate was specially designed for grains screening and the holes in the sieve plate were like fish scales, which was shown in Fig. 5.

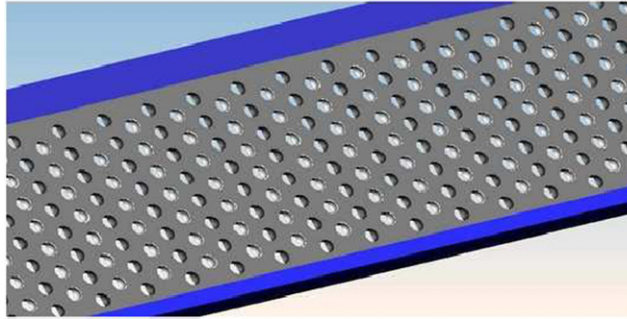
2.4. System control

The work flowchart of the rice thresher is shown in Fig. 6. The whole working process was controlled by PLC. Thus the thresher was able to thresh the paddy and screen the grains automatically. And the workflow of the thresher included following steps:

- (1) Putting the panicles per plant onto the conveyor in a sequence.
- (2) The photoelectric switch sensing, and the controller deciding whether the photoelectric switch effective. If true, PLC disabled the photoelectric switch. If not, PLC did not act and the workflow went to step (5).
- (3) PLC started threshing unit.
- (4) PLC started vibrating unit and centrifugal fan, and they worked in collaboration.
- (5) If the whole plant finished threshing, the next plant began. If not, going to step (1).



(a) 3D rendering of fish scale sieve plate.



(b) Details of fish scale holes.

Fig. 5. Design of the fish scale sieve plate.

3. Results

In order to evaluate the thresher performance, two batches of rice plants (Zhonghua 11, Huageng 295) were tested. And the plant numbers were 101 and 71, respectively. Before tested, the rice plants were dried up in the sun and then the panicles were cut from the plants. And the filled grains, unfilled grains, and broken grains in the straw exit and grains exit p were counted for each plants, respectively.

The threshing results are shown in Fig. 7. The results of threshing loss, filled grains, unfilled grains and broken grains for Zhonghua 11 and Huageng 295 were listed in the figure, respectively.

$$ATLP = \frac{1}{n} \sum_{i=1}^N \frac{x_{li}}{x_{ti}} \quad (1)$$

$$ABGP = \frac{1}{n} \sum_{i=1}^N \frac{x_{bi}}{x_{ti}} \quad (2)$$

$$ATLP_{fg} = \frac{1}{n} \sum_{i=1}^N \frac{x_{fli}}{x_{fti}} \quad (3)$$

$$ATLP_{ug} = \frac{1}{n} \sum_{i=1}^N \frac{x_{uli}}{x_{uti}} \quad (4)$$

where the parameters of x_{li} , x_{ti} , x_{bi} , x_{fli} , x_{fti} , x_{uli} and x_{uti} represent threshing loss number, total grains number, broken grains number, filled grains lost number, filled grains total number, unfilled grains lost number, and unfilled grains total number, respectively.

The result analysis for the two of rice plants is listed in the Table 1. The Average Threshing Loss Percent ($ATLP$), defined by Eq. (1) and Average Broken Grains Percent ($ABGP$) defined by Eq. (2) for Zhonghua 11 were 4.07% and 3.16%, respectively. And the $ATLP$ and $ABGP$ for Huageng 295 were 4.80% and 3.60%, respectively. And the Average Threshing Loss Percent for Filled Grains ($ATLP_{fg}$) defined by Eq. (3) and Average Threshing Loss Percent for Unfilled Grains ($ATLP_{ug}$) defined by Eq. (4), were 2.30% and 6.55% for Zhonghua 11, 2.77% and 9.70% for Huageng 295, respectively.

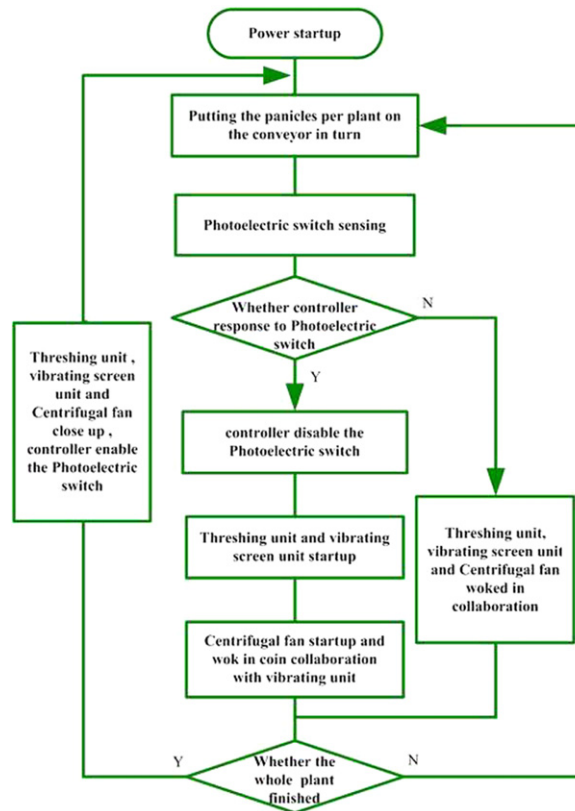


Fig. 6. The work flowchart of the rice thresher.

Table 1

The results analysis for threshing errors.

Rice variety	Plant number	ABGP (%)	ATLP (%)	ATLP _{fg} (%)	ATLP _{ug} (%)
Zhonghua 11	101	3.16	4.07	2.30	6.55
Huageng 295	71	3.60	4.80	2.77	9.70

4. Discussions

4.1. High precision threshing system

The results proved that the thresher generally performed high threshing precision, due to the specifically designed threshing device, in which the threshing units for filled and unfilled grains were separated and the different grains could be threshed respectively with high precision. And it was also demonstrated that the unfilled grains were more difficult to thresh than filled grains due to their characteristics difference. Theoretically grains were able to be threshed exactly by adjusting the screw properly, but the threshing loss and damaged grains were unavoidable in practice. And the threshing loss or threshing breakage was able to be improved by adjusting the screw, but the threshing loss decrease probably increased the threshing breakage. And it was believed the threshing system had an optimum threshing effect on filled grains than unfilled grains, because of the connectivity-force difference between grains and straw. In addition, the experiments also showed that there was no threshing residue in the system, which was crucial to prevent interference for single plant rice traits evaluation.

4.2. High separation threshing system with no residues

The results proved that the thresher generally performed high separation precision, due to the specifically designed threshing sieving unit, in which the fish scale sieve plate was adopted. In addition, centrifugal fan worked with the sieving unit in collaboration to eliminate the threshing residues. The experiments also showed that there was no threshing residue in the system, which was crucial to prevent interference for single plant rice traits evaluation.

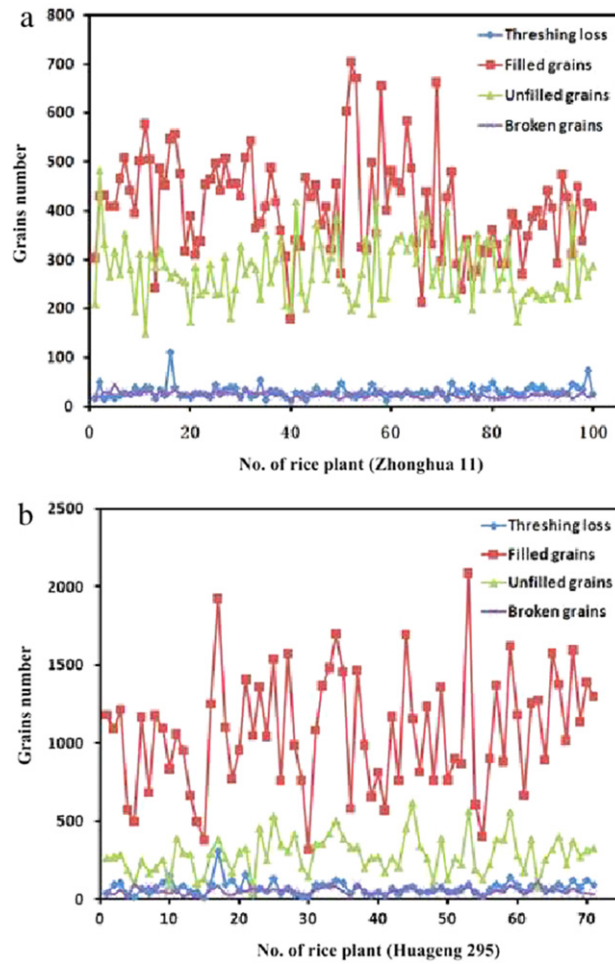


Fig. 7. The threshing results of rice (a) Zhonghua 11 and (b) Huageng 295.

4.3. Automatically threshing system

The entire threshing process was controlled by the PLC and the thresher ran automatically. Generally, it took about 20 s for the thresher to finish a rice plant automatically, which would promote the development for automatic traits evaluation of rice. Although the rice thresher realized the function of high precision and automatic threshing, a proper pressure between the conveyor and the roller needed to be obtained for each rice variety by adjusting the screw before threshing. And the process was time consuming and tedious. In future, the thresher should be adaptive to different rice varieties automatically, which could be achieved by setting fixed pressure stages for different varieties.

5. Conclusion

This paper demonstrated a whole feeding and automatic rice thresher for single plant. The thresher adopted a hierarchical multi-rollers threshing unit and fish scale sieving unit to achieve high precision threshing. And the programmable controller technique was applied to automate the whole threshing. The results proved that the thresher had the advantages of high threshing-precision, low breakage and no residue. In conclusion, this work provides a novel threshing device for high-precision and automatic rice yield-related traits evaluation.

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