

Article

Grain Sieve Loss Fuzzy Control System in Rice Combine Harvesters

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Abstract: The main working parts of the cleaning device of a rice combine harvester can be controlled by an established control strategy in real time based on the monitored grain sieve loss. This is an efficient way to improve their cleaning adaptability, since as a consequence, the main working parameters of combine harvesters can automatically adapt to crop and environment changes, and the corresponding cleaning performance can be improved. To achieve the target of cleaning control based on the monitored grain sieve loss, a fuzzy control system was developed, which selected S7-1200 PLC as the main control unit to build the lower computer hardware system, utilized ladder language to complete the system compilation, and used LabVIEW 14.0 software to design the host-computer interface. The effects of fan speed, guide plate angle, and sieve opening on the grain sieve loss and grain impurity ratio have been investigated through a large number of bench tests. The relevance level of the operating parameters on the performance parameters has been determined also, and finally, a fuzzy control model was developed for the cleaning system. The experiment results indicated that the designed fuzzy control model can control the cleaning section settings, such as fan speed and guide plate angle automatically, and reduce the grain sieve loss to some extent.

Keywords: rice; combine harvester; cleaning system; sieve loss; control; experiment

1. Introduction

The use of combine harvesters for harvesting rice fields is rapidly increasing year by year in China as the planting area and yield keep increasing [1]. As there are different rice varieties and harvesting times, the harvesting performance of the combine harvesters significantly fluctuates under different crop-harvesting conditions. The automation of the combine harvesters is one good way to guarantee the harvesting performance, and the flagship combine harvesters made by European companies have realized the functions of operation process fault diagnosis, forward speed control, adaptive threshing and cleaning, chassis lift control, and so on, significantly improving the overall operating efficiency and performance [2–7]. However, the relevant research on the state monitoring of the operation of combine harvesters is still in its infancy period in China. Most combine harvesters merely have engine revolution speed monitoring devices installed, parameter settings can only be adjusted when combine harvesters stop working based on the experience of the operator, and the cleaning performance varies dramatically. The cleaning device as one of the core parts of the machine and cleaning performance is another one of the major factors to weigh the performance of the whole machine. However, to date, automatic control systems for the cleaning units are not commercially available.

Scientists have carried out enormous relevant research on the cleaning processes of combine harvesters, and some investigations can be found investigating the effect of fan revolution speed, the area of the fan air inlet, sieve opening, and sieve vibration amplitude on the movement of grains and material other than grain (MOG) in the cleaning shoe, and several corresponding mathematical

models have been developed [8–11]. Better insight into the characteristics of the cleaning process was obtained owing to the interpretation of these mathematical models. However, a complete mathematical model that is applicable to the cleaning process would need to include several equations that are difficult to obtain and would probably be very complex. On the other hand, on the basis of analyzing the existing experiment data, and comparing the merits and drawbacks of the existing control strategy, a common drawback of most standard modeling and control techniques is that they are always based on an accurate mathematical model, and cannot make effective use of the expert knowledge of experienced engineers and operators [12]. The fuzzy control methodology, which combines the advantages of the white-box and black-box approaches, is widely used in agriculture machinery control systems, and improves the performance greatly [13–15]. Therefore, utilizing sensor technology and fuzzy control theory to develop a control system that can monitor grain sieve loss and the main working parts of the cleaning system that can be controlled by the established control strategy in real time is an efficient way to improve their cleaning adaptability. On the basis of studying the grain sieve loss sensor [16,17], this paper mainly studies the correlation between grain sieve loss and the related working parameters (fan speed, guide plate angle, and sieve opening) to determine the main factors affecting cleaning performance; then, a cleaning process fuzzy control system was designed to maintain the cleaning system with a good cleaning performance.

2. Material and Methods

2.1. Overall Research Method

To achieve the cleaning process control based on the monitored grain sieve loss, the technical blueprint adopted in this paper is introduced as follows:

(1) First, we outline the working parameters, including on-line monitoring and automatic adjustment technology, and design relevant actuating devices to pave the way for the step-less of the working parameters to require less adjustment during cleaning.

(2) Experiment results have shown that the cleaning performance is affected by several working parameters, and the effect of each working parameter on cleaning performance varies significantly. Therefore, relationships among working parameters (sieve opening, fan speed, guide plate angle, etc.) and performance parameters (sieve losses, grain impurity rate) have to be investigated through a large set of bench tests, and it is important to determine the relevance of the parameter settings and performance results according to the obtained test results. The most important information should be extracted, then the candidate input variables need to be ranked as possible control variables.

(3) The control model is the key to the automation of the cleaning section. On the basis of analyzing the existing test data, and comparing the merits and drawbacks of the existing control algorithm, we establish a control strategy for cleaning control. At last, we verify the robustness and adaptability of the control model through a test bench experiment.

2.2. Working Principle of the Multi-Duct Cleaning System

A cleaning test bench is shown in Figure 1. Some working parameters of the test bench, such as sieve opening, vibration frequency, and fan revolution speed can be adjusted separately. In the working parameters' adjustment process, a push rod is used to drive the relevant mechanism to fulfill the task of sieve opening and guide adjusting the plate angle. The fan speed and sieve vibration frequency can be controlled by adjusting the corresponding motors' shaft revolution. In addition, the cleaning throughput can be adjusted within $0.5\text{--}4.0\text{ kg}\cdot\text{s}^{-1}$ by controlling the vibration frequency of the electromagnetic vibration feeder. The test bench is also equipped with sensors to extract the airflow velocity, fan speed, and grain sieve loss. The working process of the multi-duct cleaning device is as follows: a return plate was added under the longitudinal axial flow threshing rotor to concentrate its threshed material and the tailings' return to the start of the cleaning shoe, and evenly distribute them. The grain pan and sieve have the same vibration frequency and amplitude. However, they have

an opposite vibration direction angle to reduce the overall vibration. Thus, all of the threshed outputs can enter into the sieve surface in a uniform way. Then, at the joint action of vibration and airflow from different fan outlets, the grain will penetrate the sieve promptly. The designed working parameter adjusting mechanism is shown in Figures 2 and 3. The principle of the working parameter adjusting mechanism can be found in our patent (PCT/CN2015/074348). The adjustment range of the working parameters is shown in Table 1.

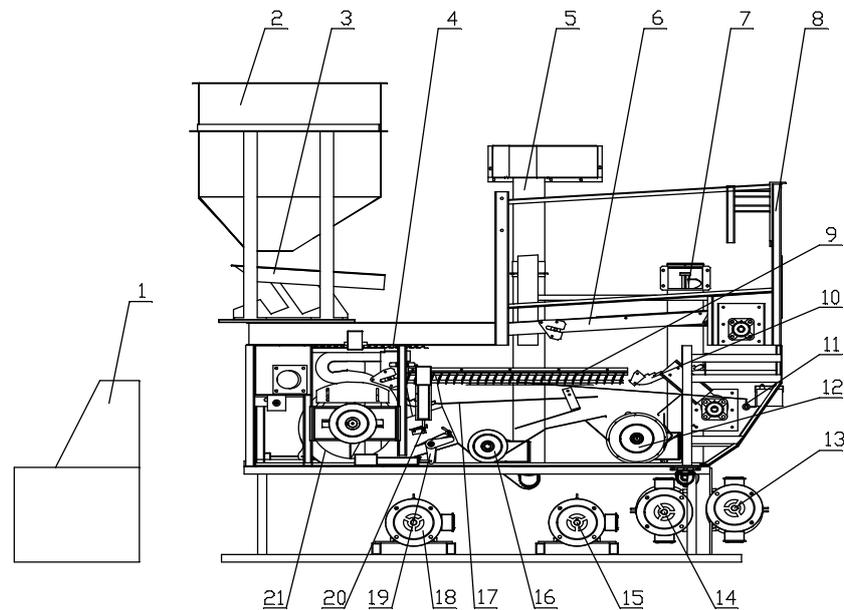


Figure 1. Schematic diagram of the multi-duct cleaning device. 1. Human–Machine Interface (HMI), 2. Threshed outputs container, 3. Electromagnetic vibration feeder, 4. Grain pan, 5. Vertical grain auger, 6. Return plate, 7. Vertical tailings auger, 8. Framework, 9. Louver sieve, 10. Tailing sieve, 11. Sieve-opening adjusting mechanism, 12. Horizontal tailing auger, 13. Sieve-driven motor, 14. Return plate-driven motor, 15. Grain/tailing auger-driven motor, 16. Horizontal grain auger, 17. Woven screen, 18. Fan-driven motor, 19. Airflow deflector i adjustment mechanism, 20. Airflow deflector ii adjustment mechanism, and 21. Centrifugal fan.

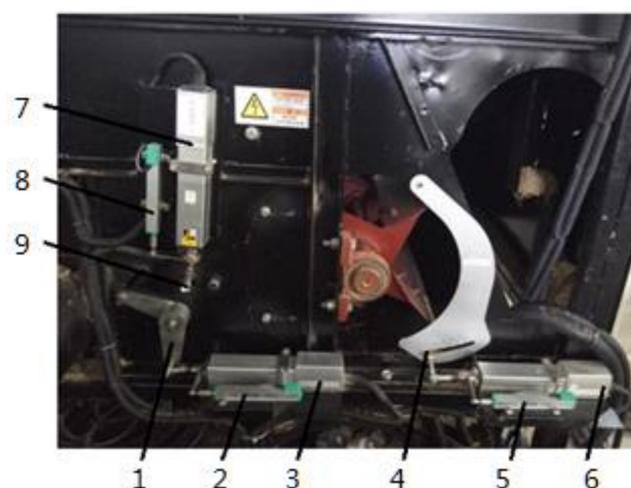
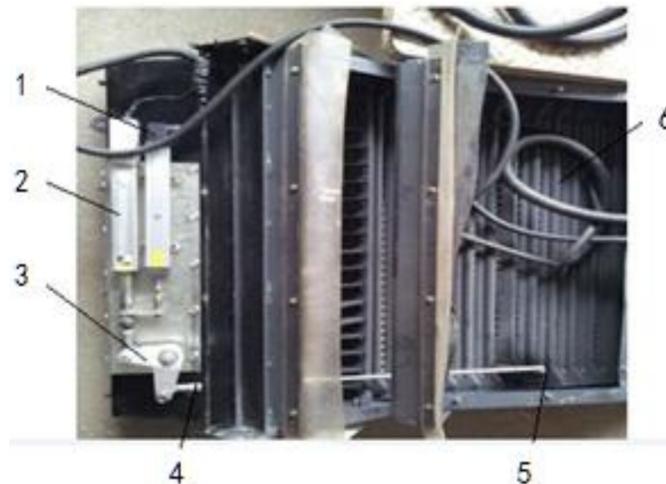


Figure 2. Working principle of the guide plate-angle adjusting system. 1. Direction converter, 2. Displacement sensor 1, 3. Push rod 1, 4. Airflow inlet adjust plate, 5. Displacement sensor 2, 6. Push rod 2, 7. Push rod 3, 8. Displacement sensor 3, 9. Joint bearing.

Table 1. Adjustment range of the working parameters.

Variables	Range
Length of return plate/mm	900/1100/1300
Return plate vibration frequency/HZ	4–9
Sieve vibration frequency/HZ	4–9
Fan speed/rpm	0–1500
Grain auger speed/rpm	800
Tail auger speed/rpm	1000
Sieve opening/mm	20–30
Guide plate I angle/°	8–45
Guide plate II angle/°	13–45

**Figure 3.** Working principle of the sieve-opening adjusting system. 1. Displacement sensor, 2. Push rod, 3. Direction converter, 4. Joint bearing, 5. Connector, 6. Active sieve.

2.3. Hardware and Software System of the Test Bench

The hardware circuit of the control system mainly comprises the power circuit, working parameters' knob-adjusting circuit, the displacement sensor signal-acquiring circuit, the motor revolution speed-controlling circuit and grain sieve loss, fan revolution speed, the return plate, and the sieve vibration frequency-acquisition circuit. The EPLAN 8.23 software (EPLAN, Mattis Nerheim, Germany) was used to design the corresponding circuit, integrate the above-mentioned circuits, and connect the electrical components according to the input/output (I/O) distribution to construct the hardware system. The software system is composed of the Human–Machine Interface (HMI) and the lower computer program. We selected the SIEMENS S7-1200 PLC, SM1231 AI8 analog input module, SM122 DQ16 digital output module, CM1241 RS485 communication module, frequency converter G120C (SIEMENS, Munich, Germany), and some transmitters to build the lower computer hardware system. Ladder language was utilized to complete the system compilation. The HMI was programmed by LabVIEW 14.0 software (National Instruments, Austin, TX, USA) to complete the information display and storage functions, and send instructions to the lower computer. Modbus-TCP communication protocol was utilized to fulfill the task of information exchange between the lower computer system and the HMI. The control strategy can be programmed in LabVIEW 14.0; once the control strategy is activated, the inherent algorithm selects the current grain sieve loss and current working parameters as input, and the target value of the ideal working parameters can be calculated out. Then, they were transferred into the lower computer system through communication protocol to finish process of adjusting the working parameters. The designed hardware structure of the operating monitoring and control system is shown in Figure 4.

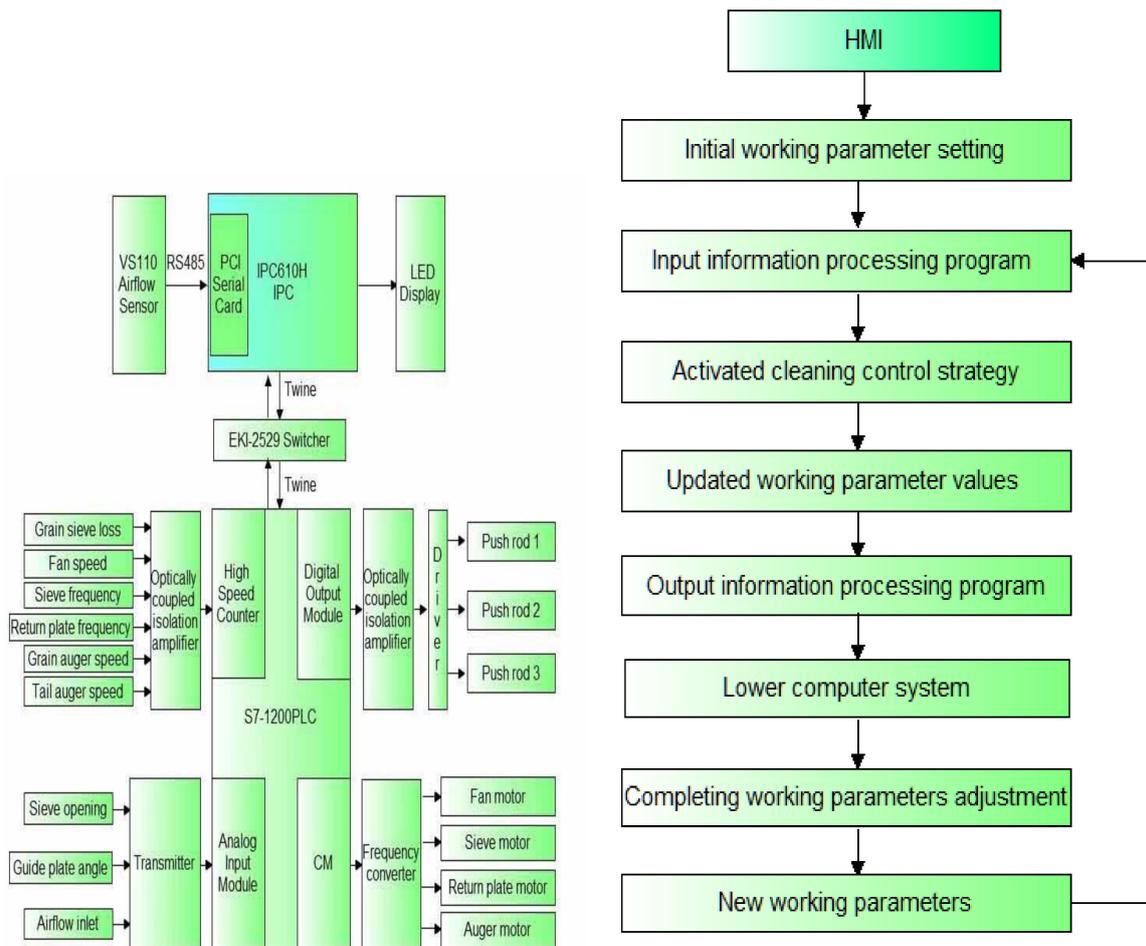


Figure 4. Hardware structure of operating monitoring and control system.

2.4. Cleaning Performance Evaluation under Different Working Parameters

The sieve loss ratio and grain impurity ratio in the grain tank are two main factors that are used to judge the cleaning performance, and the higher those two values are, the worse the cleaning performance. Taking the fan speed, guide plate angle, and sieve opening as experimental factors, a cleaning experiment was carried out in the test bench (Figure 1) utilizing the threshed outputs from the thresh-separation test bench [18]. The total amount of threshed outputs was 60 kg, the feeding rate was 2.5 kg/s. An oil-skin was used to collect all the cleaning residual at the rear of the test bench; then, the full grains were filtered out from the MOG using the stationary re-cleaner (Agriculex ASC-3 Seed Cleaner, Guelph, Ontario, CA, Canada), weighed, and the grain sieve loss ratio was calculated. The grain impurity ratio can be calculated by sampling from the grain tank (0.2–6 kg with an accuracy of ± 1 g) according to the national standard in China (DG/T 014-2009). The grain sieve loss should be $\leq 1\%$, and the grain impurity ratio should be $\leq 2\%$ (Chinese standards JB/T 5117-2006). A preliminary screening experiment was designed with D-optimal design criterion, which focuses on precise parameter estimation, and the experiment results indicated that the fan speed, guide plate II angle, and sieve opening are the main factors that affect the cleaning performance. In this paper, a response surface experiment was designed with I-optimal design criterion in JMP12.0 software (SAS, Cary, NC, USA) to learn the variation trends in the cleaning performance [19]. The basic characteristics of the rice used in the test are shown in Table 2.

Table 2. Basic characteristics of the rice used in the test.

Parameter	Measured Value
Plant height/mm	750~850
Ear height/mm	150~170
Stalk moisture content/%	58~67
Grain moisture content/%	22~29
Straw/grain ratio	1.9~2.2
One thousand grain weight/g	31.2

2.5. Grain Loss Control Strategy and Performance Checking

Selecting the deviation of the monitored grain sieve loss and its deviation variation rate as input variables, a fuzzy model was developed to control the cleaning process. The grain sieve loss sampled frequency was 10 Hz. By analyzing the time series of the recorded grain sieve loss under different working conditions, the basic domain of grain sieve loss was obtained. The output variables were the controlled quantities obtained by applying fuzzy inference to the corresponding input variables. To check the control performance of the designed fuzzy cleaning controller, the fuzzy query tables for the working parameters were obtained separately according to the maximum membership principle. Then, the corresponding proportional coefficients were multiplied into the values in the fuzzy query tables to obtain the actual regulation. After converting the actual regulation into the ‘if-else’ control statements respectively, the experiment was carried out in the test bench to check the controller performance. Before the experiment, the threshed outputs container in the test bench was filled with 120-kg threshed outputs, and it was ensured that all of the threshed outputs could be fed into the cleaning system within 50 s, which took several trials. The control effect could be checked by comparing the monitored grain sieve loss variation. Airflow velocities at certain points inside the cleaning shoe were measured by self-heating hot-wire anemometry (VS110, Nanjing, Neng Zhao Technology Co., Ltd., Nanjing, China, with a scope of 0.5–50 m·s⁻¹ and a resolution of 0.01 m·s⁻¹) to reflect the changing of the cleaning working parameters. The cleaning experiment was carried out under the condition that the controller was not being activated first, and the initial working parameters of the cleaning system were defined as the combination that had the worst cleaning performance. Then, about 10 s later, when the cleaning system was filled with threshed materials and the anemometer monitoring value was stable, the controller was activated. The corresponding sieve loss number was continuously recorded, which was beneficial to analyze the control effect afterwards. At last, collecting all of the cleaning residue on the oil-skin, the grains were obtained by removing the MOG through using a re-cleaner (Agriculex ASC-3 Seed Cleaner, Guelph, ON, Canada), and the grain sieve loss ratio could be obtained immediately. The grain sieve loss ratio was compared through utilizing the controller and the grain sieve loss ratio at the initial working parameters. The experimental process and location of the anemometers and grain sieve loss sensor in the cleaning shoe were as shown in Figure 5.



Figure 5. Cleaning material acquire process for testing the performance of the controller, 1. Grain sieve loss sensor, 2. Residual flow, 3. Anemometer.

3. Results and Discussion

3.1. Response Surface Experiment Results Analysis

The JMP 12.0 software was used to analyze the effects of the main working parameters on grain sieve loss utilizing the experimental results shown in Table 3, and the analysis results are shown in Table 4. From Table 3 can be learnt that the grain sieve loss ratio and grain impurity ratio could meet the Chinese standard in the most of conditions, compared with the single duct cleaning device, the cleaning performance was improved significantly [20]. When using JMP and other professional statistical software for hypothesis testing, the *p* value (*p* value) is often used to quantify the statistical significance of the evidence. In general, *p* < 0.05 is significant, *p* < 0.01 is very significant, meaning that the probability of sampling errors caused by differences between samples is less than 0.05 or 0.01 [19].

Table 3. Response surface experiment results on cleaning performance.

Test No.	Fan Speed/rpm	Sieve Opening/mm	Guide Plate II Angle/°	Grain Loss Ratio/%	Impurity Ratio/%
1	1300	25	45	0.39	0.64
2	1300	20	29	0.15	1.22
3	1100	20	45	0.14	1.28
4	1500	20	45	1.02	0.78
5	1500	30	45	0.93	1.06
6	1300	25	13	0.62	1.31
7	1100	20	13	0.25	2.37
8	1500	20	13	2.01	1.73
9	1300	30	29	0.53	3.34
10	1100	30	45	0.24	1.76
11	1500	30	13	1.80	2.58
12	1500	25	29	1.28	0.75
13	1300	25	29	0.69	1.26
14	1100	25	29	0.45	0.52
15	1100	30	13	0.60	0.47
16	1300	25	29	0.56	1.31

Table 4. Surface response experiment results analysis for grain sieve loss.

Source	Log Worth		<i>p</i> Value
Fan speed (1100,1500)	4.016		0.0001
Guide plate II (13,45)	2.338		0.0046
Fan speed ●guide plate II	1.732		0.0185
Fan speed ●Fan speed	1.463		0.0344
Fan speed ●Sieve opening	0.918		0.1207
Sieve opening ●Sieve opening	0.372		0.4250
Sieve opening ●Guide plate II	0.197		0.6346
Guide plate II ●Guide plate II	0.187		0.6505
Sieve opening (20,30)	0.046		0.8991

From the sieve loss response surface experiment results shown in Table 4, it can be seen that the combination of fan speed and guide plate II angle can accurately reflect the variation trend of grain sieve loss. To establish the mathematical model for monitoring the grain sieve loss, the grain

distribution at the tail sieve was studied under the different fan speeds and guide plate II angles. The interaction profiler for grain sieve loss is shown in Figure 6.

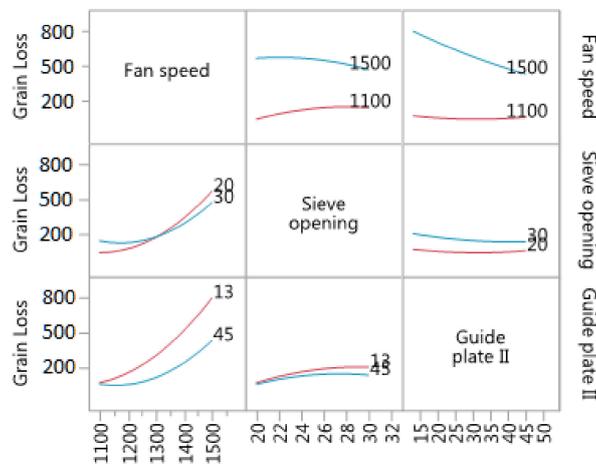


Figure 6. Interaction profiler for grain sieve loss.

3.2. Relationship among Working Parameters and Grain Impurity Ratio

The analysis of the surface response experiment results regarding the grain impurity ratio is shown in Table 5. It can be seen from Table 5 that the correspondence *p*-value of the sieve opening is ≤ 0.05 . Therefore, it is considered that the sieve opening is the main variable that affects the grain impurity ratio. To understand the variation in the grain impurity ratio under different working parameters, a prediction profiler for the grain impurity ratio is shown in Figure 7.

Table 5. Surface response experiment results analysis for grain impurity ratio.

Source	Log Worth		<i>p</i> Value
Sieve opening ●Sieve opening	1.511		0.0309
Fan speed ●Sieve opening	0.898		0.1265
Fan speed ●Fan speed	0.695		0.2019
Sieve opening ●Guide plate II	0.651		0.2232
Fan speed ●Guide plate II	0.606		0.2479
Guide plate II (13,45)	0.603		0.2494
Sieve opening (20,30)	0.574		0.2665
Guide plate II ●Guide plate II	0.217		0.6064
Fan speed (1100,1500)	0.173		0.6707

In Figure 7, the closer the desirability value is to 1, the more satisfactory the result; the closer the desirability value is to 0, the more unsatisfactory the result. From Figure 7, it can be learned that the value of the corresponding desirability of the sieve opening experiences a great fluctuation, while the corresponding desirability of the fan speed and guide plate II angle have a slight change. It further confirms that the sieve opening is the main parameter to judge the grain impurity ratio in a grain tank.

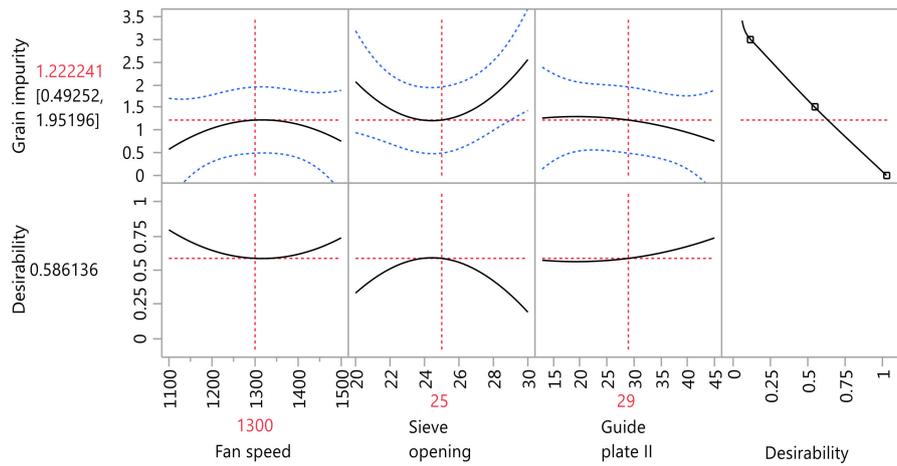


Figure 7. Prediction profiler for grain impurity ratio.

3.3. Fuzzy Controller for Cleaning System

There is no commercial grain impurity ratio monitoring system available at present; thus, it is currently impossible to obtain the grain impurity signals in a grain tank in real time. From the experiment shown in Table 5, it can be learned that when the sieve opening is 25 mm, the cleaning system has the lowest grain impurity ratio in a grain tank. Therefore, fixing the sieve opening at 25 mm, and selecting the fan speed and guide plate II as variables can establish the control strategy and thus ensure the grain impurity ratio $\leq 2\%$ in the grain tank. As the control target is to keep the grain sieve loss ratio $\leq 0.5\%$ under the condition of a grain impurity ratio $\leq 2\%$ in the grain tank, according to the feeding rate of 2.5 kg/s, the optimal set point of the grain sieve loss ratio is 0.5%, the corresponding grain sieve loss is 12.5 g/s, and the grain sieve loss is about 420 gains/s, according to a 1000 grain mass of rice of 30 g. Based on the proportion of grain mass in the monitoring area, the control threshold is set to six gains/100 ms.

The control variables of the fuzzy controller are the fan speed and the guide plate II angle. The adjusting range of the fan speed is 1100–1500 rpm, while the guide plate II angle is distributed within 13–45°. As shown in Figure 8, the experimental results indicated that the grain sieve loss ratio increases at a rate of 0.75 g/r as the fan speed increases, and the decrease rate of the grain sieve loss is about 2.2 g/° with the increase of the guide plate II angle. The cleaning system has a good performance with the fan speed at 1300 rpm and a guide plate II angle of 29°, as the corresponding grain sieve loss and grain impurity ratio are relative low. Combined with the cleaning performance under different conditions, the grain sieve loss ratio is larger when the fan speed is 1500 rpm, which is not conducive to getting a better cleaning performance. Therefore, the fan speed can be adjusted in the range of 1100–1400 rpm, and the guide plate II angle can be changed within 23–41°.

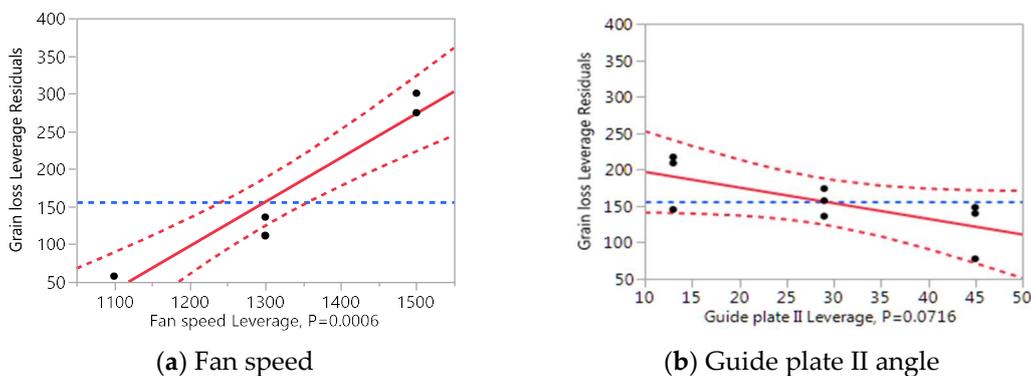
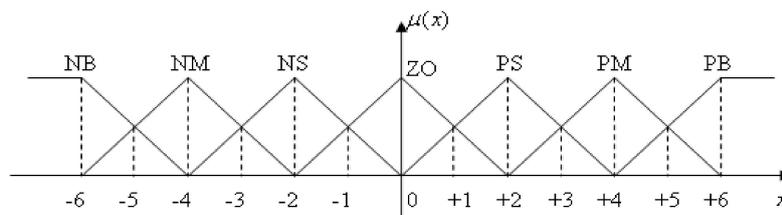


Figure 8. Effects of working parameters on grain loss with a confidence interval of 95%.

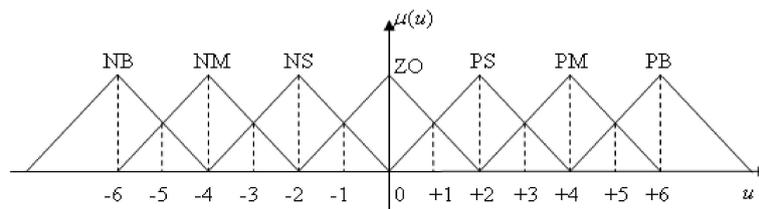
Experiments have shown that the fan speed has a major effect on grain sieve loss. Thus, a faster loop (cycle time of five seconds), which regulates the fan speed, and a slower loop, which regulates the guide plate II angle (cycle time of 10 s), were designed to control the working process. During the working process, the cleaning controller checks whether the current grain sieve loss is approximate to the optimal set point. If the monitored grain loss number is much higher than the optimal set point, the faster loop is activated, and the fan speed is changed. Once the monitored grain sieve loss approaches the optimal set point, the slower control loop will manage the fine-tuning of the guide plate II angle to keep the grain sieve loss below the set point and without impairing the cleaning efficiency. If the monitored grain sieve loss number falls below the optimal grain sieve loss set point, the fan speed can be increased to some extent to ensure cleaning efficiency. The basic domain of the grain sieve loss is obtained as shown in Table 6. The membership functions are all triangular, as shown in Figure 9; its fuzzy domains were E and EC, and U represents their fuzzy domains. The fuzzy subsets of the input and output linguistic variables are expressed as negative big (NB), negative middle (NM), negative small (NS), zero (ZO), positive small (PS), positive middle (PM), and positive big (PB). The fuzzy system includes 49 strips of rules for the fan speed and guide plate II angle, as shown in Tables 7 and 8.

Table 6. Changing range of the cleaning performance.

Item	Deviation Domain	Change Rate of the Deviation
Grain sieve loss	[−12, +12], grains/100 ms	[−100, +100], grains/s



(a) Membership function of E and EC for grain sieve loss



(b) Membership function of E and EC for fan speed and guide plate II angle.

Figure 9. Membership functions of the input and output variables.

Table 7. Fuzzy control strategy for fan speed.

U		U						
		NB	NM	NS	ZO	PS	PM	PB
E	EC	PB	PM	PS	NS	NS	ZO	ZO
	E	PB	PM	PS	NS	NS	ZO	ZO
	NB	PB	PM	PS	NS	NS	ZO	ZO
	NM	PB	PM	PS	NS	NS	ZO	ZO
	NS	PM	PS	PS	PM	ZO	ZO	ZO
	ZO	PS	PS	ZO	ZO	NS	NS	NM
	PS	NS	NS	ZO	PS	NS	NM	NM
PM	NS	ZO	ZO	NS	NM	NB	NB	
PB	ZO	ZO	PS	PM	NM	NB	NB	

Table 8. Fuzzy control strategy for guide plate II.

E \ U	U							
	EC	NB	NM	NS	ZO	PS	PM	PB
NB	ZO	ZO	ZO	ZO	ZO	PS	PS	ZO
NM	ZO	ZO	ZO	ZO	ZO	PS	ZO	ZO
NS	ZO							
ZO	ZO	ZO	ZO	ZO	ZO	ZO	PS	PS
PS	PS	PS	ZO	PS	PS	PS	PS	PM
PM	PS	ZO	ZO	PS	PS	PS	PM	PB
PB	ZO	ZO	PS	PM	PM	PM	PB	PB

3.4. Controller Performance Checking

The initial working parameters are as follows: the fan speed is 1500 rpm, the guide plate I angle is 26.5°, the guide plate II angle is 13°, and the sieve opening is 25 mm. The experimental results indicated that there is a large sieve loss under this condition. From Figure 10, it can be seen that when the controller was not activated in the first 10 s, the airflow velocity at the upper outlet and tail sieve is large because of the higher fan speed and the smaller guide plate II angle. Under the accelerated action of airflow, the threshed material is easily blown out, resulting in a sharp increase in grain sieve loss. After activating the controller at 10 s, the monitored grain loss is gradually decreasing. With the stability of the grain sieve loss, the controller adjusts the fan speed to increase the cleaning efficiency. The grain loss is increased as the fan speed increases. At last, the grain sieve loss is stable near the set point, and the grain sieve loss is reduced.

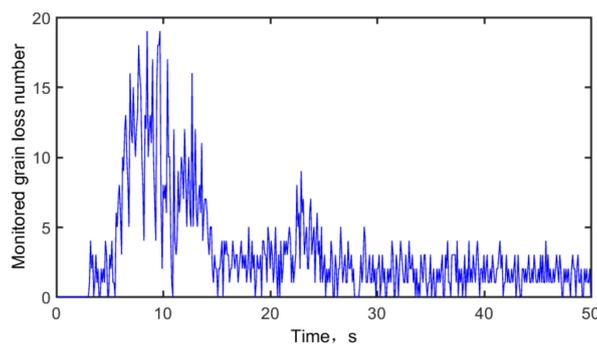


Figure 10. Comparison of grain sieve loss variation before and after activating the controller.

The combination of working parameters in the cleaning device determines the airflow distribution in the cleaning shoe. Therefore, the change of the airflow field is an indirect proof of the changes in the working parameters. The airflow velocity variation in the first 20 s is as shown in Figure 11, and the control performance of the controller is verified by the airflow velocity variation. From Figure 11, it can be seen that the airflow velocity at different measurement points varies dynamically during the cleaning process. It can be proven that the relevant working parameters are changing at the action of the controller. At 10 s, the airflow velocity distribution in the cleaning shoe is far from the ideal airflow velocity distribution form. According to previous experience, the grain sieve loss is larger and the relevant working parameters need to be adjusted in order to avoid the grain loss continuing to increase. After the control algorithm was activated in the first 10 s, the airflow velocity in the cleaning shoe rapidly reduced at 15 s, and the airflow velocity in the cleaning shoe gradually became close to the ideal airflow velocity distribution at 20 s. The calculated grain sieve loss with the activated controller was 0.53%. However, from Table 4, it can be known that the grain sieve loss is 0.83–2.01% under the working conditions that are similar to the initial working parameters: fan speed 1500 rpm, sieve opening 20–30 mm, guide plate II angle 13–45°, and guide plate I angle 26.5°. The grain sieve loss

after the controller is activated is significantly reduced. Since the control algorithm was not activated in the first 10 s, the grain sieve loss was a bit higher.

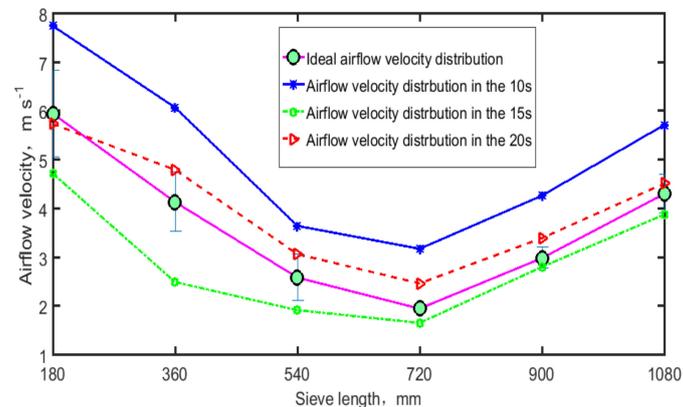


Figure 11. Variation of airflow velocity distribution above the sieve within the first 20 s.

4. Conclusions

Selecting S7-1200 PLC to build the lower computer hardware system, utilizing ladder language to complete the system compilation, and using LabVIEW 14.0 software to design the host-computer interface, a multi-duct cleaning device performance monitoring and control system was developed. The effects of fan speed, guide plate angle, and the sieve opening on the sieve loss ratio and grain impurity ratio were investigated through a large number of bench tests. The experimental results indicated that the combination of fan speed and guide plate II angle can accurately reflect the variation trend of grain sieve loss, and the grain sieve loss ratio increases at a rate of 0.75 g/r as the fan speed increases, and the decrease rate of the grain sieve loss is about 2.2 g/° with the increase of the guide plate II angle. Based on the proportion of grain mass in the monitoring area, the control threshold is set to six gains/100 ms. Then, a fuzzy control model of the cleaning process was developed for the multi-duct cleaning system, and the experimental results indicated that when the controller was not activated in the first 10 s, the airflow velocity at the upper outlet and tail sieve was large because of the higher fan speed and the smaller guide plate II angle. Under the accelerated action of airflow, the threshed material is easily blown out, resulting in a sharp increase in grain sieve loss. After activating the controller at 10 s, the monitored grain loss gradually decreased. With the stability of the grain sieve loss, the controller adjusts the fan speed to increase the cleaning efficiency. The grain loss increased as the fan speed increased. The designed fuzzy control model can fulfill the automated control of cleaning settings, such as fan speed and guide plate angle, and thus reduce grain sieve loss.

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