WHEAT HARVESTING QUALITY ONLINE DETECTION SYSTEM AND EXPERIMENTAL VERIFICATION
/
小麦收获质量在线检测系统与试验验证

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ABSTRACT
Harvest quality is one of the key indicators for evaluating the performance of mechanized wheat harvesting. To enable real-time monitoring of harvest quality during the wheat combine harvesting process, this study integrates an online detection system specifically designed for wheat harvest quality. The system is capable of real-time monitoring of threshing and cleaning losses, breakage rate, and impurity rate. To assess the effectiveness of the online detection system, field experiments were conducted. The experimental results showed that the average threshing and cleaning loss rates of the harvester measured manually were 0.69% and 0.75%, respectively, while those detected by the online system were 0.52% and 0.50%, respectively. The average grain breakage rates obtained through manual measurement were 0.67% and 0.58%, whereas the system detected breakage rates of 0.49% and 0.52%, respectively. For impurity rate, manual measurements yielded average values of 0.81% and 0.69%, while the system recorded 0.73% and 0.67%, respectively. The results demonstrate that the developed online wheat harvest quality detection system can effectively perform real-time assessments of harvest quality during combine harvesting operations.

摘要
收获质量是衡量小麦机械化收获性能的关键指标之一。为了实现对小麦机收过程中收获质量的实时监控，本文集成了小麦收获质量在线检测系统，该系统能够对脱粒清选损失、破碎率、含杂率进行实时检测。为了评估小麦收获质量在线检测系统的效能，进行了田间试验。试验结果显示：人工检测收获机清选脱粒损失率的平均值分别为0.69%和0.75%，而小麦收获质量在线检测系统检测到的收获机清选脱粒损失率的平均值分别为0.52%和0.50%；人工检测收获机破碎率的平均值分别为0.67%和0.58%，系统检测到的收获机破碎率的平均值分别为0.49%和0.52%；人工检测收获机含杂率的平均值分别为0.81%和0.69%，系统检测到的含杂率的平均值分别为0.73%和0.67%。本研究开发的小麦收获质量在线检测系统能够有效地完成收割机小麦收获作业质量的检测任务。

INTRODUCTION
China is one of the largest wheat-producing countries in the world, with wheat cultivation widely distributed across the country *(Zhao et al., 2024)*. The major wheat-growing regions include the Huang-Huai-Hai Plain, the middle and lower reaches of the Yangtze River, and the inland areas of Northwest China *(Zhao et al., 2025)*. Among these, the Huang-Huai-Hai region serves as the core wheat production zone, accounting for over 60% of the national planting area and total output. Wheat production in China is dominated by winter wheat, supplemented by spring wheat, with typical cropping systems including double cropping per year or rice-wheat rotation *(Wang et al., 2024)*. In recent years, with the continuous advancement of agricultural modernization, the level of mechanization in wheat production has increased significantly *(Li et al., 2025; Li et al., 2024; Vlădut et al., 2023)*.

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The comprehensive mechanization rate of tillage, sowing, and harvesting has surpassed 95% *(Zhang et al., 2024; Chen et al., 2023)*. In particular, during the harvest stage, the widespread adoption of combine harvesters enables centralized and efficient harvesting, substantially enhancing both harvest efficiency and timeliness.

Online detection of wheat harvest quality is a key component in achieving intelligent and precise management in modern agriculture *(Xie et al., 2024; Liao et al., 2025)*. It plays a vital role in ensuring grain quality and enhancing economic benefits *(Geng et al., 2024)*. During the harvesting process, factors affecting wheat quality include impurity rate, breakage rate, and loss rate. Traditional manual sampling methods can no longer meet the demands for rapid, continuous, and high-precision monitoring. By leveraging online detection technologies, real-time acquisition of quality data throughout the harvesting process becomes possible *(Gu et al., 2025)*. This enables timely identification of issues and dynamic adjustment of operational parameters. Intelligent regulation of critical processes—such as threshing, screening, and air separation—can thus be achieved, effectively reducing harvest losses and grain breakage, while improving the whole kernel rate and net content *(Ding et al., 2025; Liu et al., 2023)*.

With the continuous advancement of agricultural equipment intelligence, online detection of wheat harvest quality is expected to become one of the key functional modules of combine harvesters *(Audu et al., 2021)*. It will play a significant role in safeguarding national food security and promoting the development of smart agriculture in China *(Wang et al., 2024)*. Zhang Qi et al. proposed a method for detecting wheat breakage rate and impurity rate based on the DeepLab EDA semantic segmentation model and developed a corresponding detection system. The average errors in detecting wheat breakage rate and impurity rate were 13.32% and 9.77%, respectively *(Zhang et al., 2024)*. Chen Man et al. introduced an online detection method for wheat impurity rate during mechanical harvesting, based on an improved U-Net model integrated with attention mechanisms. In both bench and field tests, the average impurity rates detected online were 1.69% and 1.48%, which were 0.26 and 0.13 percentage points higher than the manually measured values, respectively *(Chen et al., 2023)*. Tang Zhong et al. utilized an array-type polypropylene fluoride (PVDF) piezoelectric film sensor to measure the grain quantity beneath the toothed longitudinal axial-flow drum of a longitudinal flow combine harvester during field operation. By applying a separation matrix equation, the entertainment loss mass was calculated, with a measurement error ranging from –4.82% to –5.87% *(Tang et al., 2012)*. Li Yibo et al. combined time-frequency images of granular vibration piezoelectric signals with machine learning techniques to classify grains and impurities and evaluate corn cleaning loss. The piezoelectric detection unit based on the optimal Naïve Bayes (NB) model was able to control the absolute error of grain loss rate within 0.43% *(Li et al., 2024)*. Wu Zhiping et al. developed a lightweight detection system for measuring impurity content and breakage rate in rice, and optimized the corresponding computational models. The relative errors for impurity content and breakage rate detection were 7.99% and 8.46%, respectively *(Wu et al., 2024)*. Liu Lei et al. designed a machine vision–based monitoring device for impurity rate and proposed a dedicated CPU-Net semantic segmentation model tailored for corn impurity detection. The average relative measurement error was 4.64% *(Liu et al., 2022)*. Although significant progress has been made in single-point technologies for measuring threshing and cleaning loss rate, breakage rate, and impurity rate, a comprehensive evaluation system for wheat harvest quality remains underdeveloped. Moreover, given the wide variety of wheat cultivars and harvesting machinery types in China, how to construct a robust online wheat harvest quality detection system has become a key focus of this study.

Therefore, to enable real-time monitoring of harvest quality during the wheat combine harvesting process, this study integrates an online wheat harvest quality detection system and conducts field experiments to verify its feasibility.

MATERIALS AND METHODS

System Composition

The online wheat harvest quality detection system consists of an entrainment loss sensor, a cleaning loss sensor, a breakage rate sensor, an impurity rate sensor, a threshing and cleaning loss data acquisition controller, a breakage and impurity data acquisition controller, a human–machine interaction (HMI) system, and a 12V power supply unit. The system block diagram is shown in Figure 1. Specifically, the entrainment loss sensor and the cleaning loss sensor detect the impact of lost grains on the sensitive plates during combine harvester operation and output corresponding electrical signals. The threshing and cleaning loss acquisition controller receives the electrical signals from both sensors and performs real-time online detection of grain loss per unit area over time.

Based on its built-in algorithm, it calculates and outputs the real-time threshing and cleaning loss rate, which is transmitted to the HMI system via the CAN bus. The breakage rate sensor and impurity rate sensor are responsible for real-time acquisition of grain image data during harvesting, outputting dynamic grain images. The breakage and impurity data acquisition controller receives these image signals and conducts online segmentation and identification of whole grains, broken grains, and impurities in the images. It then calculates and outputs the real-time breakage rate and impurity rate based on its internal algorithm, and sends the data to the HMI system via the CAN bus. The HMI system allows for the configuration of both harvester parameters and crop parameters. Once set, these parameters are transmitted via the CAN bus to the threshing and cleaning loss acquisition controller and the breakage and impurity acquisition controller. The 12 V power supply unit provides a stable 12 V output voltage to ensure the reliable operation of the entire wheat harvest quality detection system.

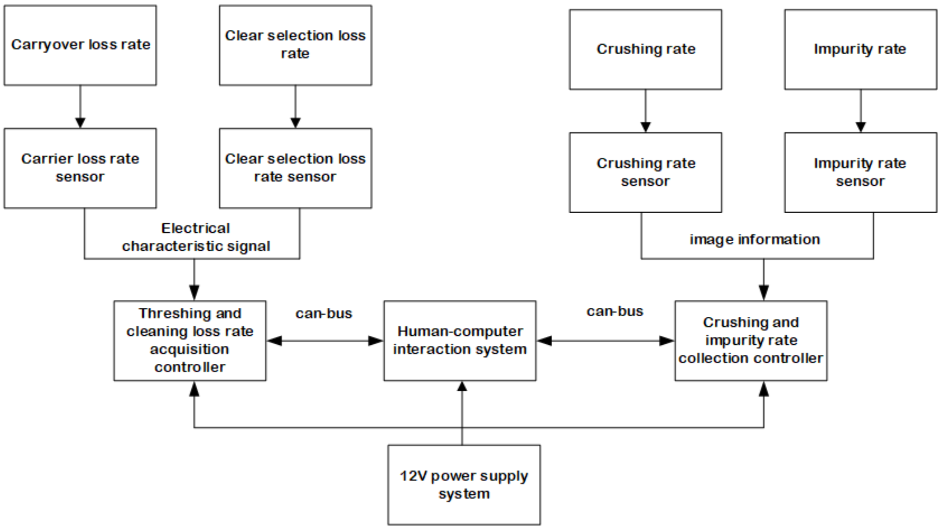


Fig. 1 – Composition of online wheat harvest quality detection system

Field Validation Experiment Design

During the optimal harvest period for wheat, experimental plots were selected that were firm underfoot and free of standing water. Prior to the experiment, the plots were trimmed and leveled, and three regular-shaped test areas were prepared. Before the trial, the wheat cultivar planted in the test area was confirmed. Representative samples were collected to determine plant height, thousand kernel weight, moisture content, and the number of naturally shed grains per unit area. Environmental data such as ambient temperature and humidity were also recorded. In addition, the basic parameters of the combine harvester to be tested were confirmed and documented. The online wheat harvest quality detection system was installed on the combine harvester under test. The system was then calibrated and debugged to ensure proper functioning. The operator conducted two harvesting operations in the designated plots using two standard operating gears of the combine harvester according to the product specifications. During the harvesting process, the quality detection system performed real-time monitoring and recorded the operational quality data, generating detection results automatically. Manual sampling and measurements were performed concurrently. The results obtained by the online wheat harvest quality detection system were compared with those from manual inspection to evaluate the system's detection accuracy and effectiveness.

Field Survey

On June 7, 2024, a wheat harvest experiment was carried out in Dantu District, Danyang City, Jiangsu Province (119°17′11.969″E, 32°12′50.263″N). Three test plots with dimensions of 40 m in length and 25 m in width were prepared. Two plots were randomly chosen for the experiments and labeled as Test Group 1 and Test Group 2. The field survey data are presented in Table 1.

Table 1

Field investigation record

Item	*Parameter*	*Item*	*Parameter*
Variety	Yangmai 33	Plant height / cm	84.6
Spike length / cm	9.8	1000-seed weight / g	43.2
Moisture content / %	18.1	Yield / kg/m^2	0.74

The test site photos are shown in Figure 2. The combine harvester used in this experiment was the WoDe 4LZ-6.0ME(Q)(G4) RuiLong Cross-Region Enhanced Edition, manufactured by Jiangsu WoDe Agricultural Machinery Co., Ltd. This model is equipped with a 125-horsepower, National IV (China IV) high-pressure common rail engine, a 45cc large-displacement hydraulic transmission (HST), and an 85-strengthened dedicated gearbox. The engine's rated power is 92 kW, with a rated speed of 2400 rpm. The minimum ground clearance reaches 43.5 cm. It features a "riding" style chassis wheel system with 53-section, 500 mm wide high-tooth tracks. The cutter header has a working width of 2.10 m and a feed rate of 6 kg/s. It is equipped with lengthened and thickened reel teeth with spring fingers, a reinforced anti-grass entanglement divider, and a floating feed inlet design. The operational hourly productivity ranges from 0.27 to 1.0 hectares per hour. The threshing drum is extended to 2.01 m, and the fish-scale sieve has six adjustable openings. Both airflow volume and direction can be regulated. The harvester supports a 360° extended rotary grain unloading system.

a) Testing site: *b) Manual sampling inspection*

Fig. 2 – Wheat harvest experiment

Data Acquisition and Processing Methods

The threshing and cleaning loss rate, breakage rate, and impurity rate of the combine harvester during the experiment were obtained through manual sampling inspection. During the harvesting operation, three random harvesting passes were selected. For each pass, a 20-meter section of the material discharged from the rear of the combine was collected. The lost grains were separated from the straw, and the quantity of lost grains was measured. By converting this to a per unit yield basis, the threshing and cleaning loss rate of the combine harvester for the test process was calculated.

From the grain tank of the combine harvester, three random grain samples were taken, each weighing no less than 1 kg. The non-grain materials and broken grains were manually separated and counted, allowing for the determination of the breakage rate and impurity rate of the combine harvester during the test.

Simultaneously, the wheat harvest quality online detection system performed real-time monitoring throughout the experiment, saving detection data at each time point. After the test, the relevant data were exported from the system for performance analysis.

The detection performance of the system was analyzed statistically by calculating the maximum, minimum, mean, standard deviation, and coefficient of variation of the measured indicators: threshing and cleaning loss rate, breakage rate, and impurity rate.

Table 2

Statistical table of manual detection data on threshing and cleaning loss rate

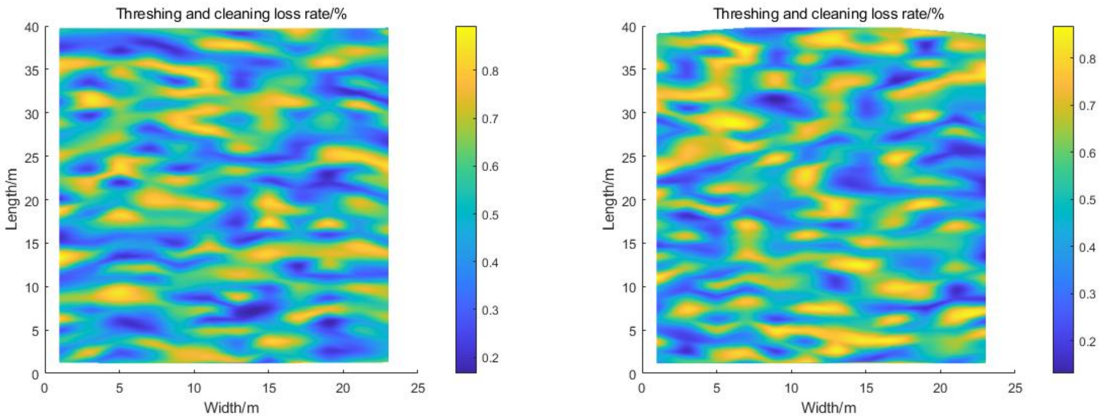
Test group	Threshing and cleaning loss rate / %			
1	Measured data	0.76	0.81	0.49
	Maximum value	0.81	Minimum value	0.49
	Average value	0.69	Standard deviation	0.14
	Coefficient of variation		20.29	
2	Measured data	0.63	0.76	0.86
	Maximum value	0.86	Minimum value	0.63
	Average value	0.75	Standard deviation	0.09
	Coefficient of variation		12.00	

The results were processed by Microsoft Office Excel (version 2021, Microsoft Corp., USA) and Matlab (version 2021a, MathWorks Corp., USA). Single factor analysis of variance (ANOVA) was carried out with IBM SPSS Statistics (version 24, IBM Corp., USA).

RESULTS

Results and Analysis of Threshing and Cleaning Loss Rate Detection

The statistical results of the threshing and cleaning loss rate obtained by manual sampling inspection are presented in Table 2. During the test, in Plot 1, the manually measured threshing and cleaning loss rate had a maximum value of 0.81%, a minimum value of 0.49%, an average value of 0.69%, a standard deviation of 0.14%, and a coefficient of variation of 20.29%. In Plot 2, the manually measured threshing and cleaning loss rate had a maximum value of 0.86%, a minimum value of 0.63%, an average value of 0.75%, a standard deviation of 0.09%, and a coefficient of variation of 12.00%.



a) Experimental Zone 1: ***b) Experimental Zone 2***

Fig. 3 – Distribution map of threshing and cleaning losses in harvest experimental area

The experimental data from the online detection system for wheat harvest quality indicate that the overall threshing and cleaning loss rates in the first and second experimental fields are at a relatively low level (with a maximum value not exceeding 0.85%). Specifically, the average loss rate in the first field is 0.52% (standard deviation: 0.18%, coefficient of variation: 34.62%), and that in the second field is 0.50% (standard deviation: 0.20%, coefficient of variation: 40.00%). The loss rates in both fields exhibit significant fluctuations (with coefficients of variation exceeding 34%); however, the overall means are close and remain within a low range, which reflects the consistency and reliability of the system's online detection results for threshing and cleaning losses.

Table 3

Statistical table of system detection data on threshing and cleaning loss rate

Test group	**Threshing and cleaning loss rate / %**			
1	Maximum value	0.85	Minimum value	0.19
	Average value	0.52	Standard deviation	0.18
	Coefficient of variation		34.62	
2	Maximum value	0.84	Minimum value	0.16
	Average value	0.50	Standard deviation	0.20
	Coefficient of variation		40.00	

In this trial, the average threshing and cleaning loss rate of the Worde 4LZ-6.0ME(Q)(G4) Ruilong Cross-Region Enhanced Combine Harvester measured by manual random sampling was 0.72%, while the average instantaneous threshing and cleaning loss rate detected by the system was 0.51%. The absolute error between manual detection and system detection based on the average values was 0.21%.

Results and Analysis of Crushing Rate Detection

Statistical analysis of the damage rate obtained through manual sampling inspection reveals that the overall grain damage rate in Experimental Area 1 and Experimental Area 2 is at a moderately low level (with the maximum value not exceeding 0.82%). The mean damage rate in Experimental Area 1 is 0.67% (standard deviation: 0.14%, coefficient of variation: 20.90%), while that in Experimental Area 2 is 0.58% (standard deviation: 0.17%, coefficient of variation: 29.31%). A comparison of the data between the two experimental areas indicates that the mean damage rate in Experimental Area 1 is approximately 0.09 percentage points higher than that in Experimental Area 2, and the coefficient of variation is lower, suggesting that the fluctuation of the damage rate in Experimental Area 1 is relatively minor and the stability is superior. Although the mean damage rate in Experimental Area 2 is lower, individual differences are more pronounced (with a higher standard deviation and coefficient of variation), which may be associated with disparities in local operating conditions or uneven sampling distribution in the field.

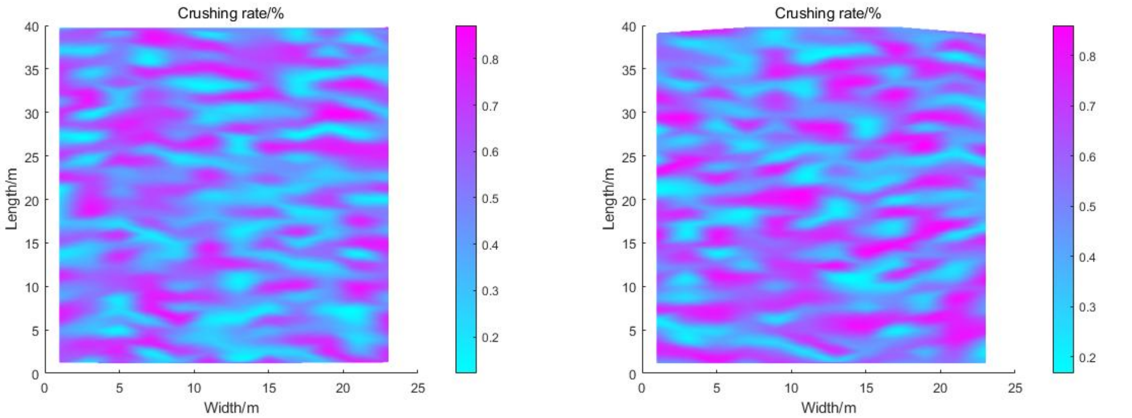
Overall, the results of manual sampling reflect the central tendency and dispersion characteristics of grain damage rates in different experimental areas, offering crucial references for evaluating the quality of harvesting operations.

Table 4

Statistical table of manual detection data on crushing rate

Test group	**Crushing rate / %**			
1	Measured data	0.69	0.49	0.82
	Maximum value	0.82	Minimum value	0.49
	Average value	0.67	Standard deviation	0.14
	Coefficient of variation		20.90	
2	Measured data	0.81	0.39	0.54
	Maximum value	0.81	Minimum value	0.39
	Average value	0.58	Standard deviation	0.17
	Coefficient of variation		29.31	

The statistical data of broken rate detected by the system are shown in Figure 4 and Table 5. During the trial, in Plot 1, the maximum broken rate detected by the system was 0.83%, the minimum was 0.14%, the average was 0.49%, the standard deviation was 0.19%, and the coefficient of variation was 38.78%. In Plot 2, the maximum broken rate was 0.84%, the minimum was 0.19%, the average was 0.52%, the standard deviation was 0.18%, and the coefficient of variation was 34.62%.



a) Experimental Zone 1 *b) Experimental Zone 2*

Fig. 4 – Distribution map of crushing in harvest experimental area

In this trial, the average broken rate of the Jiangsu Wode 4LZ-6.0ME(Q)(G4) RuiLong Cross-Regional Enhanced Version combine harvester detected by manual random sampling was 0.63%, while the system detected an average instantaneous broken rate of 0.51%. Based on the average values, the absolute error between manual detection and system detection was 0.12%.

Table 5

Statistical table of system detection data on crushing rate

Test group	**Crushing rate / %**			
1	Maximum value	0.83	Minimum value	0.14
	Average value	0.49	Standard deviation	0.19
	Coefficient of variation		38.78	
2	Maximum value	0.84	Minimum value	0.19
	Average value	0.52	Standard deviation	0.18
	Coefficient of variation		34.62	

Results and Analysis of Impurity Rate Detection

The statistical results of impurity rate detected by manual sampling are shown in Table 6. During the trial, in Plot 1, the maximum impurity rate detected by manual sampling was 0.97%, the minimum was 0.68%, the average was 0.81%, the standard deviation was 0.12%, and the coefficient of variation was 14.81%. In Plot 2, the maximum impurity rate was 1.03%, the minimum was 0.46%, the average was 0.69%, the standard deviation was 0.24%, and the coefficient of variation was 34.78%.

Table 6

Statistical table of manual detection data on impurity rate

Test group	Impurity rate / %			
1	Measured data	0.78	0.68	0.97
	Maximum value	0.97	Minimum value	0.68
	Average value	0.81	Standard deviation	0.12
	Coefficient of variation		14.81	
2	Measured data	0.59	1.03	0.46
	Maximum value	1.03	Minimum value	0.46
	Average value	0.69	Standard deviation	0.24
	Coefficient of variation		34.78	

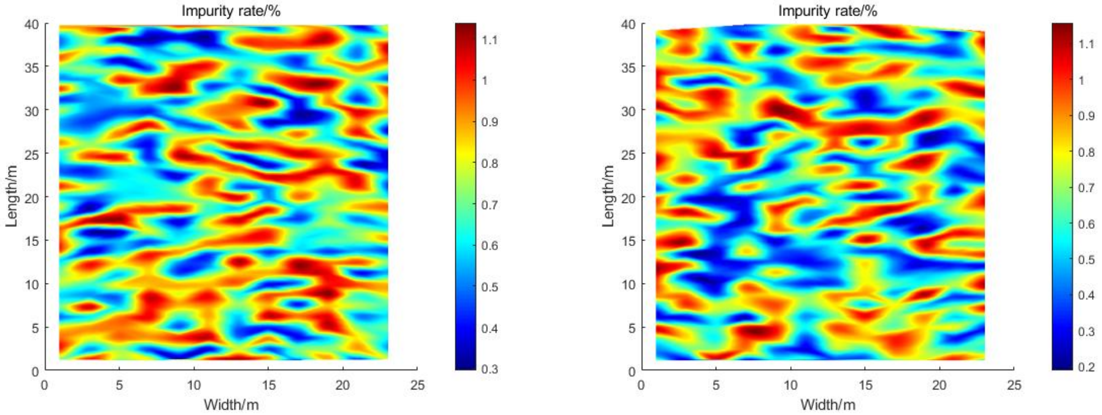
The statistical results of impurity rate detected by the online detection system are shown in Figure 5 and Table 7. During the trial, in Plot 1, the system detected a maximum impurity rate of 1.11%, a minimum of 0.32%, an average of 0.73%, a standard deviation of 0.22%, and a coefficient of variation of 30.14%. In Plot 2, the system detected a maximum impurity rate of 1.13%, a minimum of 0.23%, an average of 0.67%, a standard deviation of 0.26%, and a coefficient of variation of 38.81%.

Table 7

Statistical table of system detection data on impurity rate

Test group	Impurity rate / %			
1	Maximum value	1.11	Minimum value	0.32
	Average value	0.73	Standard deviation	0.22
	Coefficient of variation		30.14	
2	Maximum value	1.13	Minimum value	0.23
	Average value	0.67	Standard deviation	0.26
	Coefficient of variation		38.81	

In this trial, the average impurity rate of the Jiangsu Word 4LZ-6.0ME(Q)(G4) RuiLong cross-region enhanced version combine harvester measured by manual random sampling was 0.75%, while the average instantaneous impurity rate detected by the system was 0.70%. The absolute error between manual detection and system detection based on the average values was 0.05%.



a) Experimental Zone 1: ***b) Experimental Zone 2***

Fig. 5 – Distribution map of impurity in harvest experimental area

Results and Analysis of Overall Machine Operation Quality Detection

In this evaluation trial, the results of manual sampling detection showed that the maximum threshing and cleaning loss rate of the Jiangsu Word 4LZ-6.0ME(Q)(G4) RuiLong cross-region enhanced version combine harvester was 0.86%, the maximum breakage rate was 0.82%, and the maximum impurity rate was 1.03%. The digital quality evaluation system for combine harvester operation detected a maximum threshing and cleaning loss rate of 0.85%, a maximum breakage rate of 0.84%, and a maximum impurity rate of 1.13% for the same combine harvester model. Both detection methods confirmed that the three indicators—threshing and cleaning loss rate, breakage rate, and impurity rate-of the 4LZ-6.0ME(Q)(G4) RuiLong combine harvester meet the relevant technical requirements, demonstrating that the performance of this combine harvester complies with the specified standards.

CONCLUSIONS

To verify the detection performance of the wheat harvesting quality online detection system, a validation test scheme was developed specifically for wheat harvesting. Field trials were conducted in Jiangsu Province. The test results showed that:

(1) The average threshing and cleaning loss rates measured by manual sampling were 0.69% and 0.75%, while the online detection system measured average loss rates of 0.52% and 0.50%;

(2) The average breakage rates measured manually were 0.67% and 0.58%, compared to 0.49% and 0.52% detected by the online system;

(3) The average impurity rates from manual detection were 0.81% and 0.69%, whereas the online detection system measured 0.73% and 0.67%.

Compared with manual sampling results, the maximum absolute errors of the online detection system were 0.25% for threshing and cleaning loss rate, 0.16% for breakage rate, and 0.08% for impurity rate. The wheat harvesting quality online detection system developed in this study can effectively perform real-time quality monitoring of combine harvester operations during wheat harvesting.

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