

Machine Vision-Based Intelligent Rice Sorting Technology

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Abstract
Rice sorting is a critical step in ensuring rice quality and commercial value. Traditional mechanical screening and manual inspection suffer from problems such as low efficiency, insufficient accuracy, and grain damage. In recent years, the rapid development of machine vision and machine learning technologies has provided new pathways for intelligent rice detection and sorting. This study innovatively proposes an intelligent rice processing and sorting system, targeting the intelligent screening of broken rice and impurities in rice. The experiment selects rice varieties commonly cultivated in Shayang, Hubei Province, as the research object. The system aims to optimize and upgrade the rice processing through technological innovation, improve production efficiency, and strictly control rice quality, thereby providing a reference for the automated, refined, and intelligent upgrading of the rice processing industry.

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1. Introduction

Rice is one of the most commonly consumed staple foods worldwide, and China is a major country in both rice production and consumption. China's rice output and demand have been increasing year by year, making rice an indispensable staple grain on people's dining tables. The quality of rice is closely related to national food security, economic benefits, and the nutritional health of the people. Therefore, strengthening rice-related detection and screening technologies can not only further improve the quality of rice products to meet people's ever-increasing quality demands, but also provide a safeguard for China's food security and enhance China's influence in the international grain market.

The quality of rice is affected by multiple factors, including color, size, and shape, all of which influence the appearance quality of rice and consumers' choices of products. Among these factors, the content of broken rice and impurities is one of the most important indicators for evaluating rice quality. Broken rice has a high water absorption rate, and the starch at the broken surface is easily dissolved into water. An increase in broken rice content will increase the viscosity of cooked rice while reducing its elasticity. Impurities directly affect the quality and marketability of rice, are unfavorable for chewing, and greatly reduce palatability. Therefore, the broken rice and impurities contained in rice not only affect the appearance and taste of rice, but also affect its nutritional value. According to the national standard GB/T 1354-2018, broken rice refers to incomplete rice grains whose length is less than three-quarters of the average length of complete grains in the same batch of samples and which can be retained on a sieve with a round hole diameter of 1.0 mm. Therefore, to improve the quality of rice products, it is of great significance to detect and separate broken rice and impurities in rice.

Table 1: Broken rice content standards of rice and high-quality rice

Rice cultivars	Indica rice			Japonica rice		
Grade classification	Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
Broken rice percentage	≤15%	≤20%	≤30%	≤10%	≤15%	≤20%

Computer vision technology is an inseparable and jointly used technology with machine learning. The two use image understanding, processing, and detection technologies to replace human eyes and brains in analyzing and studying product quality, thereby achieving objective and quantitative detection and evaluation of relevant objects. Computer vision technology can be used to perform operations such as segmentation, measurement, analysis, and recognition on research objects in images, extract the required information, and at the same time cause no damage to products and further reduce errors caused by manual operations. Deng *et al*. developed a detection system based on computer vision and deep learning that can detect and recognize surface defects of carrots such as fractures, fibrous roots, and bad spots, realizing automatic grading of carrots. Jahanbakhshi *et al*. used a method combining deep learning and computer vision as a non-destructive technology for measuring spice quality and developed a system that can evaluate the quality of turmeric powder. Hosainpour *et al*. developed a novel machine vision system combining image processing and artificial intelligence, which images products through a digital camera and realizes quality monitoring of dried mulberries. Gururaj studied a mango grading system based on computer vision technology, identifying mango varieties through maturity stage, shape, texture features, and color, and grading mangoes according to the quality results fed back by image detection. At present, research on detection and recognition of agricultural products using computer vision technology is increasing, and the corresponding detection technologies and research theories are gradually maturing. Technologies such as machine vision and artificial intelligence can make up for the shortcomings of traditional methods, reduce the manpower and material resources required in the production process, make agricultural production faster and more rapidly developed, save costs, and further improve product quality.

Based on machine learning methods, this paper constructs a detection algorithm that can identify broken rice and chalky rice in rice, and combines it with the use of a robotic arm to transform recognition and detection technology into a practical intelligent rice screening method. An operating system integrating intelligent rice detection and sorting is established, with the aim of achieving the application transformation of rice image detection technology and providing a new method that can realize automated, intelligent, and refined rice sorting.

2. Construction of Rice Sorting Dataset

2.1. Rice Image Acquisition

The study used rice commonly available on the market with different characteristics. In the process of constructing the dataset, high-definition camera equipment was used in this project to conduct detailed photography of various types of rice, ensuring the high quality of image data. Subsequently, each image was accurately annotated through manual review to determine its category, and samples that were blurred or incorrectly annotated were removed to improve the accuracy and reliability of the dataset. A total of 1,000 rice images were collected in jpg format to cover as many different states and characteristics of rice as possible. Through this method, subtle differences in rice can be effectively captured, laying a solid foundation for subsequent image processing and model training. The rice image dataset is shown in the figure.

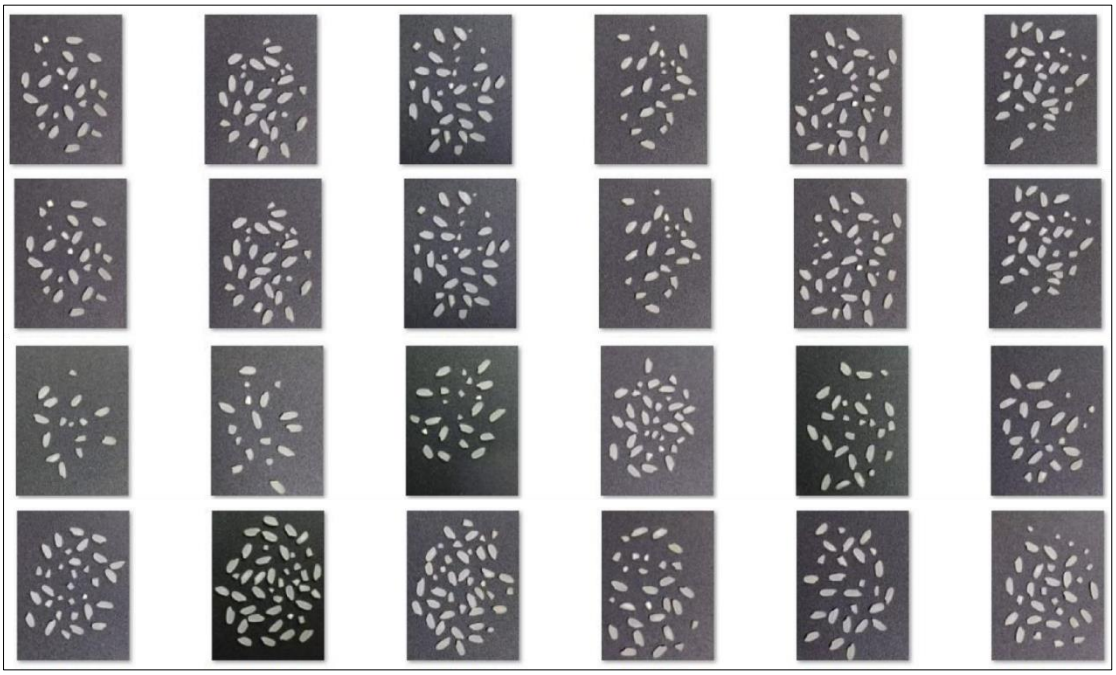


Fig 1: Sample images of rice

2.2. Image Labeling and Feature Parameter Extraction

Binary images of rice were used to add labels to the rice grains in the images. Through the labeling of rice grains, the feature parameters of each rice grain were extracted and calculated, mainly including four feature parameters: area, major axis, minor axis, and the ratio of major axis to minor axis. The area of a rice grain was represented by the number of pixels contained in the grain, and the ratio of major axis to minor axis was calculated by dividing the obtained major axis by the minor axis. The calculated rice feature parameters were output in text format, with one part used as the training set and the other part as the test set for the subsequent construction of the broken rice recognition model. In addition to the data of the four feature parameters, labels of 0 and 1 were also added to the training set data, where 0 represents broken rice and 1 represents whole rice, and these were manually entered into the last column of the text file of the training set.

2.3. Deep Learning-Based Object Detection

Deep learning technology, especially convolutional neural networks, has become one of the core technologies in the field of object detection. By automatically extracting and learning image features, CNNs can achieve efficient recognition and classification of complex image content. In rice sorting technology, this means that rice of different qualities can be identified more accurately, including defective rice, broken rice, and other non-target objects. With technological progress, a variety of neural network models have been proposed and applied to object detection tasks, including Faster R-CNN, YOLO, SSD, and others. These models have achieved optimization in different aspects, such as detection speed, recognition accuracy, and model complexity, providing more choices and flexibility for practical applications.

Proposed by Microsoft Research in 2015 and published in the proceedings of the Conference on Neural Information Processing Systems (NIPS), Faster R-CNN brought a further breakthrough in the field of object detection and became a benchmark model for subsequent research. The innovative approach of Faster R-CNN lies in the introduction of the Region Proposal Network (RPN), which shifted the detection framework toward a more end-to-end system. First, the RPN generates a set of candidate regions or bounding boxes by applying a sliding window mechanism on the feature map, predicting the locations that may contain objects of interest and finely adjusting their positions. Subsequently, the candidate boxes are processed through a pooling layer and then classified and position-refined by a classifier and a bounding box regressor, respectively.

SSD is an efficient object detection algorithm. Its main advantage lies in its ability to complete object detection in a single forward propagation process, thereby achieving high speed and high detection accuracy. It effectively enhances the detection capability for objects of different sizes by predicting bounding boxes and class probabilities on feature maps of different scales. The network structure of SSD includes a basic feature extraction network and a series of additional feature layers, which are designed to capture objects at multiple scales. Each feature layer can generate a certain number of prediction boxes and predict the object category and position within each prediction box. This design allows SSD to simultaneously handle object detection tasks at multiple scales within a single network, without the need for an additional region proposal step.

YOLO is a popular object detection algorithm. Since YOLO was first proposed, it has undergone multiple versions of iteration and improvement. YOLOv1 is the first version of the series. It achieves fast object detection by dividing the image into several small grids and predicting bounding boxes and their corresponding class probabilities within each grid. However, its performance in detecting small objects and some overlapping objects is inferior to that of later versions. YOLOv2, also known as YOLO9000, introduced techniques such as multi-scale training and batch normalization, significantly improving detection accuracy and speed. YOLOv3 further improved performance by utilizing feature maps of three different scales for prediction. In addition, YOLOv3 greatly improved its feature learning capability. YOLOv4 further improved detection accuracy and robustness by introducing new network structures and training techniques while maintaining the speed of YOLOv3. The goal of YOLOv4 is to provide higher detection accuracy while maintaining high speed. YOLOv5 quickly gained widespread attention from the community due to its outstanding performance and ease of use. It performs excellently in practical applications, is easy to deploy, and supports a variety of training optimization techniques, enabling it to run efficiently on various computing resources.

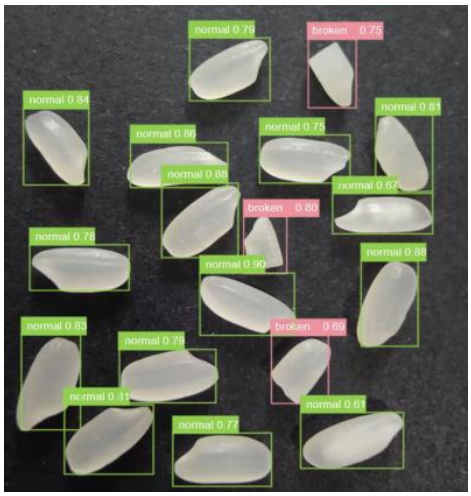


Fig 2: Rice recognition results

3. Design of Intelligent Integrated Rice Processing Line

3.1. Control System Design

This section aims to optimize and enhance the functionality and user experience of traditional combined rice processing equipment systems, achieving more efficient and intelligent rice processing operations. The realization of core functions is achieved through the collaborative work of carefully designed hardware and software components, mainly including the following aspects:

A. **Relay-controlled start and pause:** The design includes 6 relays, each responsible for controlling the start and pause of one rice processing device. After being activated by the overall start switch button, these relays will sequentially start each device according to the preset delay time and order.

B. **Real-time information display:** The display screen shows key operating information in real time, including the current time, ambient temperature, energy consumption and operating duration of each device, and the working status of the 6 rice processing devices.

C. **Fault detection and alarm system:** When any device stops running due to a fault or other problem, the corresponding photoelectric switch will trigger a signal to start the troubleshooting program. If the fault problem is not automatically resolved within a certain period of time, the system alarm will be activated.

D. **Problem diagnosis and repair:** If the alarm system is activated, the operator can intuitively learn which specific device has a problem through the display screen, and then carry out targeted repair and maintenance.

E. **Direct control and adjustment:** During the operation of the rice processing equipment, the operator can directly control and adjust the operating status of each device through the touch screen.

3.2. Main Control Unit Circuit Design

In the control system of the intelligent integrated rice processing line, the circuit design of the main control unit centers on the STM32F407 microcontroller, and its main control unit circuit is shown in Figure 3-8. The main controller controls the operation of other units, ensuring that the rice processing equipment can efficiently and accurately complete various tasks. The main controller can process temperature sensor data in real time, communicate with the touch screen, and respond quickly when abnormal conditions are detected, such as issuing alarm signals and pausing the operation of relevant equipment.

3.3. Fault Detection and Alarm Module Design

In the control system of the intelligent integrated rice processing line, the circuit diagram of the fault detection and alarm module is shown in the figure. Photoelectric switches are used to monitor the material presence status of the equipment in real time, temperature sensors are used to monitor the ambient temperature in real time, and a buzzer is used for system alarms. When the system detects that the photoelectric switch indicates excessive material saturation within a preset time or that the temperature measured by the DS18B20 exceeds the set range, the STM32F407 determines through programmed logic that the system is abnormal. At this time, the buzzer is driven to emit a continuous alarm sound to warn the operator to pay attention and check the equipment in time. If it is a material accumulation problem, the system pauses the upstream equipment with a certain delay and order, and continues to start the upstream equipment after the material accumulation problem is resolved. At the same time, the main control unit can show the specific faulty equipment to the operator through the serial port display screen, so as to quickly locate and solve the problem. This design can not only quickly and effectively notify the operator to take corresponding troubleshooting measures, but also minimize the downtime of equipment due to faults and ensure the continuous operation of the production line.

4. Conclusion

This paper researches and designs an intelligent rice processing and sorting system. Aiming at the problems existing in traditional rice processing technology, such as complex operation, difficult maintenance, and high broken rice rate, improvements and optimizations were carried out by introducing advanced technologies and equipment. The main research results of this paper include:

A. **Design of rice processing technological process:** This paper conducts a comprehensive optimization design of the traditional rice processing technology, especially introducing efficient sorting equipment at the final stage of the processing technology, and realizing accurate classification and screening of rice through machine vision technology. This improvement effectively reduces the broken rice rate and improves the rice yield and quality.

B. **Design of an efficient control system for rice processing equipment:** In order to improve the automation level and efficiency of rice processing, this paper researches and designs an efficient control system. The system also has fault detection and alarm functions, and can respond promptly to various abnormal conditions to ensure the stable operation of the processing process.

C. Experimental results show that the system and method proposed in this study have achieved the expected goals in terms of rice processing efficiency, broken rice rate control, and product quality improvement, verifying the application value and technical advantages of the system in actual rice processing production lines. The research in this paper not only provides a new technical solution for the rice processing industry, but also opens up a new research direction for the application of machine vision in the field of agricultural product processing.

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