Smart Agriculture 9

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Editors

Advanced Sensing and Robotics Technologies in Smart Agriculture

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Smart Agriculture

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Preface

Conventional agricultural approach faces challenges to meet the requirements of continuously growing population, and simultaneously, it is not in a sustainable manner. In addition, the increasing labor cost and shrinking labor pool threaten the agriculture development. Smart agriculture adopts advanced technologies and data-driven production operations to improve the agricultural production. Though the smart agricultural technology concept has been proposed decades ago, it does not come to practical applications until very recently, because of recent progress in advancing sensing, artificial intelligence, internet of things, and automation. With rapid technology progress in smart agricultural technology, it is required to propose a book to summarize the progress comprehensively and systematically.

The current book aims to present the recent technology progress in smart agriculture area, with former five chapters focusing on reviewing innovative technologies and the latter two chapters on honeysuckle detection and wheat lodging monitor. Seed quality plays an important role in guaranteeing good yield, and Chap. 1 works on detecting seed quality using appearance characteristics. After the seed germination, it is important to sensing the growing status of the crops, which generates the development of Chap. 2. Chapter 3 then specifically pays attention to greenhouse crop phenotyping, followed by Chap. 4 on tomato and apple on-site intelligent grading systems. The last review chapter works on reviewing harvest robotics. Following Chap. 5 review chapters, Chap. 6 improves YOLOv5s for infield honeysuckle detection under natural lighting, and Chap. 7 monitors wheat lodging conditions using improved MobileNetV3. To sum up, the seven chapters provide a general idea on the smart agricultural technology progress in recent years.

Drs. Yuliang Yun, Wenyi Sheng, and Zhao Zhang, the editors of this book titled *Advanced Sensing and Robotics Technologies Applied in Smart Agriculture—State-of-the-Art Technologies* have been working in the smart agriculture area for decades, and their expertise, knowledge, research experience and practical applications guarantee the high-quality content of this book. This book provides a comprehensive and timely information source for readers who are interested in learning about the important subject of smart agriculture.

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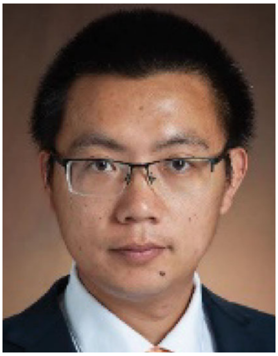

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Contents

Chapter 1
Research Progress on Seed Appearance Recognition for Major Crops

Yuliang Yun, Dehao Li, Xueke An, and Zhiyong Ma

Abstract The appearance characteristics of crop seeds can provide information about the quality, size, and variety of seeds. Through continuous research on seed appearance recognition technology, automated grading and screening of large-scale seed samples can be realized to ensure the purity and consistency of seeds and improve the quality and efficiency of crop production and breeding. Therefore, strict quality testing and identification of crop seeds are key factors in ensuring high yield, high quality, and crop safety. Currently, the main categories of appearance recognition technology include manual recognition, machine vision technology, and spectral imaging technology. Machine vision technology simulates the visual function of the human eye and combines image processing and analysis algorithms to achieve rapid and accurate identification of seed appearance characteristics. Spectral imaging technology, specifically near-infrared spectroscopy (NIR), analyzes the spectral information on the surface of seeds to reveal their internal chemical composition and structural characteristics, enabling non-destructive detection of seed varieties and quality. The application of machine vision recognition technology and spectral imaging technology provides a new solution for crop seed appearance recognition, improving the accuracy and efficiency of seed recognition and promoting the optimization of the agricultural production chain and the competitiveness of agricultural products in the market.

Keywords Crop seed · Appearance recognition · Machine vision · Spectral imaging

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1.1 Introduction

As the global population continues to grow and urbanization accelerates, food security has become one of the major challenges facing the world. As the core of agricultural production, the quality of seeds is directly related to the growth and development, yield, and quality of crops, which in turn affects the stability and security of the entire food supply chain. Therefore, improving the quality of seeds and ensuring their health and genetic superiority plays a crucial role in enhancing the efficiency of agricultural production, guaranteeing food security, and realizing sustainable development.

High-quality seeds are a good starting point for crop growth. In agricultural production, the main crop seeds include rice, wheat, peanuts, corn, cotton, soybeans, and other seeds, as shown in Fig. 1.1. In this paper, we will also delve into the appearance recognition techniques applied to these six types of crop seeds. Crop seeds are not only an important part of global food production but also play a central role in guaranteeing global food security and promoting the process of agricultural modernization. By exploring the current development and future trends of crop seed appearance recognition technology, we will gain a deeper understanding of the needs for seed quality assessment and provide strong support for the sustainable development of global agricultural production.

As the foundation of crop production, seed quality testing and accurate variety identification are of great significance in achieving high-yield, high-quality, and safe crop production. The quality of seeds is directly linked to crop growth and harvest yield. High-quality seeds ensure optimal germination and growth potential, enhance crop resistance to pests and diseases, and reduce the need for pesticides

Fig. 1.1 Seed of major crops: (**a**) Rice seed; (**b**) Wheat seed; (**c**) Peanut seed; (**d**) Corn seed; (**e**) Cotton seed; (**f**) Soybean seed

and other resources that are harmful to crops. This effectively improves crop yield and quality. Thus, quality control starting from seeds is crucial for optimizing the entire agricultural production chain and enhancing the market competitiveness of agricultural products.

Accurate identification and quality screening of seeds form the basis for selecting superior seeds for breeding and management in agricultural operations. With the rapid development of information technology and biotechnology, seed appearance recognition technologies have become a vital research area in modern agriculture. These technologies not only enhance the accuracy of seed screening and classification but also significantly increase processing speed and reduce labor costs. Variety identification of seeds also provides essential data and samples for agricultural scientific research, supporting the conservation and utilization of crop genetic breeding and genetic resources. Furthermore, through precise seed appearance recognition, early detection of seed diseases and defects is possible, enabling effective quality control and risk management prior to planting, thereby ensuring overall crop quality and yield.

The development and application of seed appearance recognition technology brings great potential and opportunities for agricultural production. By using machine vision and image processing technology, features such as shape, texture and color of seeds can be quickly and accurately extracted and analyzed to achieve automated identification and classification of seeds; in addition, spectral imaging technology is also a key technology for seed appearance recognition, which achieves high-precision identification and classification of seed appearance by measuring and analyzing the spectral features of seeds at different wavelengths. Different seeds present different features in absorption, reflection and transmission spectra, including color, texture, chemical composition, etc. Through spectral imaging technology, a large amount of spectral data can be acquired, thus obtaining more comprehensive and accurate information on seed appearance.

Traditional seed identification methods rely heavily on human expertise and visual inspection by relying primarily on manual visual inspection and manual categorization [1]. This approach suffers from the disadvantages of inefficient identification, subjectivity, and high labor costs. The need to improve the accuracy and efficiency of seed quality assessment has driven the development of various technological solutions aimed at automating these processes. The comparison between appearance recognition technology and traditional manual recognition under different features is shown in Table 1.1.

The introduction of machine vision systems in the early 2000s marked a major shift in seed technology. As detailed by Patel and Kumar [2], machine vision employs cameras and image processing algorithms to analyze physical characteristics of seeds, such as shape, size, and color. These systems provide a faster and more consistent alternative to manual inspection. For example, Martin and Davis [3] emphasized the capability of advanced machine vision systems to conduct high-throughput and high-precision seed sorting, greatly enhancing the productivity of seed processing operations.

Table 1.1 Comparison of seed appearance inspection techniques

Features	Seed Appearance Recognition Technology	Traditional manual identification of seed appearance
Automatization	Automatic extraction and recognition of seed features using machine vision or hyperspectral techniques	Reliance on manual visual inspection and judgment
Accuracy	High accuracy with consistency and reliability	Subjective factors interfering, large errors
Speed	Fast processing of large numbers of seed samples, real-time or high-throughput assays	Relatively slow, requiring more time and human resources
Data analysis and recording	Quantitative analysis, digital records and statistics	Subjective description, difficult to analyze quantitatively
Scaleability	Scalable to handle large-scale seed samples	Difficult to scale up to large-scale seed sample testing needs
Automatic defect detection	Can automatically detect and recognize seed defects, diseases, and mutations	Lack of automated defect detection capabilities and reliance on specialized knowledge and experience

Parallel to the development of machine vision, neural networks and deep learning algorithms are gaining increasing prominence in the field of seed technology. Lee and Park reviewed deep learning models developed for seed quality assessment [4], emphasizing their capacity to learn complex patterns in data, which may be overlooked by traditional machine learning methods. Studies conducted by Gomez and Lee demonstrated the efficiency of convolutional neural networks (CNNs) for seed recognition, showcasing their superior accuracy in distinguishing highly similar seed varieties based on subtle visual cues [5].

Another significant technological advancement is the utilization of spectral imaging, which offers a non-destructive approach to assess seed quality. Spectral imaging captures data at multiple wavelengths, enabling a comprehensive understanding of the chemical and physical properties of seeds [2]. This method proves particularly valuable in detecting internal defects or contaminants that are not visible to the naked eye. Nelson conducted research on the application of electromagnetic and optical spectroscopy in quality assessment, demonstrating how these techniques can effectively enhance the seed sorting process by providing detailed insights that surpass visual analysis [6].

The integration of these advanced technologies has not only improved the accuracy and efficiency of seed quality assessment, but has also facilitated the development of high-throughput systems capable of rapidly processing large quantities of seeds. The systems discussed by Larson and White and Wu and Sun have now become integral parts of the seed industry, accelerating decision-making processes and significantly reducing the amount of labor required for seed sorting and classification [7, 8].

In addition, the development of seed technology has been influenced by the increasing emphasis on sustainable agricultural practices. Advanced seed sorting technologies help reduce waste by accurately identifying viable and non-viable seeds, ensuring that resources are not wasted on seeds with poor germination prospects. This is critical in an era where the environmental impact of agricultural practices is under scrutiny.

In summary, the field of seed technology has made significant advances over the past two decades, driven by the integration of machine vision, deep learning, and spectral imaging. These technologies have transformed seed quality assessment from a labor-intensive, error-prone process to a more reliable, efficient, and automated operation. As these technologies continue to evolve, they are expected to further improve the accuracy and efficiency of seed sorting and classification, supporting sustainable agricultural practices and meeting the growing global demand for food.

1.2 Basic Features of Crop Seed Appearance

Seed quality is critical to successful agriculture because it directly affects germination rates, plant health, and crop yields. Key attributes of seed appearance include size, shape, color, and texture. Each of these characteristics can provide valuable insights into seed health and the potential for successful cultivation. In this context, understanding the relationship between seed appearance and quality is crucial for optimizing agricultural outcomes.

Seed morphology description:

SIZE: Seed size is a fundamental characteristic that is often associated with seed vigor and energy reserves. Larger seeds typically contain more resources to support early growth stages, resulting in more robust seedlings. Technologies such as machine vision systems have been used to accurately and consistently measure seed size, which can aid in the sorting process for classifying seeds based on their potential vigor [8].

Shape: Seed shape can vary greatly between species and is often a key determinant of species identification. Shape also affects the mechanical seeding ability of seeds and thus their suitability for modern agricultural practices. Figure 1.2 shows several types of peanut seeds with different shapes. Automated sorting systems using image analysis are capable of differentiating seeds based on geometric parameters, ensuring that irregularly shaped seeds that do not meet the requirements of a particular planting device are screened out [9]. Dana et al. investigated an image description method for the shape and color of flax seeds, extracting four shape features and three color features for seed classification. Principal component analysis and the unweighted

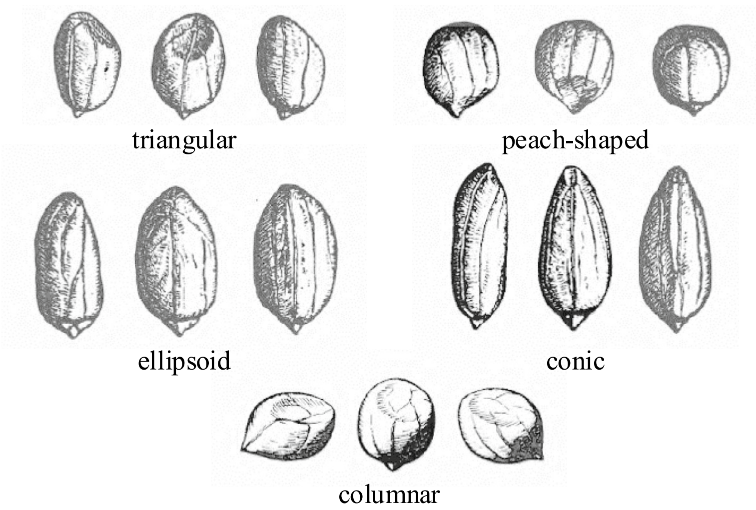

Fig. 1.2 Peanut seed shapes

group averaging method (pair group method with arithmetic mean (UPGMA)) were used for qualitative cluster analysis [10].

Color: The color of seeds can indicate their maturity, type, and sometimes even exposure to diseases or pests. For instance, discoloration may suggest a fungal infection or improper storage conditions, which can compromise seed quality. Advanced imaging techniques, such as hyperspectral imaging, go beyond visible color analysis by capturing data at multiple wavelengths to detect subtle color variations that indicate seed health [6]. Yan et al. extracted the color information of crown and side images of maize seeds under RGB and HSV color models [11], and discriminated them using the Fisher discrimination method, with correct recognition rates of different varieties of maize seeds of up to 1.5 times higher than those of other varieties. The correct recognition rate for different varieties of corn seeds was 93.75%. At present, the mainstream peanut seed screening equipment is mainly the traditional mechanical screening machine and the color sorter according to the appearance of the crop seed color photoelectric color selection. Autoline is a company specializing in the production of optical classifiers, its optical classifiers can be agricultural products, food, pharmaceuticals, etc. for accurate grading, screening and classification. The United States of America's photoelectric color sorter are used in Japan Satake Co., Ltd. production of equipment, in addition to Satake and Switzerland's Buhler, South Korea's Daehara, Norway's TOMRA and other companies are engaged in agricultural products, color sorter of the relevant research and development. The device diagrams are shown in Fig. 1.3.

Texture: The surface texture of seeds can exhibit characteristics such as smoothness, roughness, or the presence of hairs or other structures. These texture features can impact seed-soil interactions, moisture absorption, and even susceptibility to

Autoline Optical Classifier, USA

Japan Satake Machinery
EZS Series Sorting Machine

Buhler, Switzerland
SORTEX F BioVion color sorter

Fig. 1.3 Related color sorting machines

diseases. Machine vision and deep learning algorithms are particularly effective in analyzing these complex patterns on seed surfaces, providing detailed assessments that can predict quality based on texture features [5]. In 2008, Manickavasagan et al. utilized a monochromatic image system to capture grayscale images of eight different species of wheat. They extracted 32 texture features and achieved correct recognition using linear discriminant and quadratic discriminant analysis, with recognition rates ranging from 73 to 100% [12].

Seed appearance not only aids in seed identification and classification but also serves as a visual indicator of seed health and quality. High-quality seeds typically demonstrate uniformity in size, shape, and color, and are devoid of physical defects and disease symptoms.

Health assessment: Visual inspection of seeds can unveil signs of diseases, insect infestation, or physical damage. For instance, seeds exhibiting unusual spots or color changes may be infected or may have been stored under deteriorating conditions. Advanced imaging techniques, such as spectral imaging, enable more comprehensive inspection by detecting chemical changes in seeds that are not visible to the naked eye [2].

Quality prediction: The overall appearance of a seed can serve as a reliable predictor of its germination ability and potential yield. Automated systems equipped with artificial intelligence can swiftly analyze large quantities of seeds, evaluate their appearance based on predetermined quality parameters, and effectively predict their vigor [4].

Sorting and categorization: Automated sorting systems utilize attributes of seed appearance to differentiate high-quality seeds from low-quality ones. This sorting process ensures that only the best seeds are planted, which is crucial for maximizing crop yield and quality. Such systems have become integral to modern agriculture, where accuracy and efficiency play vital roles in productivity [3].

The appearance characteristics of crop seeds are not only influenced by genetic and environmental factors but also serve as a crucial basis for assessing seed quality in agricultural production. By accurately analyzing these characteristics, the efficiency of seed selection and classification can be significantly improved, ensuring that healthy and high-growth-potential seeds are chosen for planting. Moreover, these appearance indicators are also linked to food safety and the ultimate quality of agricultural products. High-quality seeds are more likely to yield high-quality crops, thereby enhancing agricultural output and market competitiveness. With technological advancements, particularly in the fields of image processing and data analysis, a more precise assessment and application of seed appearance characteristics can be achieved, leading to efficient and sustainable agricultural production. This optimization of resource utilization and reduction in agricultural production costs will also contribute to environmental protection and promote the development of agriculture in a more modern and automated direction.

1.3 Methods of Recognizing the Appearance of Crop Seeds

At present, the recognition methods for crop seed appearance can be categorized into traditional manual recognition, machine vision analysis technology, and spectral imaging analysis technology. Manual recognition is a commonly employed method for seed appearance assessment. It relies on human experience and expertise to classify and evaluate seeds by directly observing and recognizing their appearance characteristics. Machine vision utilizes computer vision algorithms and image processing techniques for automated identification. It enables computer systems to understand and analyze image or video data by capturing seed images, extracting image features such as color, shape, and texture, and employing machine learning algorithms for classification and identification. Deep learning and neural networks are integral components of machine vision. Spectral imaging analysis techniques, on the other hand, are non-destructive and rapid. Hyperspectral techniques, in particular, enable the acquisition of a large amount of spectral information, allowing for more accurate capture and analysis of seed appearance features.

1.3.1 Manual Identification Methods

In crop seed appearance identification, manual identification relies mainly on the experience and intuition of the observer to determine the quality and type of seed. However, manual identification methods have shown significant limitations in the context of modern agricultural technology, particularly in terms of processing efficiency and accuracy. This method heavily relies on the subjective judgment and experience of the operator, resulting in inefficiencies when processing seeds on a large scale, as well as poor consistency and reproducibility of results. Moreover, manual identification is susceptible to individual fatigue and distraction, which can lead to increased misjudgments, ultimately affecting the quality of the final selection, as shown in Fig. 1.4. These factors render manual recognition methods unsuitable for modern seed processing requirements, necessitating the urgent need to enhance automation, accuracy, and processing speed through modern techniques such as machine vision recognition technology and spectral imaging technology.

Fig. 1.4 Manual seed sorting

1.3.2 Machine Vision Recognition Technology

Machine vision is a field of artificial intelligence that involves enabling computers and systems to extract valuable information from images, videos, and other visual inputs, and to take actions or provide recommendations based on that information. Common tasks in machine vision include image classification, object detection, object tracking, and content-based image retrieval. To accomplish these tasks, machine vision relies on techniques such as image processing and pattern recognition, including image filtering, edge detection, feature extraction, target detection, image classification, and deep learning.

1.3.2.1 Principle of Machine Vision Technology

Machine vision technology is a technique for recognizing, classifying, and locating target objects by using cameras, image sensors, and digital processing systems to simulate the visual perception of the human eye. The development of this technology stems from the need for automation and precise control, especially in a wide range of applications such as industrial manufacturing, agriculture, medical diagnostics, and many other fields.

The basic workflow of a machine vision system includes steps such as image acquisition, image preprocessing, feature extraction, recognition and decision making. The machine vision inspection process is shown in Fig. 1.5.

Image acquisition: First, images of the target object are captured by means of cameras or other image-capturing devices. These devices must be able to ensure image quality under various environmental conditions for subsequent processing.

Image pre-processing: The purpose of image pre-processing is to improve image quality for subsequent processing. This includes noise removal, contrast adjustment, brightness adjustment, etc. Preprocessing may also include image normalization, such as normalizing image size and color depth.

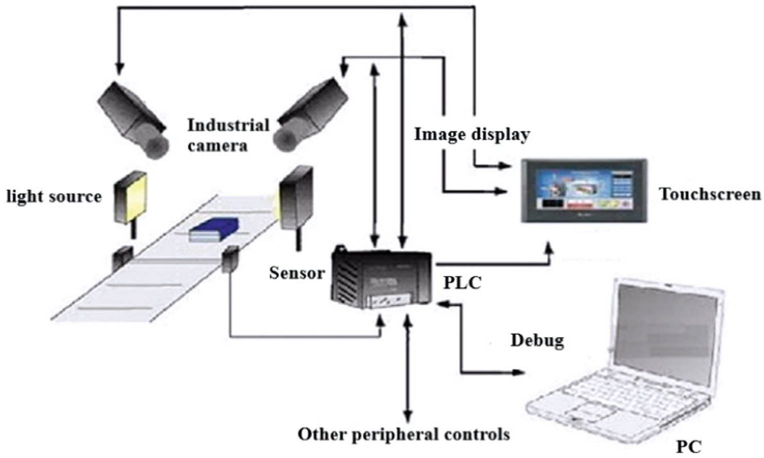

Fig. 1.5 Machine vision inspection process diagram

Feature extraction: extracting useful information from the preprocessed image, such as edges, corner points, texture, etc. These features should be representative and distinguishable to effectively support subsequent image analysis.

Recognition and Decision Making: Finally, based on the extracted features, classification algorithms (e.g., Support Vector Machines, Decision Trees, Neural Networks, etc.) are used to recognize targets in the image. This step usually involves complex algorithms and a large number of computations, and is the most critical part of the whole machine vision system. This paper studies the appearance recognition technology of major crop seeds. The process of crop seed appearance feature extraction is shown in Fig. 1.6.

As technology evolves further, machine vision systems are beginning to merge with other technologies such as robotics, the Internet of Things, and edge computing to form smarter, more automated solutions. For example, the combination of machine vision and robotics allows robots to perform more precise operations in complex environments, such as automated picking and assembly. In addition, with the popularity of IoT devices, machine vision systems are being integrated into security monitoring in smart homes and smart cities to provide real-time image analysis.

1.3.2.2 Machine Vision Recognition Technology Development and Application

The development of machine vision commenced in the 1950s, coinciding with the emergence and progress of computer science. Initially, these techniques found applications primarily in the medical and military domains, as the imaging needs of these fields drove the advancement of related technologies. From the 1970s to the 1990s, with the improvement in computer processing power and the advancements in digital