Applications of Machine Vision-Based Sorting System in Agricultural Field

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Abstract. Agriculture is one of the basic industries that human beings rely on for their survival, providing the necessary food as well as other kinds of products for people's survival. It is not only the basic pillar of economic development but also provides employment and income opportunities for countless people. As technological innovation accelerates across industries, automated classification systems have become ubiquitous across industrial sectors, which provides strong conditions for the application of visual recognition technology. Despite the significant advantages of machine vision-based sorting systems, they are still not fully popular in the agricultural field and mainly rely on traditional manual sorting. Therefore, the research theme of this paper is to analyse the sorting system, explain the principal knowledge of machine vision technology, and explore its practical application in the agricultural field. By conducting theoretical and case study analyses, the significant advantages of machine vision sorting systems are systematically clarified. Finally, this research establishes a conceptual framework and actionable reference for agricultural sorting automation and inspires future researchers.

Keywords: Agriculture, Machine Vision, Sorting System, Artificial Intelligence

1 Introduction

The sorting of agricultural products can play a pivotal role in agricultural production. For a long time, the main sorting method in the agricultural market was manual sorting, which has the disadvantages of inefficiency and high cost and is also prone to errors stemming from inter-individual perceptual variance and biological constraints such as eyesight, stress, and cognitive depletion. In the past, automated sorting devices lacked applicability, could not guarantee the quality of the sorted products, and were difficult to operate and costly to maintain, so the efficiency, accuracy, and quality of product sorting is a problem [1]. Considering these specific factors, the future development direction of the sorting system should be combined with machine vision technology and artificial intelligence. A sweet potato sorting machine based on the computer vision channel of YOLOv8 can segment and track sweet potatoes according to the bumpiness of their surface and analyse the quality in real time. Regardless of the experimental samples, the system demonstrated estimation accuracy rates of 96.7% for length and

J. Iqbal (ed.), *Proceedings of the 2025 2nd International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2025)*, Advances in Engineering Research 272,
https://doi.org/10.2991/978-94-6463-821-9_55

90.3% for width when measuring sweet potato dimensions, with an overall accuracy of 82.6% [2]. The sorting device based on machine vision technology can greatly reduce the manual intervention and the sorting error rate, thus greatly improving the efficiency. Traditional research in the development of machine vision-based sorting systems has made some progress, but in the elaboration of different kinds of crops, the advantages embodied by the machine vision-based sorting device are still not clear. In this paper, in the context of the application of machine vision-based sorting systems, this paper systematically examines the technological framework of machine vision and the composition of the sorting system, as well as the various types of applications and advantages of machine vision-based sorting systems in agricultural scenarios, to provide theoretical support for the inclusive development of digital agriculture.

2 Overview of Sorting System and Sorting Demand Analysis

2.1 Composition of the Sorting System

A robot sorting system is a device that classifies, grades, and sorts of target objects through automation technology (e.g., robotic arm, machine vision). It mainly comprises an image acquisition unit, a data processing unit, a machine execution module, and a state detection module. Its working principle is to capture the two-dimensional images in the external environment through the visual sensor function in the image acquisition unit and convert them into analogue signals and then convert the analogue signals into digital signals through an analogue-to-digital converter. Afterwards, the processor in the data processing unit analyses and processes the digital signals using predefined algorithms, generates the corresponding control instructions and transmits them to the mechanical actuator unit, so that the system can simulate human vision to identify the products and automatically trigger the mechanical actuator unit to complete the sorting task [3]. In the field of agriculture, the main goal is ‘perception-analysis-processing’ to achieve efficient classification and quality control of agricultural products.

2.2 Analysis of Key Requirements of Agricultural Product Sorting System

Traditional manual sorting is always limited by physiological limits, which means that human efficiency decreases as the working time increases. In addition, prolonged engagement in manual sorting operations elevates occupational risks of chronic musculoskeletal pathologies stemming from repetitive motion patterns. This shows that the need for efficiency is one of the core needs that differentiates the advantages of manual sorting from those of sorting systems. In tomato sorting, automated sorting devices can achieve thousands of tomatoes per minute compared to an average of 726 per hour by experienced workers [4-5] (Table 1). Utilizing Raspberry Pi 4B's computational architecture, Hou et al. engineered a robotic tomato grading system employing a manipulator as the end-effector mechanism, which processes up to 1,350 tomatoes per hour and achieves an overall sorting accuracy of over 99.1% [6]. The error rate of manual sorting gradually increases with time due to subjectivity and visual fatigue, while machine sorting can achieve standardised grading through deep learning algorithms. Wang et al. developed an automated system for sorting white mushrooms, utilizing OpenCV 2.4.10 and Visual Studio 2010 as the control software, with an average of 102.41 mushrooms/min, and an accuracy rate of 97.42% (Table 1). Compared with manual grading, the grading process saw a 38.86% increase in speed, and a 6.84% improvement in accuracy [7]. In the future, the number of people involved in sorting and harvesting of agricultural products will continue to decrease due to the diversity of the society and the aging social situation continues to rise, while the labour required for picking fruits accounts for 60-70% of the entire production process and sorting fruits accounts for 30-40%, which makes the high labour cost also one of the main challenges for fruit farmers [8], which indirectly proves that in the future long term cost advantages offered by machine sorting. Sofu et al. designed an automatic apple sorter based on the C4.5 classification algorithm. The actuating part consists of rollers, carriers, and grade conveyors. The modular design can reduce the maintenance cost [9].

Table 1. Performance requirements for different sorting methods

Key requirements	Manual sorting	Machine sorting
Efficiency	Hundreds per minute	Thousands per minute
Quality	Higher error rate	Lower error rate
Cost	Long-term labour cost	Maintenance and commissioning cost

3 Overview of Machine Vision Technology

3.1 Machine Vision Technology Principles and Processes

Machine vision is the use of machines to simulate the human eye to identify and measure the technology. Its origins can be traced back to the statistical recognition model introduced in the 1960s [10]. A machine vision system typically consists of three components: image acquisition, data processing, and deployment and execution [11]. The main working principle is to collect optical information of target objects through image sensors, combine image processing algorithms and deep learning models to achieve object classification and recognition functions, and finally deploying the system to execute control and execution commands. The workflow of the machine vision system is illustrated in Fig. 1 [12].

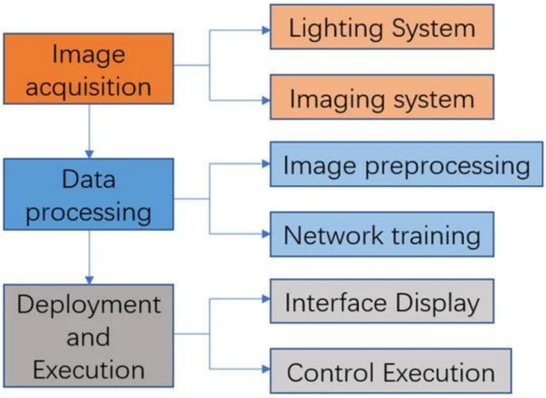

Fig. 1. The workflow chart of the machine vision system [12].

3.2 Image Acquisition

The initial stage in machine vision is image acquisition. Using industrial cameras (CCD and COMS are two mainstream choices) with a ring LED light source, backlight light source, etc., to capture the optical information of the target object and transmit the image data to the processing unit through a high-speed interface. The quality of image acquisition will directly affect the subsequent processing and analysis. The general principle of machine vision is shown in Fig. 2 [13].

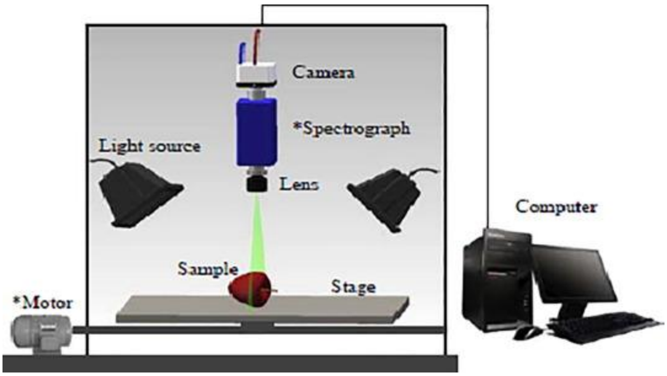

Fig. 2. General principle of machine vision [13].

3.3 Data Processing

Immediately following is the data processing part, including key technologies such as image segmentation and feature extraction. In the general sorting process, people judge the eligibility by observing the surface of the crop, for example, judging the ripeness or immaturity based on the colour or contour, and judging whether it is rotten and spoiled based on the surface condition, but in the machine's perspective, it is necessary to segment the image of the object and the background first. The colour space model (RGB, HIS, LAB) is used to obtain information, and then filtering and thresholding are performed to segment the background and achieve the classification of the object. To isolate the potato image and remove the background color, L. Yao et al. applied a thresholding technique where the differences R-B<T1 and G-B<T2 to segment the potato image, then the RGB color space was transformed into the HSV color space to extract the saturation and finally binarised with the S-component [14].

3.4 Deep Learning

In the last stage, the model of deep learning performs the function of recognizing objects. Neural network learning is a branch of automated learning, If machine vision gives the machine eyes, then the deep neutral network framework is the brain. It represents a type of AI itself, which means it is capable of human-like behaviour, such as finding useful knowledge from previous databases for learning, improving, and summarising based on previous experience, thus enabling computers to solve deeper and more difficult problems [15]. Recent advances in computer vision have meant that Convolutional Neural Network (CNN) architectures have been recognized as the standard deep learning model for image-based machine learning [16]. Kuznetsova et al. devised a computer vision system for detecting apples aimed at an orchard based on the YOLOv3 algorithm (a CNN-based target detection algorithm), which incorporates a unique pre- and post-processing system to make it fully adapted to an apple-harvesting Robot. The actual data shows that the average time spent to complete the apple detection is 19 ms, the false detection rate is 7.8%, and the leakage rate is 9.2%, which is lower compared to the analogous system [17]. The architecture of the convolutional neural network is shown in Fig. 3 [15].

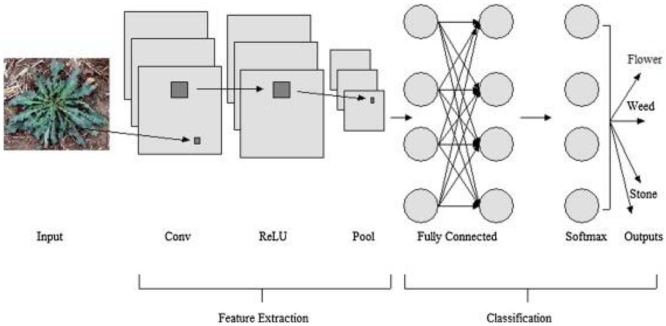

Fig. 3. Convolutional neural network architecture [15].

4 Applications in Agriculture

4.1 Implementation of Machine Vision-based Sorting System in Sorting Regular-Shaped Agricultural Products

With a yearly global yield exceeding 80 million metric tons, apples maintain their position among the world's most widely cultivated and consumed fruits [18], and China makes a significant contribution to the world's apple production [19]. The by-products made from apples, such as juice and jam, may be more valuable than the apples themselves, so it is crucial to enhance the quality of apple sorting. Numerous researchers from both domestic and international contexts have developed devices for sorting apples based on machine vision techniques. Jia et al. designed an apple-picking system based on Mask R-CNN by examining a random test set of 120 images of apples, which resulted in accuracy and recall of 97.31% and 95.70%, respectively [20]. Unay proposed a cascaded CNN with two novel architectures to design a multi-category apple grading system. The apples are first classified as healthy or defective by CNN model 1, and then CNN model 2 further discriminates the first model to classify the apples labelled as defective into one of the set four defective categories, and the grading accuracy can reach 90.5% [21]. The grading process is shown in Fig. 4 [21].

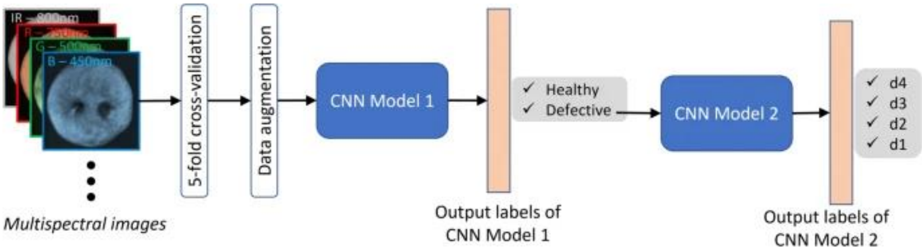

Fig. 4. Flowchart of grading process for the two-plex level [21].

4.2 Implementation of Machine Vision-based Sorting System in the Field of Sorting Irregularly Shaped Agricultural Products

Potatoes rank among the world's most significant crops. As early as 2018, China's potato cultivation area exceeded 4.81 million hectares, with an output of 90.32 million tonnes. These figures account for 27.36% of the global total cultivated area (24.53% of worldwide potato output) dedicated to this crop [22]. Potato is rich in carbohydrates, proteins, trace minerals and dietary fiber [23], making it popular among the public because of the abundance of processed products (starch, crisps, French fries). However, the standardization of potato classification in post-harvest operations remains challenging due to substantial morphological diversity, inconsistent quality parameters, and irregular surface topography, necessitating continued reliance on skilled laborers for visual inspection-based manual sorting [24]. Therefore, a sorting device using a machine vision system is very necessary. Su et al. developed a potato grading system, which consists of a softmax classifier and CNN modules, the softmax-integrated computational architecture demonstrated 94.4% precision in volumetric assessment tasks, whereas the convolutional neural network paradigm attained 94.5% efficacy in dimensional profiling, along with 91.6% reliability in surface morphology evaluation. It also maintained robust anomaly identification capabilities through experimental validation and was able to successfully detect abnormal defects [25].

5 Conclusion

This paper systematically discusses the application of a machine vision-based sorting system in the field of agriculture. By analysing the principle and core technology of machine vision technology, the composition and advantages of the sorting system, and combining it with the actual cases of sorting devices in apple and potato sorting, it verifies the excellent advantages of machine vision-based sorting system in improving the efficiency and quality of agricultural products sorting. However, the technology also faces many challenges. Experience gained from designing sorting devices suggests that the high cost of complex structures and the difficulty of recognising stacked objects are the main challenges at present. To meet these challenges, it is crucial to reduce costs and improve recognition techniques. In conclusion, the application of machine vision-based sorting systems not only optimises traditional sorting methods, but also lays the foundation for the development of automation in the agricultural sector, and it is, therefore, more researchers and industry players will promote and study this type of technology to meet future challenges of global food efficiency and security.

References

1. Wang, C., Wei, Z., Yan, C.: 'A review of sorting robots based on machine vision technology. Science Technology and Engineering, 2022, 22 (03), pp 893-902
2. Xu, J., Lu, Y.: 'Prototyping and evaluation of a novel machine vision system for real-time, automated quality grading of sweetpotatoes ', Computers and Electronics in Agriculture, 2024, 219, 108826
3. Wang, C., Yan, C.: 'A review of research on the application of machine vision technology in sorting systems '. Manufacturing Technology and Machine Tools, 2020, (05), pp 32-37
4. Afolabi, A.: 'Selected anthropometric study and energy required for grading tomatoes by farmers using hoes in Zaria', Ama-Agricultural mechanization in Asia Africa and Latin America, 2016, 47, pp 41-46.
5. Nyalala, I.: 'Weight and volume estimation of single and occluded tomatoes using machine vision. International Journal of Food Properties ', 2024, 24(1), pp 818–832.
6. Hou, L., Liu, Z.: 'Tomato Sorting System Based on Machine Vision', Electronics 2024, 13, 2114
7. Wang F., Zheng, J.: 'Automatic sorting system for fresh white button mushrooms based on image processing, Computers and Electronics in Agriculture', 2018, 151, 8(01), pp 416-425
8. Vougioukas SG (2019) Agricultural robotics. Annu Rev Control Robot Auton Syst 2:365–392
9. Sofu, M. M., Er O.: 'Design of an automatic apple sorting system using machine vision,Computers and Electronics in Agriculture', 2016, 127, pp 395-405

10. Mei, Z., Yan C., Hu Het al.: 'Design of waste sorting system with robot and machine vision. Mechanical Design and Manufacturing', 2022, (04), pp 275-278
11. Zhu, Y.: 'Research progress and prospect of machine vision technology', J. Graph. 2020, 41, 20.
12. Yang, Z.; Ma, W.: 'The Application Status and Trends of Machine Vision in Tea Production', Appl. Sci, 2023, 13, 10744.
13. Anuja, Bhargava.: 'Fruits and vegetables quality evaluation using computer vision: A review',Journal of King Saud University-Computer and Information Sciences, 2021, 33, 3, pp 243-257
14. L. Yao, L. Lu, R. Zheng.: 'Study on Detection Method of External Defects of Potato Image in Visible Light Environment', 2017 10th International Conference on Intelligent Computation Technology and Automation (ICICTA), Changsha, China, 2017, pp 118-122
15. Melvyn L. Smith, Lyndon N. Smith, Mark F. Hansen.: 'The quiet revolution in machine vision - a state-of-the-art survey paper, including historical review, perspectives, and future directions', Computers in Industry, 2021, 130, 103472
16. Manuel Knott., Fernando Perez-Cruz.,Thijs Defraeye.: 'Facilitated machine learning for image-based fruit quality assessment', Journal of Food Engineering, 2023, 345, 111401
17. Kuznetsova, A., Maleva, T., Soloviev, V.: 'Using YOLOv3 algorithm with pre- and post-processing for apple detection in fruit-harvesting robot'. Agronomy 2020, 10, 1016
18. Baneh, N.M.,Navid, H. 'Development and Evaluation of a Small-Scale Apple Sorting Machine Equipped with a Smart Vision System'. Agri. Engineering, 2023, 5, pp 473-487
19. P. world, apple, 'World apple production by country 2023', Accessed: 2023-07-10 (2023).
20. Jia, W.: 'Detection and segmentation of overlapped fruits based on optimized mask R-CNN application in apple harvesting robot', Computers and Electronics in Agriculture 2020, 172, 105380
21. Unay, D.: 'Deep learning based automatic grading of bi-colored apples using multispectral images'. Multimedia Tools and Applications, 2022,11(01), pp 38237–38252
22. Wang, Z.: 'Potato Processing Industry in China: Current Scenario, Future Trends and Global Impact', Potato Res. 66, 2023, pp 543–562
23. Vito,Buono.: 'Tuber quality and nutritional components of “early” potato subjected to chemical haulm desiccation', Journal of Food Composition and Analysis, 2009, 22, 2, pp 556-562
24. Elmasry, G.: 'In-line sorting of irregular potatoes by using automated computer-based machine vision system, Journal of Food Engineering'. 2012. 112, 1-2, pp 60–68.
25. Su, Q.: 'Potato Quality Grading Based on Depth Imaging and Convolutional Neural Network', Journal of Food Quality, 2020, 88, p. 9