Vol. 20 (2026): Proceedings of 2026 International Conference on Materials Science, Energy Engineering and Automation Control (ICMSEAC 2026)
E-ISSN: 3105-0522 P-ISSN: 3105-0514
DOI: https://doi.org/10.70267/mseac.2026164172

Research on the Application of Machine Vision in Industrial Robots

Zeda Li*

Chinesisch-Deutsche Technische Fakultät, Qingdao University of Science and Technology, Qingdao, China

**Corresponding author: Zeda Li.*

Abstract

With the rapid development of intelligent manufacturing and Industry 4.0, industrial robots have been widely applied in modern manufacturing processes. However, traditional industrial robots often rely on pre-programmed instructions and fixed trajectories, which limit their flexibility and adaptability in complex environments. Machine vision technology enables industrial robots to perceive, identify, and analyse surrounding objects through image acquisition and processing. This paper systematically studies the application of machine vision in industrial robots. First, the basic concepts, components, working principles, and image processing technologies of machine vision are introduced. The structure and operating principles of industrial robot systems are then analysed. Furthermore, several typical applications of machine vision in industrial robots are discussed, including workpiece identification and positioning, visual guidance in welding and assembly, product quality inspection, and automatic sorting systems. In addition, the current challenges in machine vision technology, including environmental interference, target occlusion, high hardware costs, and real-time processing requirements, are analysed. Finally, future development trends are explored, including the integration of artificial intelligence, multi-sensor fusion, digital twins, and intelligent manufacturing systems. The study shows that machine vision plays an important role in improving the accuracy, efficiency, and automation level of industrial robots and will continue to promote the intelligent development of modern manufacturing.

Keywords

machine vision, industrial robots, visual guidance, intelligent manufacturing, automation technology

1. Introduction

With the rapid development of Industry 4.0 and the strong promotion of the idea of intelligent manufacturing, manufacturing is being transformed in an orderly and systematic way towards digitalisation, networking, and intelligence [1]. Given their high efficiency, accuracy, and continuous operation, industrial robots have been widely applied across a range of applications, including automotive production, electronics manufacturing, and logistics sorting. Most traditional industrial robots are based on pre-programmed instructions and fixed trajectories, so they are not very flexible in various situations. With image acquisition and analysis capabilities, machine vision technology can be used for various purposes, including robot target recognition, positioning guidance, and quality inspection, to enhance production efficiency and automation levels [2].

Research in this field has been conducted for many years and has been widely applied in industrial inspection, automatic assembly, target recognition, and robot guidance. Perez et al. believe that machine vision can enable industrial robots to perceive their environment and thus realise workpiece identification, positioning, and quality inspection [3]. Ghofrani et al. found that advances in deep learning and computer vision over the past few years have also improved the recognition and environmental adaptability of machine vision systems [4]. Therefore, international research has gradually shifted from a traditional two-dimensional to a three-dimensional and intelligent vision system [3]. Under the guidance of the "Made in China 2025" initiative and the rapid development of intelligent manufacturing, China's industrial robot and machine vision industries have developed rapidly. Therefore, machine vision technology is currently used in various applications, including automotive production, electronic assembly, logistics sorting, and product quality inspection. At home, universities, research institutions, and enterprises have been conducting research on visual positioning, target recognition, and defect detection; deep learning has been applied to industrial vision systems to improve inspection efficiency in harsh environments.

Although some good results have been achieved in the application of machine vision technology, changes in light, target occlusion, and background interference in the industrial environment can affect the accuracy of recognition [4], and high-precision vision systems require high-demand hardware and computing resources; thus, the cost of these systems is also relatively high [3]. The purpose of this paper is to explore the application of machine vision in industrial robots to overcome the shortcomings of traditional robots, improve production efficiency and processing accuracy, and reduce human error and labour costs. First, the basics of machine vision technology will be systematically introduced in this paper; next, the system of industrial robots will be sorted out; then, typical applications of machine vision in industrial robots will be discussed; Finally, existing problems, future trends, and technological prospects will be analysed and looked forward to.

2. Fundamentals of Machine Vision Technology

2.1 Definitions and Components of Machine Vision

Machine vision is a technology that obtains information about objects using image-capturing devices and, after processing and analysing these images, can automatically recognise, locate, and operate on them. The five parts of a machine vision system are, in general, the image acquisition system, the light source system, the camera, the image processing system and the control system. Among them, a light source system is employed to provide a stable light source; a camera is used to obtain an image of the target; an image acquisition system is employed for the transmission of image information; an image processing system is used for analysis and recognition of the image; based on the results of processing, the control system sends corresponding instructions to control equipment such as industrial robots.

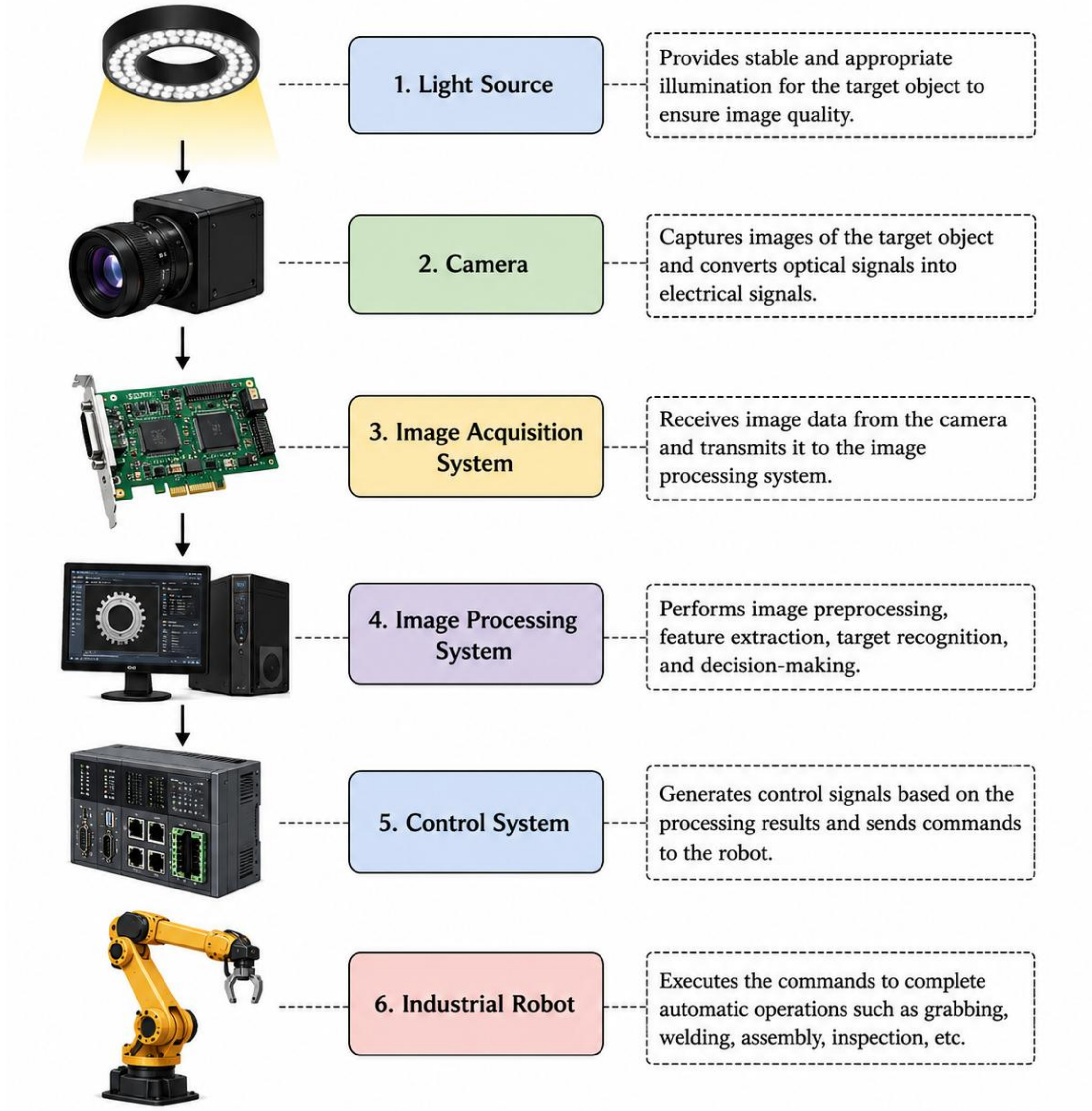
2.2 Working Principle of Machine Vision

The five stages of the machine vision process are generally as follows: Image acquisition, Image preprocessing, Feature extraction, Image recognition, and Output control signal. First, the object under test is imaged by a camera, and then preprocessing is performed to enhance image quality. Then, features such as colour, shape, texture, and edges are extracted from the image, and the target's position, category, and state are identified using the corresponding algorithms. Finally, based on the recognition result, control signals are generated and sent to the industrial robot's actuator. The automation has been carried out.

2.3 General Image Processing Techniques

Image processing technology is the foundation of machine vision for target recognition and detection. The general types of image processing include edge detection, image segmentation, pattern recognition, and feature matching. The boundary of an object is obtained by identifying regions in the image with relatively large grey-value differences, and this outline serves as the basis for further study. Image segmentation is a type of image understanding that divides an image into many areas of different types to separate the object of interest from the background. Algorithms in machine learning and deep learning are used to perform pattern recognition for classification and identification of extracted features in object detection and state judgment [6]. Feature matching is the process of finding the corresponding parts of two targets by comparing key points, textures, and shapes in an image, and it is applied to many purposes, such as localising targets, visual navigation, and robot guidance [7]. As artificial intelligence advances, these image processing techniques will become more precise and intelligent.

Figure 1: Composition of a machine vision system for industrial robots



2.4 Advantages of Machine Vision

Machine vision is fast and accurate; it does not contact the workpiece, and it is completely automatic. Machine vision can acquire and process images at high speed and continuously; it offers excellent recognition and measurement accuracy, reduces subjectivity in manual operations, and improves production efficiency and product quality. Machine vision is a non-contact inspection method that does not damage the inspected part. Machine vision can be used to work with industrial robots and automated production lines to enable autonomous control and intelligent operation and maintenance of the entire production process, thereby increasing production efficiency.

The first few sections of this chapter cover the basic concepts and system architecture of machine vision. The main theoretical basis for this work is the research results on machine vision-guided technology in industrial environments by Perez and others, as well as the systematic review literature on robot machine vision technology by Ghofrani and others [3, 4].

3. Overview of Industrial Robot Systems

3.1 Definition and Classification of Industrial Robots

Industrial robots are intelligent mechanical devices that can perform tasks according to pre-programmed control instructions and are now widely used in the production process of modern manufacturing. Due to the different functions and application circumstances of various industrial robots, they are generally divided into types such as welding robots, material-handling robots, assembly robots, and spraying robots. Different types of industrial robots have varying operating requirements across production lines, thereby increasing production efficiency and product quality.

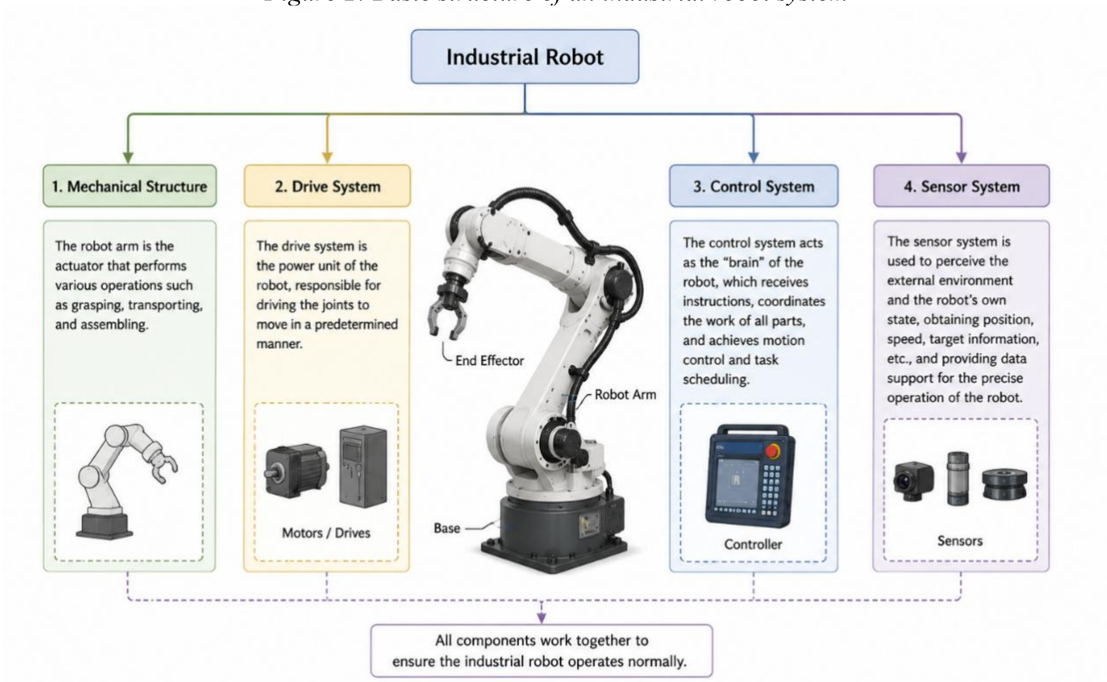
Table 1: Classification and Typical Applications of Industrial Robots

Robot Type	Main Function	Application
Welding Robot	Welding	Automobile Manufacturing
Assembly Robot	Assembly	Electronics Industry
Handling Robot	Material Transport	Warehousing
Spraying Robot	Surface Coating	Automotive Industry

3.2 Basic Structure of an Industrial Robot

Generally, an industrial robot comprises a structure, a drive system, a control system, and a sensor system. The robotic arm is the robot's actuator; it can perform various operations, such as grasping, transporting, and assembling. The Drive System is the power unit of the robot; it is responsible for driving the joints to move in a predetermined way. The Control System acts as the "brain" of the robot, receiving instructions, coordinating the work of all parts, and controlling motion and scheduling tasks. The Sensor System is used to perceive the external environment and the robot's own state, obtain position, speed, target information, etc., providing data support for the precise operation of the robot. All the parts work together to make the industrial robot operate normally.

Figure 2: Basic structure of an industrial robot system



3.3 Principles of Motion Control for Industrial Robots

Motion control is essential for achieving high-precision operation of industrial robots; kinematic analysis, path planning, and control mode are the three basic components. Kinematic analysis generally concerns how the movement of each joint in a robot relates to the position and orientation of its end-effector. Thus, it builds a kinematic model to achieve accurate robot positioning. Path planning is the process of determining a feasible path for the robot that meets task requirements and environmental constraints, thereby improving operational efficiency and avoiding collisions [8]. Based on the planning results, the robot adjusts its control mode accordingly. The basic control modes include position, speed, and force control, among others. With the development of intelligent control technology, industrial robots have been moving towards higher precision and greater autonomy [9]. A reasonable motion control plan needs to be developed to ensure the robot operates smoothly at all times and produces high-quality products efficiently and in good condition.

3.4 Development of Industrial Robot Technology

Industrial robot technology has a very clear, highly logical evolution from single-automation to flexibility and intelligence: The first generation of industrial robots could complete repetitive tasks according to pre-programmed sequences and had a high degree of automation but lacked environmental adaptability. The development of computer, sensor, and control technologies has greatly improved the motion accuracy and stability of industrial robots and expanded their application scope. In recent years, with the rapid advancement of technologies such as artificial intelligence, the Internet of Things, and big data, industrial robots have begun to evolve toward greater flexibility and intelligence. According to production requirements and to meet the demands of multi-variety and small-batch production, these can be operated flexibly.

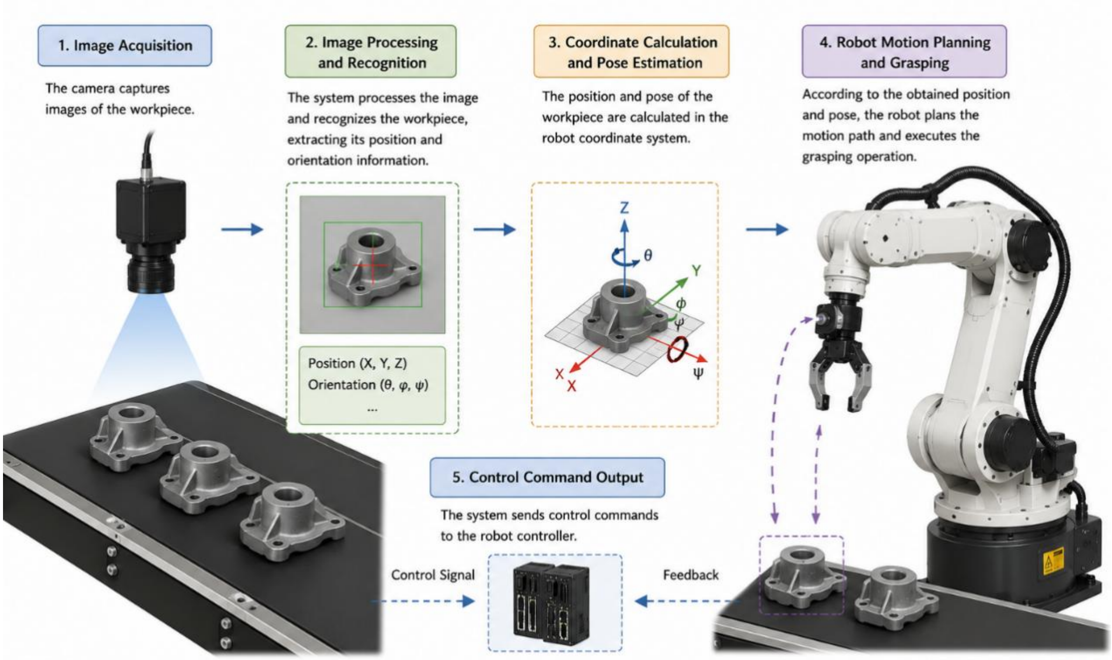
This section will present the general ideas, construction structure, movement control methods and development history of industrial robots. The main content of the above references is research literature on robot motion planning and control technology by Orthey et al. [8].

4. Application of Machine Vision in Industrial Robots

4.1 Workpiece Identification and Positioning

Workpiece identification and positioning are typical applications of machine vision in industrial robots. A camera performs target recognition to acquire an image of the workpiece. Then, image processing algorithms are used to identify the part's shape, size, and other attributes. Based on the recognition result, the robot knows where and how to grasp the workpiece, and then performs an automatic grasp. Machine vision can obtain real-time position data for the workpiece and correct it to improve the accuracy and efficiency of gripping and operation [3].

Figure 3: Machine vision-guided robot grasping process



4.2 Visual Guidance in Welding and Assembly

Visual guidance is one of the key application areas for machine vision in industrial robotics. In robot welding, an industrial camera captures a live image of the weld seam, and, through image-processing algorithms, information such as feature positions and shapes can be extracted for weld-seam tracking [3]. If there are problems with workpiece offset or weld deviation, the vision module can promptly provide this information to the robot for adjustment of the movement path; at that time, the welding gun will continue to run along the preset path, thereby improving welding quality and increasing production efficiency. Machine vision is employed in the two primary functions of automatic assembly: target recognition and pose determination. After the system acquires an image of the part, it calculates the part's spatial position and pose and then sends this data to the robot control unit [10]. The robot will adjust its grasp and assembly plan based on the visual information it has independently obtained to ensure a tight fit between the parts. At the same time, the vision system will monitor the entire assembly process in real time, correct deviations, and ensure the accuracy of assembled parts and the quality of the final product.

4.3 Product Quality Inspection

The current quality inspection process is manual, inefficient, and prone to human error. Using machine vision technology, industrial robots can perform high-speed, accurate automatic inspection of products, improving production efficiency and product quality. For surface defect detection, a camera captures images of products, and a computer then identifies and recognises scratches, cracks, dents, stains, and other flaws. For the size inspection part of the system, image measurement technology is used to obtain product size information, such as length, width, and diameter; this information is then compared with standard values to determine whether the product meets production requirements. For the first type of precision inspection, machine vision can determine the position, shape, and assembly accuracy of parts. It can also identify defects in processing or assembly early, ensuring the stability and consistency of product quality [11].

4.4 Automatic Sorting System

Automatic sorting is a typical application of machine vision in industrial robots. It is widely used in the fields of logistics and warehousing, electronic manufacturing, food processing, etc.; first, a picture of the object is taken by the camera, and then image processing methods are employed to extract the colour, shape, size and other characteristics of the object to achieve object recognition and classification. In the intelligent sorting process, after the visual system identifies the target, it sends the detected object's position and type information to the robot control system. The robot can use it to pick up, carry and organise goods. Based on the properties of the items, a new sorting plan will be automatically generated to improve sorting speed and accuracy. Compared with manual sorting, the automatic sorting system offers high speed, high accuracy, and continuous operation; therefore, it can reduce labour costs and increase production efficiency [3].

Table 3: Applications of Machine Vision in Industrial Robots and Their Benefits

Application	Vision Function	Benefits
Positioning	Object Recognition	Improve Accuracy
Welding	Seam Tracking	Improve Quality
Inspection	Defect Detection	Reduce Errors
Sorting	Classification	Increase Efficiency

5. Problems and Trends of Machine Vision in Industrial Robot Applications

5.1 Current Problems

Although machine vision technology has made significant progress in industrial robotics, it still has some deficiencies in practical applications. First of all, the environment of industrial sites undergoes frequent changes in lighting conditions, which can degrade image quality and directly affect target recognition and detection results [4]. Secondly, the objects that need to be identified often exhibit occlusions, deformations, and complex backgrounds in the actual working environment; thus, the accuracy of image recognition is relatively low [4]. Thirdly, the high-performance industrial camera, light source equipment, and image processing hardware are all expensive, and the construction, operation, and maintenance costs of the corresponding systems are very high [11]. Fourthly, with the recent development of industrial automation, industrial robots now need to carry out image processing and decision-making control in a very short time; due to the large amount of data that needs to be processed, a system response delay will inevitably occur, and thus, real-time performance has become a new problem [12].

5.2 Directions for Improvement

In light of the current technical problems, the industry is constantly advancing machine vision towards greater intelligence and higher performance. New Deep Learning Algorithms can be employed to improve the accuracy of visual recognition and feature extraction, and the problem of operating under bad weather can be reliably addressed. Continuous improvements and upgrades have been made to the hardware at the sensor data-acquisition level to obtain richer image data and strengthen the foundation for the accuracy of positioning and detection. A perception scheme that uses multiple sensors to collect complementary information can be employed to enhance the robot's environmental perception and improve system stability. At the control end, we can strengthen automation and enable autonomous decision-making and dynamic adjustments to shorten response time and improve operating efficiency [13].

5.3 Future Trends

With the development of artificial intelligence, big data and intelligent manufacturing, machine vision will be applied to industrial robots in more ways in the future. In the future, artificial intelligence, vision, and deep learning will be used to enhance robots' ability to more intelligently recognise and perceive in diverse work environments, make independent decisions, and ensure high accuracy and efficiency across all tasks. The combination of digital twins and machine vision can build digital models of the production process to monitor and predict equipment faults, optimise the process, and more, thereby promoting the intelligent upgrading of production lines [14]. Machine vision, in conjunction with cloud computing and the Internet of Things, can be used for data transmission and remote operation; thus, it can be employed flexibly in robots. In the future, industrial robots will continue to advance along the paths of autonomy, intelligence, and connectivity to further support the digitalisation of manufacturing.

6. Conclusion

This paper conducts a systematic study of the application of machine vision in industrial robots and presents the relevant technical principles, system architecture, typical application scenarios, and related issues. As the foundation of intelligent perception for industrial robots, machine vision can address the problem of fixed-path movement of traditional robots. Given its advantages of high accuracy, non-contact operation, and automation, this technology has been widely applied in many areas, including workpiece recognition and positioning, welding guidance, precision assembly, quality inspection, and automatic sorting. It can help improve production efficiency and the accuracy of product processing, reduce human errors and labour costs, promote the automation and standardisation of the production line, etc. Now, it is one of the technical supports for intelligent manufacturing in our country.

There are still issues with the large number of operating scenarios: recognition accuracy is low, hardware costs are high, and the system's response speed is slow, hindering the widespread application and development of machine vision technology. Given the industry's development trend and the continuous advancement of technologies such as artificial intelligence, digital twins, and the Internet of Things, machine vision will also improve in the future; that is, it will become more intelligent, capable of multi-modal perception fusion, and highly interconnected. By combining algorithmic iteration and multi-sensor cooperation, the system's environmental adaptation ability will be improved to a certain extent, and new application models, such as remote operation and maintenance and digital simulation, will also be introduced gradually. In the future, the integration of machine vision and industrial robots will become more mature, continuously promote the digitalisation and flexibility of manufacturing, and provide strong support for the continued development of the intelligent manufacturing industry.

References

[1] Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent manufacturing in the context of Industry 4.0: A review. *Engineering*, *3*, 616–630. https://doi.org/10.1016/J.ENG.2017.05.015

[2] Zhou, H. A., Wolfschläger, D., Florides, C., Werheid, J., Behnen, H., Woltersmann, J.-H., Pinto, T. C., Kemmerling, M., Abdelrazeq, A., & Schmitt, R. H. (2026). Generative AI in industrial machine vision: A review. Journal of Intelligent Manufacturing, 37, 1447–1470. https://doi.org/10.1007/s10845-025-02604-6

[3] Pérez, L., Rodríguez, Í., Rodríguez, N., Usamentiaga, R., & García, D. F. (2016). Robot guidance using machine vision techniques in industrial environments: A comparative review. *Sensors*, *16*(3), 335. https://doi.org/10.3390/s16030335

[4] Ghofrani, J., Kirschner, R., Roßburg, D., Reichelt, D., & Dimter, T. (2019). Machine vision in the context of robotics: A systematic literature review. arXiv:1905.03708.

[5] Yu, Y., Wang, C., Fu, Q., Kou, R., Huang, F., Yang, B., Yang, T., & Gao, M. (2023). Techniques and challenges of image segmentation: A review. Electronics, 12(5), 1199. https://doi.org/10.3390/electronics12051199

[6] Manakitsa, N., Maraslidis, G. S., Moysis, L., & Fragulis, G. F. (2024). A review of machine learning and deep learning for object detection, semantic segmentation, and human action recognition in machine and robotic vision. Technologies, 12(2), 15. https://doi.org/10.3390/technologies12020015

[7] Huang, Q., Guo, X., Wang, Y., Sun, H., & Yang, L. (2024). A survey of feature matching methods. IET Image Processing, 18(6), 1385–1410. https://doi.org/10.1049/ipr2.13032

[8] Orthey, A., Chamzas, C., & Kavraki, L. E. (2023). Sampling-based motion planning: A comparative review. arXiv. https://doi.org/10.48550/arXiv.2309.13119

[9] Dong, L., He, Z., Song, C., & Sun, C. (2021). A review of mobile robot motion planning methods: From classical motion planning workflows to reinforcement learning-based architectures. IEEE Transactions on Systems, Man, and Cybernetics: Systems

[10] Wang, H., Salunkhe, O., Quadrini, W., Lamkull, D., Ore, F., Despeisse, M., Fumagalli, L., Stahre, J., & Johansson, B. (2023). A systematic literature review of computer vision applications in robotized wire harness assembly. Procedia CIRP, 120, 1071–1076. https://doi.org/10.1016/j.procir.2023.09.127

[11]Werheid, J., Behnen, H., Woltersmann, J. H., He, S., Hamann, T., Abdelrazeq, A., & Schmitt, R. H. (2025). Machine vision in manufacturing SMEs: A review. Discover Applied Sciences, 7(5), 371. https://doi.org/10.1007/s42452-025-06923-4

[12] Wang, C., Lin, C.-Y., & Tomizuka, M. (2014). Statistical learning algorithms to compensate slow visual feedback for industrial robots. Journal of Dynamic Systems, Measurement, and Control, 136(2), 021025. https://doi.org/10.1115/1.4025988

[13] Robinson, N., Tidd, B., Campbell, D., & Kulić, D., & Corke, P. (2021). Robotic vision for human-robot interaction and collaboration: A survey and systematic review. Journal of the ACM, 37(4), Article 111. https://doi.org/10.1145/1122445.1122456

[14] Faqeer, H. A., & Khajavi, S. H. (2025). Digital twin and computer vision combination for manufacturing and operations: A systematic literature review. *Applied Sciences*, *15*(18), 10157. https://doi.org/10.3390/app151810157

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.