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REVOLUTIONIZING THE APPLICATION OF AUTOMATIC INSPECTION SYSTEM FOR INDUSTRIAL PARTS USING AI MACHINE VISION TECHNOLOGY

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Abstract. This paper addresses the challenges of large data management, prolonged operation times, and low detection efficiency encountered in automatic detection systems. To overcome these issues, we propose a novel research and application method utilizing AI machine vision technology. The methodology employs the Pulse-Coupled Neural Network (PCNN) algorithm for analyzing machine control points, enhancing system reliability and detection efficiency. Furthermore, a three-stage sliding table mechanism is implemented to facilitate seamless operation restarts. Notably, our approach significantly reduces the time required for key operations, such as feeding, imaging, decision-making, on-site inspection, and re-inspection, all within 5 seconds and 1 meter distance. It supports high-precision dynamic identification, detection, and correction of errors during high-speed movement, thereby enhancing overall system performance. The experimental results demonstrate exceptional accuracy, particularly in detecting small parts measuring 28.87 mm in length and 12.36 mm in width, achieving an impressive precision of 0.04 mm. Additionally, our system boasts meticulous hardware selection, robust software stability, and high-performance capabilities, culminating in improved detection efficiency and accuracy. This research not only contributes novel ideas and results but also holds significant commercial value in industrial applications. Overall, our proposed methodology represents a noteworthy advancement in automatic inspection systems, offering superior performance and reliability compared to existing approaches.

Key words: Pulse-Coupled Neural Network; decision-making; on-site inspection; re-inspection; high-precision dynamic identification.

1. Introduction. In recent years, with the continuous deepening of industrial restructuring and transformation and upgrading of modern manufacturing industries, more and more enterprises have begun to implement "machine substitution". The combination of robotics and machine vision technology has become a disruptive force in the ever-changing field of modern manufacturing, transforming industries around the world. The need for industrial restructuring and the constant search for efficiency and innovation have led to exceptional adoption of these technologies in recent years. The era of "machine substitution" has arrived, as companies in the aerospace and automotive industries gradually integrate robots into their operations. Robots have become essential tools driving innovation in many industries, from automating complex production lines to speeding up logistics procedures [1]. Figure 1.1 vividly illustrates the growing scope of robotics, which is penetrating various sectors and driving supporting industries. At the heart of this revolution is the very essence of robotics: the magic of engineering power and intelligence. As shown in Figure 1.2, the emphasis on the advancement of robotics technology has been increased, highlighting its strategic importance in the fields of modern technology and industry. Making robots in automobiles, logistics, aerospace, ships and even food, and other fields have been more and more widely used, and led to the development of related industries. Robot is a kind of automation equipment or device that integrates various advanced technologies such as machinery, sensing, recognition, decision-making and control, and has some intelligent capabilities; the emphasis on development is increasing day by day. Robot technology and its application have become a "must fight" for today's technology and industrial development, and have important strategic significance.

As the "eye" of the robot, the machine vision system is a device that obtains the characteristic image of the detected object with the help of optical devices and non-contact sensors, and extracts information from the image through a computer for analysis and processing, thereby realizing detection and control. Machine vision system has the advantages of good real-time performance and high positioning accuracy, which can effectively increase the flexibility and intelligence of robots, and is one of the important means to realize industrial

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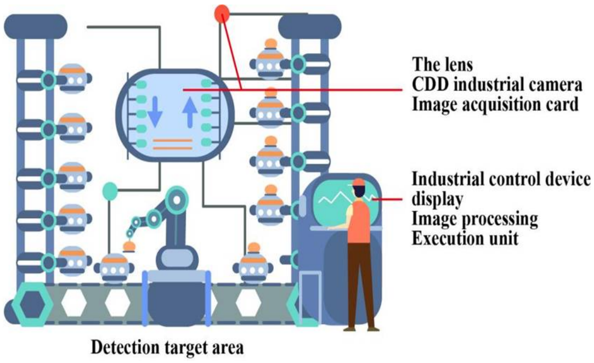

Fig. 1.1: Automatic recognition and detection based on machine vision

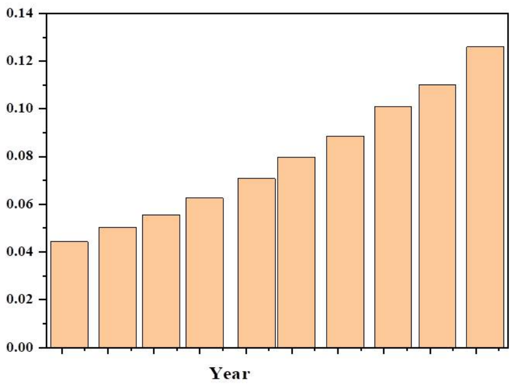

Fig. 1.2: Scale of the global machine vision industry from 2008 to 2018

automation and intelligence [1]. With the continuous improvement of various technologies and the increasing demand for high-quality products in the manufacturing industry, machine vision has been mainly used for defect detection in industrial electronic assemblies from the beginning, and has been gradually applied to automobile manufacturing, food monitoring, visual navigation, transportation, military, textile processing and other fields, the market scale continues to expand [2]. The vision system is connected with the mechanical servo mechanism to form an open-loop control visual servo mechanism. The introduction of visual servo system can improve the degree of automation of product inspection, but there are still shortcomings in acquisition accuracy, detection speed and algorithm robustness [3]. Therefore, it is of great significance to study machine vision related technologies to improve the industrial development of industrial intelligent robots. The author mainly summarizes and analyzes the development history, research status, related core technologies and automatic identification and detection system of machine vision, taking the research progress of machine vision technology as the breakthrough point, and makes an outlook on the future development trend [4].

In industrial production, the pursuit of precision, efficiency, and quality assurance are essential requirements. As the industry evolves and consumer demands increase, the need for reliable and efficient test systems becomes increasingly important. To meet this need, the integration of artificial intelligence (AI) and machine vision technology is emerging as a revolutionary force that is expected to redefine the flexible inspection system landscape. Traditionally, manual inspection processes are labor-intensive, time-consuming, and prone to human error, creating major challenges for manufacturers seeking to ensure consistency and quality. However, recent advances in AI and machine vision technology have brought about a paradigm shift, providing unprecedented opportunities for automated testing and quality control. The combination of AI algorithms and vision systems gives these inspection machines the cognitive capabilities to distinguish complex details, detect errors, and classify anomalies. It often provides superior accuracy and efficiency. This combination of technologies not only streamlines the testing process, but also increases accuracy and reliability, minimizing the risk of errors and optimizing production efficiency. Additionally, AI-based vision systems have the ability to continuously learn and adapt, allowing them to adapt to changing production needs and changing environments. Through iterative feedback loops and improvements, these systems continually improve their performance and strengthen their position as essential assets in modern industrial environments. This article explores the transformative potential of AI machine vision technology to revolutionize automated industrial part inspection systems. Explore the applications, benefits, and various future prospects of this breakthrough technology based on recent advances, case studies, and industry insights. From automotive assembly lines to precision engineering systems, the integration of AI-driven image processing promises to open new frontiers in quality assurance, productivity, and innovation.

1.1. Contribution. Automated sensor systems play a central role in modern industrial environments, ensuring the quality and accuracy of manufactured parts. However, these systems often encounter challenges such as handling large data sets, long operating times, and low detection efficiency. In response, our paper proposes a new research and application method that leverages AI machine vision technology to overcome these obstacles and improve the performance of automated inspection systems. The methodology of our method is the use of the PCNN (Pulse Coupled Neural Network) algorithm, a powerful tool for analyzing machine checkpoints. By integrating PCNN into our system, we improve detection reliability and efficiency, allowing for more accurate and faster error identification. In addition, we are introducing a three-stage sliding table mechanism designed to support smooth restart of operations, meeting the need for uninterrupted workflow in industrial environment. This mechanism ensures that key operations, including feeding, imaging, decision-making, spot checking and re-checking, are completed in just 5 seconds and at a distance of 1 meter, maximizing efficiency and performance. A notable feature of our method is its support for highly accurate dynamic error identification, detection, and correction during high-speed motion. This capability significantly improves overall system performance, allowing for real-time adjustments and minimizing production disruptions.

The rest of this article is arranged as literature review in section 2, methods in section 3, results and discussion in section 4 followed by conclusion in section 5.

2. Literature Review. The literature review provided covers a wide range of research efforts that advance object detection and segmentation techniques in various fields. Each study brings unique insights and methods to address the complex challenges inherent in detecting objects in complex backgrounds or dynamic environments. Let us discuss each contribution: Lee, E. proposed extended object detection in complex backgrounds based on fractal features [5]. This approach can explore the fractal characteristics of objects to improve detection accuracy, especially in situations where objects are embedded in cluttered or irregular backgrounds. Nguyen, N.H. presented a pulse-coupled neural network for detecting aerial and bridge targets [6]. This neural network architecture excels at detecting targets in complex contexts, leveraging principles inspired by the synchronization of biological neurons. Binh, K. proposed morphologically enhanced relative connectivity entropy for automatic object detection [7]. This method can use morphological operations and entropy calculations to improve the robustness of object detection, especially in situations with different object sizes or shapes. Jeong, H.G. presented a multi-motion object segmentation algorithm based on the level set method [8]. This algorithm can use the level setting method to delineate the boundaries of moving objects in dynamic scenes, thereby providing accurate segmentation regardless of object motion. Zhao, W. proposed a method for fast division of level sets [9]. This method is capable of optimizing the computational efficiency of level set-based segmentation, allowing for rapid and accurate identification of objects in real-time applications. Roos, M. H. proposed a moving object detection algorithm based on gradient direction information [10]. This algorithm can take advantage of gradient direction signals to identify moving objects in video sequences, thereby providing robust detection performance under different environmental and lighting conditions. Ma, C. introduce automatic target detection based on watershed transformation combined with genetic algorithm [11]. This approach can use genetic algorithms and watershed transformations to identify targets in images, providing strong noise and clutter resistance. Krebs, J. proposed an improved level setting method for multiple object detection and tracking [12]. This method can improve traditional level set algorithms to facilitate accurate detection and tracking of multiple objects in complex scenes. Vuong, Z. conducted extensive research on multi-object detection and image sequence tracking [13]. This research can explore advanced algorithms and techniques to simultaneously detect and track multiple objects in dynamic environments. Li, R. presented a target segmentation method that involves subsample extraction and correlation calculation [14]. This method can use pattern matching and clustering techniques to accurately segment targets from background clutter, thereby providing robustness in object recognition. Wu, S. proposed a target detection method using random decision trees and statistical matching subwindows [15]. This approach can use statistical and machine learning methods to detect targets in images, providing scalability and adaptability to a variety of scenarios. Wieduwilt, E. introduces gradient direction histogram detection operator for target detection [16]. This operator can take advantage of gradient information to distinguish between positive and negative samples, thereby improving the accuracy of target detection in harsh environments. Overall, these contributions highlight the breadth and depth of research efforts aimed at advancing automatic object detection and segmentation techniques. By leveraging innovative methods and interdisciplinary approaches, researchers aim to meet the changing needs of object detection in various application areas.

2.1. Research gaps. Based on the comprehensive literature review provided, several research gaps and opportunities for further investigation can be identified: Some studies address the detection of objects in complex backgrounds, such as Lee's discovery of fractal features [5], and Bin's proposal for improved entropy calculation [7], methods are still needed. It can reliably detect objects in the middle of very cluttered or irregular backgrounds. Developing robust algorithms capable of accurately distinguishing objects from complex environmental contexts remains a significant research gap. Jeong's work on multi-motion object segmentation [8] and Roos' algorithm for moving object detection [10] highlight efforts to address segmentation objects in dynamic scenes. However, there is still much room for improvement in algorithms that can effectively segment objects subject to complex motions, such as occlusions, deformations, or rapid changes in appearance. Despite Zhao's proposal of a fast level set segmentation method to improve computational efficiency [9], achieving real-time performance is still a challenge for many object detection algorithms, especially in applications that require fast, high-performance processing. resolution image or video stream. Research focuses on speeding up algorithms without compromising guaranteed accuracy. Several studies, including Krebs's improved level setting method [12] and Wang's research on multiple object detection and tracking [13], consider detecting and tracking multiple objects at the same time. However, there is a need to further explore algorithms that can robustly handle occlusions, object interactions, and scale variations, especially in cluttered or dynamic environments. Adaptability to varying conditions: Although Wu's approach using stochastic decision trees is promising for target detection [15], achieving robust performance under Varying environmental conditions, such as changes in lighting, weather or viewing angles, remain a challenge. Research focused on developing algorithms that are adaptable and flexible to such variations is essential for real-world implementation. Most of the reviewed research focuses on image-based object detection; However, there is growing interest in integrating multiple methods, such as LiDAR, radar or depth sensors, to improve detection performance, especially in challenging situations such as low visibility. Research on fusion techniques and multimodal approaches can lead to significant advances in object detection. Evaluation metrics and benchmark datasets: Although the experimental results presented in the reviewed studies demonstrate the effectiveness of the proposed methods, evaluation metrics are lacking standardized and benchmark datasets to compare the performance of different algorithms. Developing comprehensive evaluation frameworks and datasets tailored to specific application areas can facilitate fair comparisons and reproducibility of research results.

Filling these research gaps will be the main goal of this research work. This not only involves advancing the state-of-the-art in automated object detection and segmentation, but also contributes to the development of more robust, efficient and adaptable systems for various industrial and practical applications.

3. Methods.

3.1. The basic working principle of PCNN and its algorithm improvement. PCNN has a multi-neuron model, which is a bionic machine for animal visual recognition, where each neuron is a layer of a neural network capable of recognizing the results of the network without training[17]. It also includes: spatio-temporal summation characteristics, dynamic pulse emission characteristics, and vibration and oscillation characteristics due to synchronous pulse emission. In image processing, PCNN can be widely used in digital image segmentation, edge detection, detection, enhancement, fusion, pattern recognition, target classification, intrusion prevention, etc. It can be used in wavelet theory, mathematical morphology, and fuzzy processing, and together with other signal processing technology, it is widely used in graphics and other operations. The wiring process of the neuron can be approximated as the transfer process of the integration loss, which is the linear output [18-19]. PCNN is a feedback mechanism built by connecting many neurons, each neuron usually has three parts: a receiver, a network (multiple transformations) and a machine electric pulse [20-21]. In real-world imaging, the neural network's connectivity corresponds to the pixels in the image one-to-one, that is, the number of pixels in the image corresponds to the neurons in the network, more. it will be. This corresponds to many neurons.When used for edge detection, the performance of the algorithm changes with the number of iterations, and so does the detection result. Each iteration corresponds to a binary image output showing the details of the target and the background, but the results of each iteration are not ideal. According to the maximum data entropy rule, as the number of iterations increases, the maximum data entropy is often used to determine the quality of the image, because the highest value The amount of image information entropy indicates that the image contains important information. the number of iterations.It is not possible to determine which results are better before testing, which is one of the shortcomings of PCNN, that is, its results cannot be objectively evaluated. Considering the shortcomings of the traditional PCNN edge detection algorithm, the author wrote a PCNN algorithm program based on the average maximum information entropy detection of objects, stationary objects, and images, and improved the traditional PCNN algorithm. , reducing unnecessary repetition, speeding up the algorithm, capturing the joint target in time, and obtaining target information.The author detects the edges of the image lena.png by using the advanced PCNN algorithm and traditional edge detection algorithms such as Sobel operator, Roberts operator, Prewitt operator, LOG operator, and Canny operator as complete and with good continuity, but there are many spurious ones. edge in the extracted result.The edge removal by improving PCNN is very successful, and the target edge can be extracted more in areas with complex backgrounds.

3.2. The network model of PCNN. The PCNN model consists of basic neurons, and each neuron is mainly composed of two functional units: the feedback input domain and the connection input domain, which are connected to its neighboring neurons through the synaptic connection weights M and W, respectively.

3.3. Visual inspection and recognition automation system design. The author developed a PCNN-based recognition and detection system by combining LabVIEW software and Matlab software.The system has two parts: the vision system and the control system. The vision sees and sees the incoming objects, and after receiving large data, converts it into a control signal, and sends the control signal to the control card to control the corresponding functions;Additionally, the control has a XYZ three-degree-of-freedom slide table. First, the workpiece is moved to the camera and the focal length is adjusted to place the part in the best measurement position, while the vision system records the image of the part and precisely defines the edges of the part. PCNN algorithm, then the edge of the part is processed by the Vision Assistant module, and the control signal is generated according to the measurement, identification and recognition of the car size, and the control signal is converted into energy control card using the control of the control parts of the mechanism. The specific process is shown in Figure 3.1.

3.3.1. Experimental platform construction. The equipment of the final chair is composed of upper computer (production computer), lower computer (Leisai four-axis motion control card and image capture card), servo motor , driver, CCM three-axis sliding table and shadowless space and DC power supply. These include: The upper computer is used to send motor control instructions, receive graphic and operating instructions, display information, and human interaction- computer; The four-axis control card of the downstream computer receives instructions from the upstream computer, generates voice control signals, and sends the signals to the servo motor drive. digital I/O port and the driver completes the speed and direction. . monitoring, signal amplification, engine operation; After the motor receives the driver's control signal, it is used as an actuator to perform the corresponding function, and the CCM three-axis sliding table mechanism can move three levels of movement: left, right, front and rear. freedom and education; The optical card receives signals from the

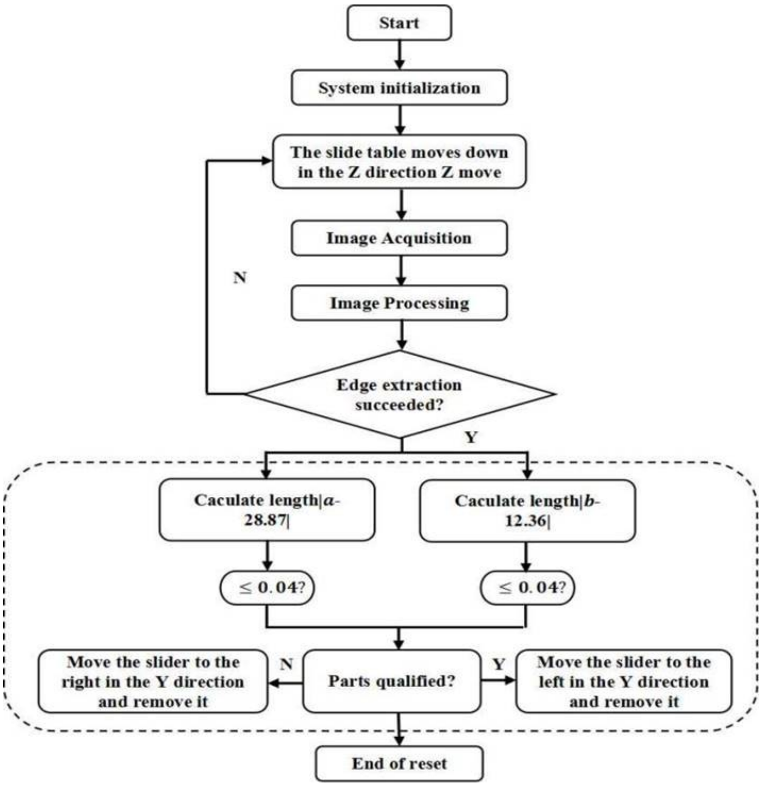

Fig. 3.1: Program running process

control computer, collects an image of the area, and then sends the image data back to the supercomputer for processing. done through the digital I/O port.

3.3.2. Software development. In the professional development of LabVIEW2011, the author uses the MatlabScript node to call the Matlab program, and the controller is connected to LabVIEW to realize and control the automatic equipment, as shown in Figure 3.2. After the program starts running. , the first control card sends the control signal to move the slide in the Z direction, send the part, run the camera with LabVIEW's VisionAcqusition module, collect the image of the part, and bite it with the values , and then call him. In order to run the PCNN edge search on a node, Matlab converts the edges to digital images after processing, and then LabVIEW's VisionAssistant module measures the length, width, and end of the ratio. measure the measured value with the standard value, determine the quality of the part, and make a motion control diagram to understand the movement of the Y-table three-level slider. No need to wait for another time to complete the orientation, location measurement, reset after completion, or explain the measurement.

The integration of LabVIEW and MATLAB application in the evolution of PCNN-based detection and recognition systems represents a holistic approach that leverages the strengths of both platforms for effectual and effective implementation. This system further consists of the two main components: the vision system and the control system, each of which carry out separate but interrelated functions.

3.3.3. Visual System. The visual system is incorporated as the "eyes" of the system and is accountable for capturing images of incoming objects and processing them for analysis. First, use the camera carriage with 3 degrees of freedom to position the part within the field of view of the camera. This ensures precise alignment and optimal measurement conditions. After positioning, the camera captures images of the part, which are processed using the PCNN algorithm. PCNN's edge detection feature allows the system to accurately identify the edges of a part. This is important for subsequent analysis. The processed edge information is further refined with the Vision Assistant module, which can integrate another image processing techniques to improve

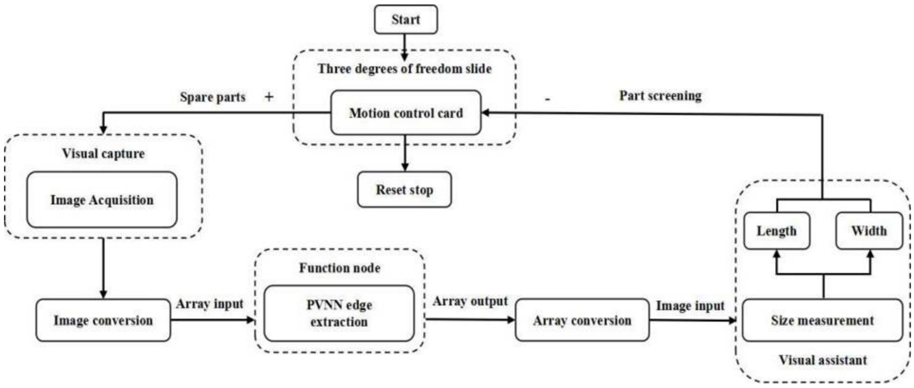

Fig. 3.2: Flowchart of the control system

edge sharpness and remove noise and artifacts. The vision system then performs measurement, identification, and recognition tasks based on the features extracted from the parts, such as size, shape, and specific features. The results of these analyzes are converted into control signals that provide instructions for further action by the control system.

3.3.4. Control System. A control system converts the output of a vision system into executable commands to control mechanical components or devices. The control signals generated by the vision system contain information about the measurement results and object properties and are received by the control system. Using LabVIEW software, the control system processes these signals and converts them into commands suitable for controlling the 3 degrees of freedom carriage and other related mechanisms. The control system communicates with the power control board or other hardware components to perform specific actions. Adjust part positions or activate specific tools based on analysis. Analysis is performed by a visual system.

In summary, LabVIEW and MATLAB integration facilitates seamless communication and coordination between vision and control systems, allowing PCNN-based detection and recognition systems to detect, analyze, and accurately detect incoming objects in real time. This multidisciplinary approach leverages the strengths of both software platforms to create important and adaptable solutions for a wide range of industrial applications.

4. Results and Discussion. The main characteristics of field detection and analysis automation systems are the ability to guarantee accurate measurements, robust algorithms, and stable system operation. The authors began a thorough investigation to determine these important aspects and began collecting images with different backgrounds under uniform illumination. Using traditional edge detection methods and an improved pulse-coupled neural network (PCNN) algorithm, the authors carefully analyzed and identified the edges of the object. A comparative analysis of edge extraction using traditional methods and his PCNN algorithm enhanced in the background yielded convincing results. Images processed using the PCNN algorithm had more detail and improved sharpness than images processed using traditional methods. It is noteworthy that the ability of the PCNN algorithm to improve accuracy on difficult backgrounds and enable robust edge and object detection even in difficult scenarios. The evaluation was then extended to repeated measurements using both the LabVIEW algorithm and the improved PCNN algorithm as shown in Figure 4.1. A standard model with known dimensions (length 28.87 mm, width 12.36 mm) serves as a benchmark, and measurements are performed under constant illumination conditions and indirect position guidance. As the position of the scale changes continuously, the length and width measurements also change. In particular, measurements performed using the improved PCNN algorithm had smaller deviations from the sample values compared to those obtained with the LabVIEW algorithm. This result highlights the excellent stability and accuracy of the PCNN algorithm,

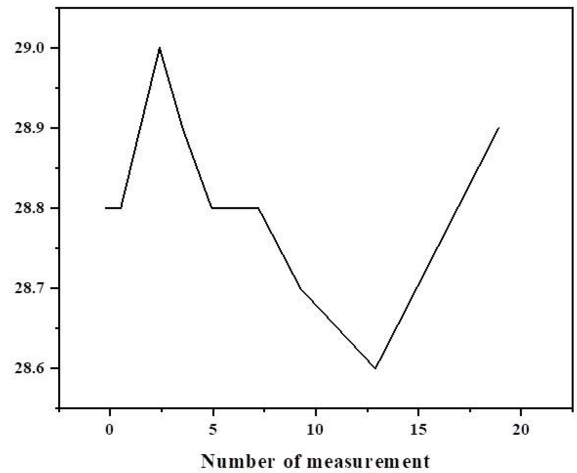

Fig. 4.1: Detection results of arbitrary parts in position and direction under the same illumination

Table 4.1: Experimental results

	length/mm	width/mm	Parts display
Right	28.84	12.34	Qualified
left	28.92	12.40	Failed

which facilitates accurate measurements even under fluctuating conditions.

Additionally, the system's ability to accurately detect position during high-speed movement (1 m/s) was evaluated, providing an outstanding detection accuracy of ± 0.04 mm. Extensive testing on 20 production batches confirmed the system's effectiveness in establishing appropriate product dimensions (length [28.83 mm, 28.91 mm] and width [12.32 mm, 12.40 mm]), thus ensuring consistent and reliable analysis results as shown in Table 4.1. Comprehensive evaluation shows that when system accuracy is maintained at 0.04mm, objects can be clearly separated, with the entire analysis process achievable in a fast timeframe of 5 seconds. Notably, discrepancies between measured and actual dimensions were quickly identified, highlighting the system's ability to accurately detect potential differences and defects. Essentially, the systematic evaluation highlighted the robustness, reliability, and effectiveness of the field detection and analysis automation system. By leveraging advanced algorithms and precise measurement techniques, the system delivers excellent accuracy and stability, facilitating seamless and reliable analysis of objects in a variety of environments, conditions and different activities.

The detection machine has a stable, high precision and good working time, and during the detection and confirmation, the three-axis sliding table is working parallel, which improves the level of automation the system [22-24].

A runtime comparison of traditional edge detection methods and an improved PCNN (Pulse Coupled Neural Network) algorithm provides valuable insights to improve accuracy and increase computational efficiency. This result clearly shows that using the improved PCNN algorithm significantly reduces the execution time, from 256 seconds for the traditional method to just 100 seconds for the PCNN algorithm. This significant reduction in processing time highlights the superior computational efficiency of the PCNN algorithm in edge detection tasks. Notably, the PCNN algorithm still maintains or improves accuracy despite its increased processing speed

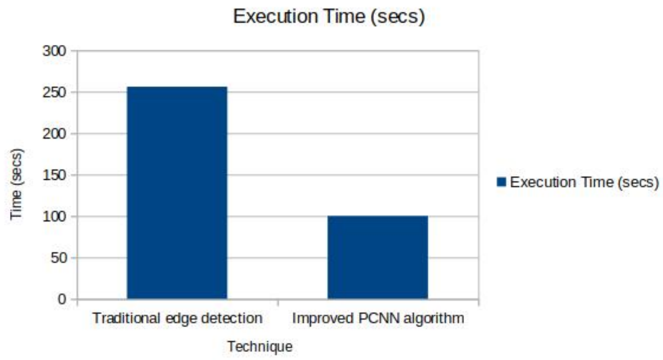

Fig. 4.2: Execution Time

compared to traditional methods. This efficiency increase not only improves the overall performance of the detection system, but also enables rapid image analysis and facilitates rapid decision-making in a variety of applications. In summary, the observed runtime differences highlight the significant computational advantages offered by the PCNN algorithm, making it an attractive choice for edge detection in automated analysis systems.

5. Conclusion. The author presents an innovative automatic search and authentication control system, underpinned by a vision-based detection and recognition automation package developed through the integration of LabVIEW and MATLAB software. Employing the refined PCNN edge extraction algorithm, experiments conducted on a fixed platform in a garden setting yielded promising results. The observational analysis underscores the system's adaptability to dynamic measurement scenarios, wherein fluctuations in measurement position induce corresponding changes in length and width values. Notably, the integration of the vision system with a servo mechanism establishes an open-loop optical servo mechanism, elevating product control automation capabilities. This enhancement addresses deficiencies inherent in conventional control systems, such as low control precision, inadequate automation efficiency, and lack of trust, while facilitating comprehensive analysis and defect detection across diverse tasks including food inspection, size analysis, and partial analysis. The system achieves remarkable efficiency, with tasks such as photographing, size analysis, partial analysis, and table reset completed within a mere 5 seconds. Moreover, the system demonstrates robustness in detecting and analyzing objects in motion, showcasing its potential for real-time applications even at speeds of up to 1m/s. The developed system represents a significant advancement in automation and control technology, offering unparalleled accuracy, efficiency, and adaptability. By seamlessly integrating cutting-edge software tools and innovative algorithms, it promises to revolutionize various industrial processes and elevate the standards of product inspection and control automation.

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