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The Application of Machine Vision in Defect Detection Systems

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Abstract: With the rapid development of computer vision technology, artificial intelligence algorithms, and high-performance computing platforms, machine vision technology has gradually shown its great potential in automated production lines, especially in defect detection. Machine vision technology can be applied in many industries such as semiconductor, automobile manufacturing, aerospace, food, and drugs, which can significantly improve detection efficiency and accuracy, reduce labor costs, improve product quality, enhance market competitiveness, and provide strong support for the arrival of Industry 4.0 era. In this article, the concept, advantages, and disadvantages of machine vision and the algorithm framework of machine vision in the defect detection system are briefly described, aiming to promote the rapid development of industry and strengthen China's industry.

Keywords: Machine vision; Defect detection system; Image preprocessing

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1. Introduction

The *Guiding Opinions on Accelerating Scene Innovation to Promote High-Quality Economic Development with High-Level Application of Artificial Intelligence* clearly points out that with a smarter city and a more caring society as the guidance, it will continue to explore opportunities for artificial intelligence application scenarios in urban management, traffic management, ecological environmental protection, medical health, education, elderly care, and other fields, and carry out application demonstrations of intelligent society scenarios. In the field of urban management, urban brain, urban IoT perception, invisible government data availability, digital procurement, and other scenarios are explored. In the field of traffic governance, scenarios such as traffic brain, smart roads, smart parking, self-driving travel, smart ports, and smart waterways will be explored. In the field of ecological and environmental protection, we will focus on scenarios such as intelligent environmental monitoring and autonomous drone inspection. In the field of smart communities, scenarios such as future communities, unmanned delivery, community e-commerce, and digital restaurants will be explored. In the

medical field, scenarios such as intelligent diagnosis assisted by medical images, decision support assisted by clinical diagnosis and treatment, medical robots, Internet hospitals, intelligent medical equipment management, smart hospitals, and intelligent public health services are actively explored. In the field of education, online classes, virtual classes, virtual simulation training, virtual teaching and research rooms, new teaching materials, teaching resource construction, and smart campuses are actively explored. The elderly care sector is actively exploring scenarios such as home intelligent monitoring and smart wearable device applications. In the rural sector, we are actively exploring scenarios such as smart rural governance, digital rural housing, and online government services. Machine vision, as a part of artificial intelligence, should give play to its detection ability to better detect defects, so as to better promote the development of industry and achieve industrial progress [1].

2. Overview of machine vision

2.1. The concept of machine vision

Machine vision is a rapidly developing branch of the field of artificial intelligence, which mainly refers to the use of machines instead of human eyes to make measurements and judgments [2]. Machine vision is a combination of image processing, mechanical engineering, optical imaging, sensor technology, analog and digital video technology, as well as computer hardware and software technology (including image enhancement and analysis algorithms, image cards, etc.), and other fields of knowledge. It also includes image capture, light source system, image digitization, digital image processing, intelligent judgment decision and mechanical control execution, and other modules, to achieve automated detection and decision.

2.2. The advantages of machine vision

2.2.1. Higher production efficiency and accuracy

On the production line, compared with the traditional manual inspection, the machine vision system can not only continue to work but also will not affect the detection efficiency due to fatigue or inattention. On the contrary, it will detect faster, have a stronger ability to process information, and can quickly process and analyze the data to achieve automatic integration and real-time feedback of information. It also improves the ability of enterprises to optimize the production process [3]. For example, in the automobile manufacturing workshop, the factory can use machine vision to detect the paint film applied to the body, check whether the car has scratches, and whether there is a dent or uneven color problem; if there is any problem, the factory can immediately make decisions and changes.

2.2.2. Strong adaptability and flexibility

Machine vision systems can adapt to high or low temperatures, humidity, dust, and other complex environments, where people cannot work [4]. For example, in the process of growing food, farmers can use machine vision technology to monitor the growth of crops, weed distribution, and disease and insect pests; according to this precise application and irrigation, they can reduce the overuse of pesticides, improve the yield and quality of crops, and can even customize and optimize according to the needs of different farmers to meet different needs.

2.3. The shortcomings of machine vision

2.3.1. Limited comprehension and reasoning ability

Although it can process and analyze a large amount of image data, it is far inferior to humans in terms of in-

depth understanding and reasoning of images, because it relies on pre-set algorithms and models for image recognition and analysis, and these models are not able to analyze complex images. Recognition of abstract concepts in images and understanding of the relationship between the context of the scene and emotional knowledge is difficult to process, so machine vision is difficult to completely replace human beings in some application scenarios requiring high intelligence and flexibility [5].

2.3.2. Poor adaptation to complex scenes and backgrounds

Machine vision system mainly relies on optical imaging technology for image capture and processing, so it is easy to be affected by lighting changes, occlusions, noise, and other factors, which will lead to the performance decline of machine vision systems [6]. In the environment of low light or large light changes, the machine vision system may not be able to accurately capture and identify the target object in the image. In the case of a complex background or the presence of multiple similar target objects, there may also be misrecognition or missed recognition [7].

3. The algorithm framework of machine vision in the defect detection system

3.1. Image preprocessing

Due to the imperfection of the imaging system, interference of the transmission medium, or improper operation in the image processing process, these images exist in the form of Gaussian noise and salt and pepper noise (isolated pixels or pixel blocks. Although they have nothing to do with the information of the image itself, it has a great impact on the image processing steps of the following edge extraction and feature recognition. How to suppress these noises in the defect detection system, improve the image quality, and ensure the accuracy and efficiency of the detection data has become the key we need to discuss [8]. The detection system can first use the median filter, which will sort the pixel values of the neighborhood, and then select the middle value as the output, effectively removing the isolated noise points while maintaining the edge and details of the image. Then, using the Gaussian filter in the way of weighted summation, give different weights to the neighborhood pixels, the weight size is determined by the Gaussian function, so that not only can smooth the noise but also can better retain the edge information of the image, reduce the influence of Gaussian noise, enhance the overall contrast of the image. After such pretreatment steps, the image will improve the quality of the image, highlight the defect features, and provide a solid foundation for the subsequent feature extraction and classification recognition [9].

3.2. Region of interest extraction

Threshold segmentation and edge detection are the two most commonly used methods of ROI extraction image segmentation technology, so we will elaborate on the application of these two methods in ROI extraction, defect recognition, and classification in machine vision defect detection systems through specific examples.

First, the application of threshold segmentation in ROI extraction. In the defect detection system, threshold segmentation is an algorithm that divides the image into areas with properties significantly different from the background or other normal areas by setting one or more thresholds based on the image's grayscale value or color and other attributes. Taking semiconductor chip defect detection as an example, defects on the surface of the chip (such as scratches, stains, omissions, etc.) usually appear as grayscale differences from the surrounding normal area. First of all, the detection system can use image processing software or algorithms to process the chip image, such as denoising and enhancing contrast, which can better improve the accuracy of

threshold segmentation [10]. Secondly, according to the gray histogram of the pre-processed image, one or more appropriate thresholds can be selected for segmentation, and the defective area on the surface of the chip can be divided from the normal area. At this time, according to the location, shape, and size of the flaw area, the smallest rectangular box or irregular polygon containing the flaw can be manually or automatically outlined as ROI, which will greatly reduce the amount of computation and improve the processing speed [11].

Second, the application of edge detection in ROI extraction. Edge detection is based on the mutation of pixel values in the image to identify the edge of the object to determine ROI. In textile defect detection, the detection system extracts the flaw edge contour of the textile such as holes, stains, and color difference, and preprocesses the textile image using image processing algorithms such as filter denoising and edge enhancement. After that, Canny operator, Sobel operator can be used as the classic edge detection operator, which will identify the edge by calculating the image gradient to extract the pre-processed image. After edge extraction, the edge points that constitute the contour of the edge of the defect can be obtained. The obtained edge points can not only be connected to the cultivated edges by morphologic operations such as expansion and corrosion, but also the complete contour of the defect can be extracted by a contour tracking algorithm, or a rectangular box or irregular polygon containing the smallest defect can be taken as ROI in order to ensure the accuracy of subsequent detection [12].

Third, defect identification and classification. In order to identify the defects of the color, texture, and shape of the metal surface, the detection system can use the image processing algorithm to extract the color features (such as RGB value, HSV value, etc.), texture features (such as grayscale co-occurrence matrix, local binary mode, etc.), shape features (such as area, circumference, aspect ratio, circularity, etc.) within the ROI; according to the needs of defect recognition, select a representative subset for subsequent processing. Then select a suitable classifier from a vector machine (SVM), decision tree, random forest, neural network (such as convolutional neural network CNN) to identify classification defects, and finally output detection results [13].

Threshold segmentation and edge detection are suitable for different types of defect detection tasks respectively, and can be combined with technical means such as feature extraction, feature selection, and classifier design to achieve accurate identification and classification of defects and improve the accuracy and efficiency of detection [14].

3.3. Defect recognition and classification

3.3.1. Defect identification

In PCB defect detection systems, machine vision technology always uses high-precision cameras and image sensors to capture common problems such as poor welding, broken wires, missing components, and short circuits. Therefore, the machine vision system will enhance and preprocess the acquired images by image smoothing, brightness, and contrast adjustment steps before flaw recognition, so that it can better show the detailed characteristics of the PCB surface, and provide reliable input data for subsequent defect recognition. The machine vision system will also be based on the threshold segmentation algorithm can separate the foreground and background in the image, better distinguish the defect area, understand the content of the image, and improve the accuracy of defect recognition [15].

3.3.2. Defect classification

On the one hand, the statistical classification method is to identify and classify defects by analyzing defect

features in historical data and using cluster analysis and discriminant analysis. For example, the K-means clustering algorithm needs a large amount of historical data as a training model, divides defects into different categories according to the size, shape, and other characteristics of defects, establishes an accurate statistical model, and realizes the accurate classification of defects. On the other hand, decision trees, support vector machines (SVM), and convolutional neural networks (CNN) can also learn the visual features of defects through training, and realize automatic identification of defects. For example, for PCB defect detection, CNN can be used to train the model, so that it can distinguish between normal areas and different types of defects, label the type and location of defects, and achieve better classification of defects.

3.3.3. Algorithm design

Image enhancement and pre-processing algorithms (denoising algorithm, image smoothing algorithm, brightness and contrast adjustment algorithm) can improve the accuracy of detection, and feature extraction and design classification algorithms are the keys to achieving defect detection and classification. As the name suggests, the denoising algorithm can remove the noise in the image and improve the image quality. Image smoothing algorithm is able to reduce the detail information in the image, so that the defects are more obvious. Brightness and contrast adjustment algorithm is to adjust the brightness and contrast of the image to make the defects of the image more prominent. The feature extraction algorithm can extract the texture, shape, and color similar to the defect. Classification algorithm means to classify defects according to the extracted features. In daily life, the appropriate classification algorithm can be selected according to the specific detection requirements and data characteristics, so as to improve the accuracy of classification.

3.3.4. Practical application cases

PCB defect detection system built by electronic manufacturing company using machine vision technology can identify common defects such as poor welding, wire breakage, missing components, and short circuits, and classify and record these defects to improve detection efficiency, reduce labor costs and time, ensure the stability and unity of product quality, so as to reduce unqualified products. It also improves production efficiency and provides strong support for the sustainable development of enterprises. Machine vision technology in the defect detection system can use a high-precision camera and image sensor to capture the fine features of the product, the use of image processing and analysis technology for high-precision product detection, in order to play an important role in machine vision technology.

4. Conclusion

Machine vision technology through simulation and beyond the limits of human vision for defect detection has brought a lot of changes and can solve the limitations of traditional manual detection methods in terms of efficiency, accuracy, and stability. More industrial manufacturing can provide efficient, accurate, reliable defect detection solutions, in order to promote industrial manufacturing to higher quality and efficiency, and more intelligent direction. In this paper, the application of machine vision in the defect detection system is briefly summarized, aiming to provide references and a basis for researchers studying this direction, contributing their strength to the high-quality development of industrial manufacturing, realizing the rapid development of industry, leading the industrial automation and intelligence level to a new level.

Disclosure statement

The authors declare no conflict of interest.

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