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HALCON Machine Vision Technology in Automated Inspection Study

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Abstract

Based on HALCON machine vision technology, the application advantages and practical effects in the fields of target localization, dimensional measurement, defect detection, and classification recognition were analyzed. Specific examples were combined to discuss HALCON's performance in complex, precise measurement and real-time recognition and inspection tasks, demonstrating its efficient vision solutions in the industrial, electronics, food, and aviation industries. Finally, the challenges faced by the current technology were discussed, and future development directions were proposed to promote its application and progress in various industries.

Keywords

HALCON; Machine Vision; Defect Detection; Target Localization; Dimensional Measurement; Classification Recognition.

1. Introduction

Machine vision is a technology that simulates human vision by computer and uses software algorithms to analyze and understand the images captured by the camera, so as to realize automatic recognition and judgment [1]. Its system usually includes an optical system, an image acquisition module, an image processing system and an interactive interface [2]. It involves a number of technologies such as optical imaging, sensors, video transmission, mechanical control, camera control, image processing, etc., and the accuracy and efficiency of each link directly affects the final detection results. In recent years, with the rapid development of industrial intelligence, machine vision, by virtue of its advantages of high efficiency, precision, intelligence, etc., has been widely used in many fields such as industrial [3], automotive [4], food [5], electronics [6], etc., to achieve defect detection [7], positioning guidance [8], measurement [9-10], classification and identification [11], and other functions, which significantly improves the productivity and product quality, and becomes an indispensable technical means for modernized production indispensable technical means.

HALCON is a high-performance image processing software developed by MVTec. Compared with image analysis tools such as OpenCV [12], VisionPro [13], and MATLAB [14], HALCON is known for its streamlined code and fast running speed, which can efficiently and accurately complete various complex image processing tasks [15]. It is widely used in industrial [16], automotive [17], and electronic fields, and is recognized as one of the most efficient commercial machine vision software in the world.

This paper studies HALCON-based machine vision technology, focusing on analyzing its application advantages and practical effects in target localization, size measurement, defect detection and classification recognition, aiming to promote the application and development of related technologies.

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2. HALCON Software Overview

As the world's leading machine vision software, HALCON has become the solution of choice for multiple industries and applications due to its powerful image processing capabilities, broad compatibility and flexible functionality. It not only provides advanced image analysis tools, but also enhances performance and deployment flexibility through deep learning technology and hardware acceleration. Specific features include:

Superior Performance and Parallel Processing: Supports multi-core processors and multi-processor systems, automatically parallelizes image processing tasks and optimizes performance through intelligent algorithms. Supports AVX, SSE, NEON and other instruction set extensions and GPU acceleration to ensure efficient and stable operation in complex scenes.

Wide range of hardware compatibility and openness: compatible with Windows, Linux, macOS and other operating systems, supporting a variety of industrial cameras and image acquisition cards. Open interfaces allow HALCON to seamlessly integrate with existing hardware and systems, adapting to a variety of industrial applications.

Rich image processing technology: Provides barcode and 2D code reading, Blob analysis, deep learning, morphological processing, filtering technology, OCR and OCV, matching and measurement, etc. It supports a wide range of image processing tasks from simple to complex, and ensures reliable recognition even in the case of image occlusion, poor print quality, or out-of-focus conditions.

Deep Learning and Intelligent Analysis: Integrate deep learning technology, support neural network training and image annotation, and rapidly deploy deep learning applications. Enhance the inference speed through AI gas pedal interface, and enhance the intelligent analysis capability of machine vision system.

High precision and flexibility: Provides accurate dimensional measurement, positional alignment and 3D vision technology, capable of handling complex 3D data and localized deformation of objects, widely used in high-precision inspection tasks.

Convenient development environment and ease of use: HALCON provides an intuitive HDevelop integrated development environment that supports graphical programming and a variety of programming languages (C, C++, Python, C#, etc.), enabling developers to easily implement machine vision applications [18].

3. Application of HALCON in Defect Detection

3.1 Overview of Defect Detection Technology

Defect detection technology has been widely used in industrial production. Compared with traditional manual inspection methods, machine vision technology combines image acquisition equipment and image processing algorithms to efficiently and accurately identify various types of defects, thus ensuring product quality and improving production efficiency. Common types of defects include cracks, scratches, pits, abrasions, and color differences, which may affect the functionality, safety, or durability of products [19]. In order to effectively detect these defects, commonly used methods include edge detection, texture analysis, threshold segmentation, and morphological processing. Edge detection is mainly used to identify surface cracks and irregular boundaries, texture analysis helps to detect surface defects such as stains or scratches, while threshold segmentation and morphological processing are used for defect separation and extraction.

3.2 HALCON-based Defect Detection

In HALCON image processing algorithms, the commonly used techniques include edge detection, morphological processing, threshold segmentation, template matching, shape matching, feature extraction, image filtering, and deep learning. These techniques can effectively extract defective features from images. Eddie Peng et al [20] proposed a dispensing quality inspection method based on HALCON, which mainly includes two parts: standard qualified workpiece processing and glue

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defect detection of the workpiece to be inspected, and the workflow is shown in Figure 1. First, the glue contour and width information of the standard workpiece is extracted through the steps of denoising, template analysis and image segmentation. Then, the image of the workpiece to be inspected is subjected to template matching, primary positioning glue region extraction, image segmentation and other operations to extract the glue contour and compare it with the centerline of the standard workpiece to detect glue breaks and wavy glue problems. This process effectively identifies dispensing defects. The experimental results show that the detection accuracy of the method reaches 99.6% and the average detection time is 475 ms, which fully meets the real-time detection requirements of industrial production lines.

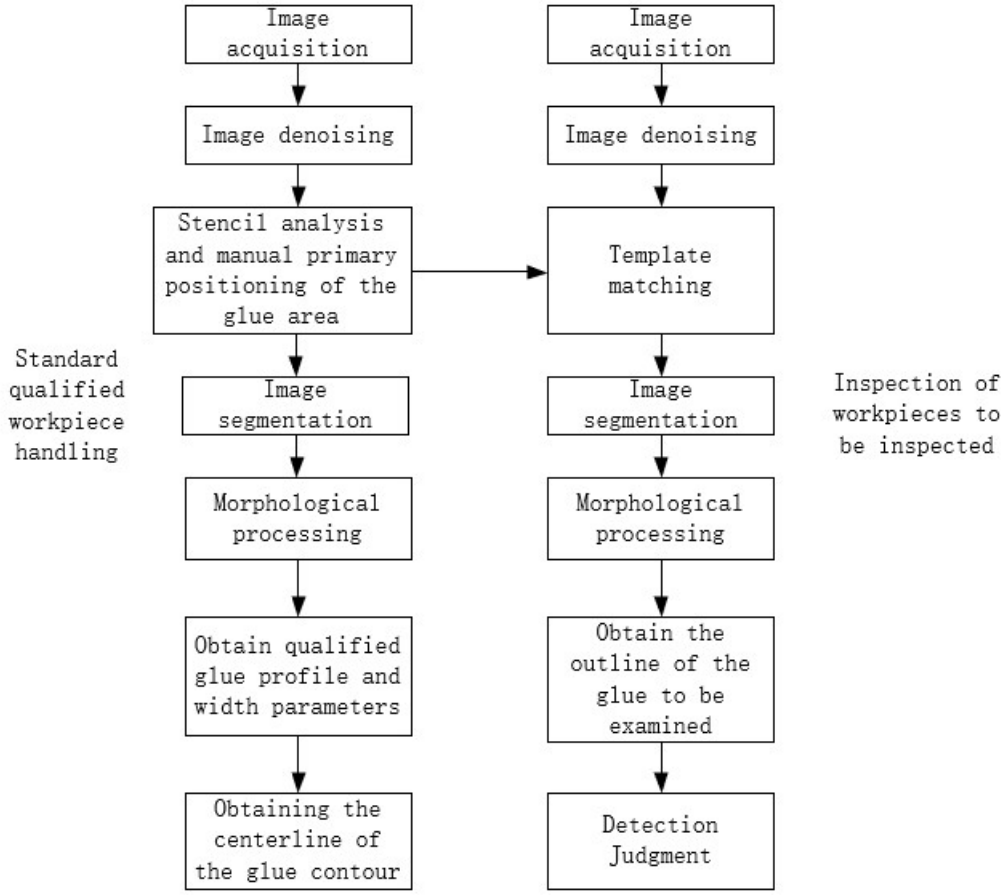

Fig.1 Detection of the basic flow chart

In recent years, many research results have been achieved in defect detection technology based on HALCON software. Cai Shuting et al [21] proposed a HALCON-based defect detection method for American Standard power cords, which combines image processing and machine vision technologies to quickly and accurately detect the box cover, terminal coupling copper wires, and wire polarity of power cords, with a detection accuracy of up to 100%; Li Wujing et al [22] developed a HALCON-based SMD IC soldering defects detection system, which successfully realizes the precise detection of major soldering defects (e.g., bridging and solder leakage) of SMD ICs in circuit boards, with a detection accuracy of 98.7%;He Xiao et al [23] applied HALCON software to detect surface defects on circular ceramic sheet, and the study shows that the method can effectively detect irregular defects and extract multiple features, and the detection accuracy reaches 98%; Zhu Zhipeng et al [24] built a system for detecting surface defects on the back plate of a cell phone based on HALCON, and the final system's misclassification rate is only 3%, and the detection rate is 94%;Ren Pengfei et al [25]

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proposed a defect detection method for paper cups based on HALCON, for the defects of stains inside the cup and deformation of the cup mouth, and realized the rapid detection by image processing technology, which can meet the defect detection needs in the production process of paper cups.

As can be seen from the above research results, the application of HALCON in defect detection has significantly improved the detection efficiency and accuracy, and successfully solved the defect detection problems in many industrial fields. Whether in ceramic chips, cell phone backplanes, power cords, SMD IC welding or paper cup production, HALCON, with its powerful image processing capabilities, provides highly accurate and robust solutions, effectively promoting the development of industrial automation and quality control, and providing strong technical support for industrial production.

4. Application of HALCON in Targeting

4.1 Overview of Targeting Techniques

Target localization technique is a key technique in the field of computer vision and image processing, which is used to determine the positional information of target objects in image or space. It is realized by template matching, detection and description, edge detection and shape matching [26]. Target localization techniques can be categorized into visual localization techniques, feature extraction and matching, deep learning, sensor localization techniques, RFID localization techniques, and combined localization techniques based on application areas and technical principles. Among them, the key technologies in target localization can be classified into several categories such as image processing and computer vision, deep learning, multi-sensor fusion and real-time localization and map construction (SLAM).

4.2 HALCON-based Targeting

HALCON-based target localization technique is based on the geometric features of the target object or feature point matching for localization. The target position is determined through image acquisition, template creation, feature extraction and analysis, target search and localization. This technology is widely used in industrial manufacturing, quality inspection, logistics and warehousing, and has excellent performance in robot assembly operations on automated production lines and automatic sorting and handling of goods in logistics and warehousing. HALCON-based target localization technology can realize the advantages of higher accuracy, more technology integration, and more application scenarios through appropriate algorithm adjustment. An Yanbo et al [27] developed an image localization algorithm for the core detector assembly based on HALCON, which solved the problem of not being able to use the theoretical coordinates when the detector assembly is dismantled due to the large deviation of the assembly. Through template matching and image capture, the detector assembly can be accurately located with high positioning accuracy to meet the requirements for positioning accuracy during dismantling. The flow chart of the positioning algorithm is shown in Figure 2. This technology enhances the degree of equipment intelligence, reduces the risk of operator dose, and shortens the dismantling time. It has been successfully applied to the K2/3 units of Karachi nuclear power plant and the 5 and 6 units of Fuqing nuclear power plant in Pakistan, realizing the precise positioning of underwater detector components. The target matching results are shown in Figure 3.

Song Luming et al [28] proposed a method of localization and path planning for a water surface garbage cleaning robot, which determines the location of garbage through image segmentation and edge detection in HALCON, and then combines a binocular camera and an ant colony algorithm for shortest path planning. Experiments verified its high efficiency in the complex water surface environment; Pan Wang et al [29] studied the fast recognition and localization problem for robot astronauts in grasping target objects, optimized the CAD model-based 3D target recognition algorithm in HALCON, with 100% recognition accuracy, processing time of about 200ms, and significant improvement in localization accuracy; Pan Guangyao [30] developed an algorithm based on the HALCON and C# programming machine vision localization and detection system, through the

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multi-threaded design to achieve image acquisition and processing, and communicate with the ABB robot to transmit the position and size information of the workpiece, and ultimately complete the robot grasping task, to improve the efficiency of industrial applications. He Ziyang [31] designed a method for wing parachute tracking and spatial localization using two zoom cameras and multi-base station information. Through the deep learning target detection and semantic segmentation algorithms in HALCON, high-precision wing parachute detection and area segmentation were realized, ensuring the efficient tracking and localization capability of the system. Liao Bingwang [32] developed a visual sorting system using HALCON and C++, which is able to quickly locate workpieces and realize accurate sorting with high accuracy and stability through image preprocessing, target matching and coordinate conversion.

In summary, HALCON-based target localization technology has demonstrated significant advantages in different application scenarios, promoted the technological development in several fields, and provided efficient and accurate visual localization solutions for related industries.

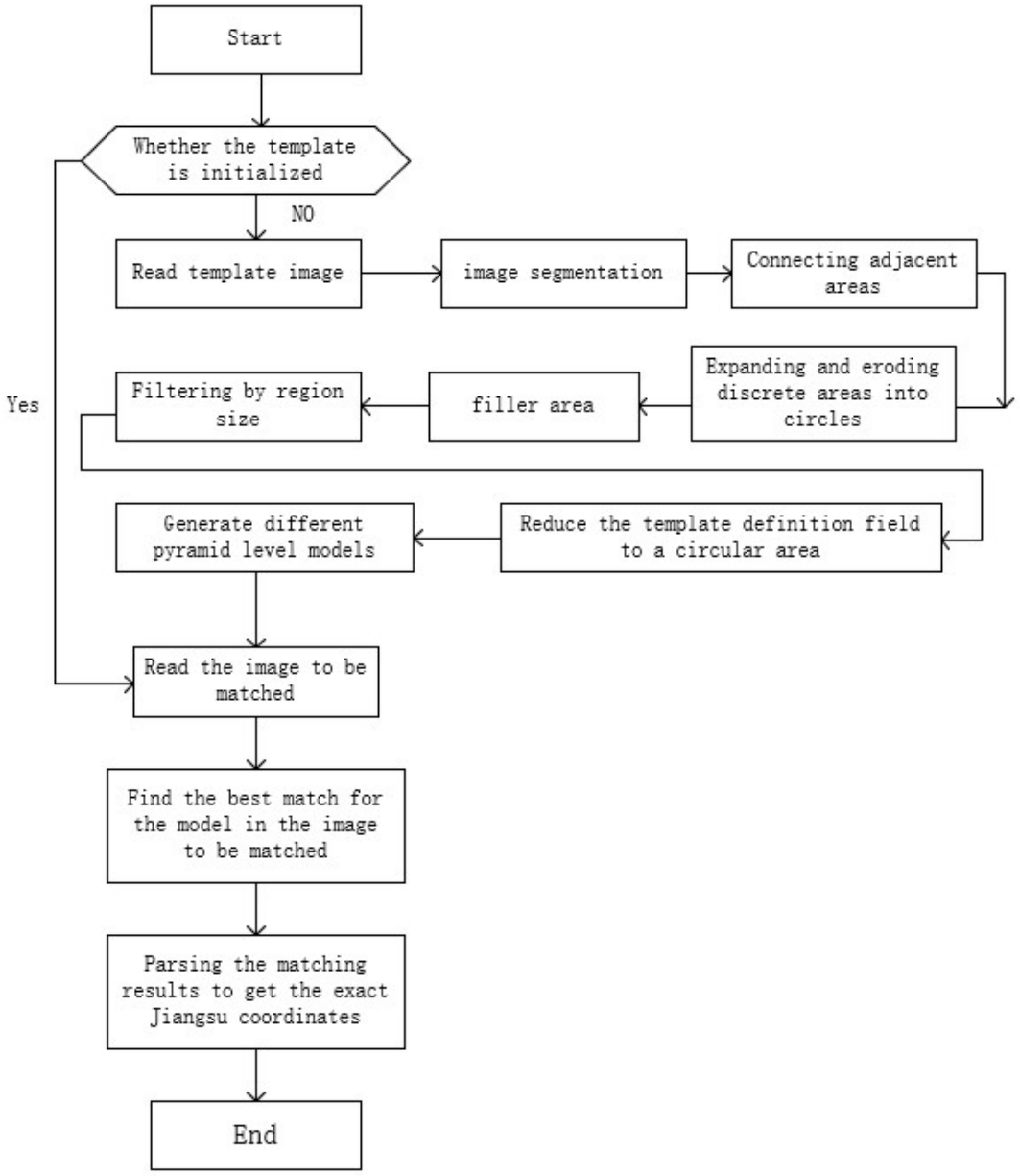

Fig.2 Flowchart of the localization algorithm

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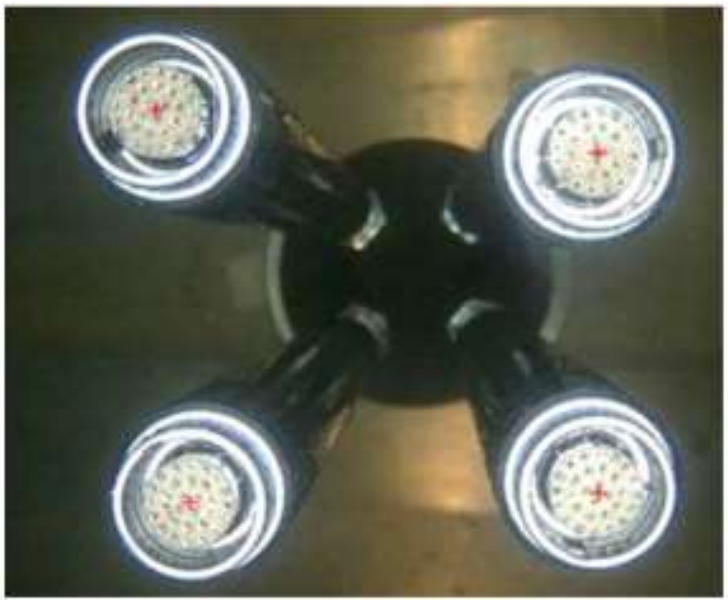

Fig.3 Target Matching Result Chart

5. Application of HALCON in Dimensional Measurement

5.1 Overview of Dimensional Measurement Technology

Dimensional measurement is the extraction of information about the actual dimensions of an object from a two-dimensional image by means of image processing techniques. This process requires establishing a correspondence between the pixel dimensions in the image and the real physical dimensions of the object to achieve accurate measurement. Dimensional measurement techniques are widely used in industrial automation, robot vision, and medical imaging, such as automatic part size detection, size judgment of robots grasping objects, and size measurement of organs or lesions. Common measurement methods include camera calibration, stereo correction, edge detection, edge fitting, feature point extraction and template matching techniques, each of which is suitable for different application scenarios. Dimensional measurement techniques can not only improve production efficiency and inspection accuracy, but also play an important role in ensuring product quality and promoting technological progress [33].

5.2 Dimensional Measurement based on HALCON

In dimensional measurement techniques, HALCON's commonly used image processing algorithms include camera calibration, edge detection, geometric fitting, region segmentation and feature extraction, and stereo matching. These techniques work in concert to efficiently and accurately extract the dimensional information of an object. Camera calibration ensures the accuracy of measurement by determining the internal and external parameters of the camera and converting the pixel coordinates in the 2D image to 3D world coordinates; edge detection uses algorithms such as Canny operator to extract the edge contour of the object; geometric fitting accurately calculates the geometric dimensions of the object such as the length of the line segments and aperture diameters by straight line fitting and circle fitting; region segmentation and feature extraction provide accurate data for size calculation by segmenting images and extracting relevant features; stereo matching is used to find the corresponding points of the same spatial object in different viewpoints.

Zou Zhe Hao et al [34] proposed a machine vision based caliper tool method for bearing precision measurement. The basic flow of the method includes image acquisition, thresholding, image preprocessing, edge extraction, and fitting, measurement and display using the caliper tool operator in HALCON. The measurement flow chart is shown in Fig. 4. The experimental results show that the method has high stability, robustness and fast measurement speed. The measurement accuracy can reach 0.008mm, and for the 688zz model bearings, the tolerance of the inner and outer diameters is in line with the national ordinary grade standard (within 0.008mm), which fully meets the

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requirements of the national standard; Lin Hui et al [35] proposed a HALCON-based precision measurement method for the dimensions of shaped parts, which realizes the precise measurement of complex geometric shapes with an accuracy of 0.04 mm. Yang Guihua et al [36] developed a chip pin measurement system, which is capable of accurately detecting the pins and analyzing the defects by means of HALCON's shape-matching and 1D measurement algorithm The system has a single image detection time of 56ms, a measurement error of ±0.01mm, and a 100% correct rate of defect detection. Li Baoli et al [37] designed a measurement system for axial dimensions of corrugated compensators, combining C# and HALCON, with high accuracy and fast speed to meet industrial needs. Jarui Luo et al [38] developed a method for aero-engine blade tenon profile dimension measurement based on machine vision technology. The system uses HALCON for image preprocessing, edge extraction, geometric feature extraction and dimensional transformation to accurately obtain dimensional information. The test results show that the average measurement accuracy of the system in straight line and angle can be controlled within 0.0236mm and 0.2701°, respectively, and a single measurement takes no more than 2s, which has a strong potential for field application.

It can be seen that HALCON-based dimensional measurement is not only capable of processing complex image data in real time, but also meets the needs of industrial production lines for fast and accurate measurement. Especially in the face of complex shapes and tiny sizes of parts, HALCON's image segmentation and geometric analysis algorithms are able to provide reliable measurement results and promote the improvement of industrial automation and quality control.

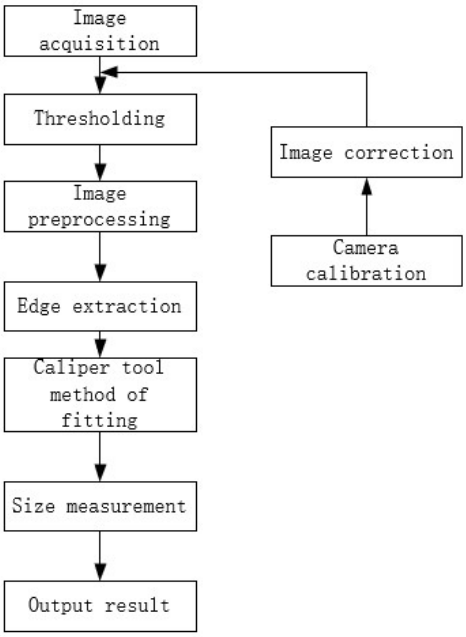

Fig.4 The basic process of image processing

6. Application of HALCON to Classification Recognition

6.1 Overview of Classification Recognition Technology

Classification and recognition techniques classify and recognize objects or targets in a scene through image processing algorithms. The image classification task is to assign images to predefined categories, while image recognition further distinguishes specific entities or objects in an image on the basis of classification. Common classification and recognition methods can be categorized into two main groups: traditional methods and deep learning based methods. Traditional methods usually include three steps: feature extraction, feature representation and classifier. Feature extraction is to

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transform the original image into feature vectors that can be used for classification, and the key is to extract features that can describe the image categories, such as color, shape, texture, etc. Feature representation converts these feature vectors into vectors of uniform dimensions for easy processing by the classifier. The classifier classifies images by learning samples of predefined categories. Traditional methods are suitable for targets with distinct features and small variations. In contrast, methods such as deep learning based Convolutional Neural Networks (CNNs) automatically learn and extract effective features from large amounts of data and are suitable for the task of recognizing complex targets.

6.2 HALCON-based Classification and Recognition

The HALCON-based classification and recognition process consists of several key steps. First, the image quality is improved through image preprocessing (e.g., denoising, contrast enhancement, grayscaling and binarization) to highlight object features. Then, features such as shape, texture and color are extracted from the image through feature extraction (e.g., edge detection, texture analysis, etc.) to provide a basis for subsequent classification. Next, object templates are compared with the captured images through template matching to recognize the object type. For more complex classification tasks, HALCON also supports machine learning (e.g., Support Vector Machine, KNN) and deep learning (e.g., Convolutional Neural Network CNN) based methods to automatically learn and extract effective features from the images, thus improving classification accuracy. Finally, target localization not only achieves classification of objects, but also accurately determines the location of objects in the image. Overall, HALCON achieves efficient and accurate classification and recognition through these methods, which are widely used in industrial inspection, object recognition and other fields. Lin Hui et al [39] developed a HALCON-based license plate recognition technology to address the limitations of domestic and international license plate recognition systems in recognizing Chinese license plates. The system consists of four main parts: image acquisition, license plate localization, character segmentation and character recognition. The steps of license plate recognition are shown in Fig. 5.First, images are captured using a black-and-white industrial camera, and image preprocessing is performed using the Sauvola local thresholding method. Next, the template matching technique is utilized to solve the Chinese character segmentation problem. Then, HALCON's MLP classifier is used to train the OCR classifier for Chinese characters to realize character recognition. The experimental results show that the success rate of the system in recognizing license plate images in different backgrounds is more than 90%, which is highly practical. The license plate recognition results are shown in Fig. 6.

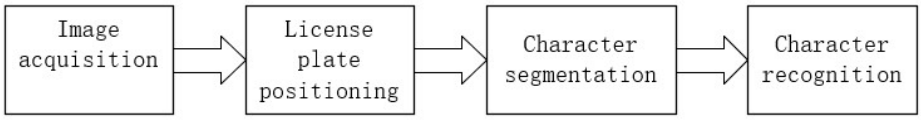

Fig.5 License Plate Recognition Flowchart

Fig.6 Character Recognition Result Chart

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The classification and recognition method based on HALCON machine vision software is not only outstanding in the field of license plate recognition, but also increasingly widely used in various fields. Yang Guihua et al [40] proposed a multi-target workpiece classification and recognition method based on the combination of connected domain (Blob) analysis and neural network classifier. The method uses Blob analysis to extract workpiece feature information for localization through the HALCON software platform, while the trained neural network classifier is applied to classify the workpieces. The experimental results show that the recognition accuracy of this method reaches 100%, the positioning accuracy is improved by 0.7mm, and the recognition and positioning time is shortened by 8.735ms; Li Zhisen et al [41] proposed a bank card number recognition method based on HALCON, which employs image preprocessing, threshold segmentation, extraction of region of interest, and Optical Character Recognition (OCR) technology to achieve accurate bank card number recognition; Zheng Ruxin et al [42] studied a fruit classification and recognition method based on Gaussian mixture model, combined with HALCON software for image segmentation and feature extraction, successfully realized the separation of fruits and background, and used GMM algorithm for classification training. The experimental results show that the method has high accuracy in fruit recognition, which verifies its effectiveness; Chen Liting et al [43] designed a robotic recognition, localization and grasping system based on binocular vision, and used the vision algorithm of MLP classifier for workpiece recognition, which is excellent in classification effect and localization accuracy, and can meet the robot's online grasping demand of the workpiece. Chen Si et al [44] studied the method of rapid development of optical character recognition system based on HALCON platform. Utilizing the classifier template and OCR assistant that comes with the platform, the recognition test of uppercase letters, numbers and Chinese characters showed a high accuracy rate.

It can be seen that HALCON-based classification and recognition technology has demonstrated excellent performance in many fields. Especially in applications such as license plate recognition, artifact classification, and bank card number recognition, HALCON is able to accurately and efficiently process complex image data to meet the needs of real-time recognition and classification.

7. Summary

HALCON image processing technology has a wide range of applications and significant value in the industrial field, especially in automated inspection, quality control and robot guidance, which require high performance and accuracy. Research shows that HALCON not only can effectively improve production efficiency and product quality, but also provides strong technical support for intelligent manufacturing and Industry 4.0. Compared with traditional image processing software, HALCON has significant advantages in high-precision inspection, complex image processing and high-speed processing, and has become a common choice for large and medium-sized industrial enterprises.

Nevertheless, HALCON still faces challenges in real-time and hardware compatibility, and future research will focus on improving the algorithm's computational speed, optimizing hardware suitability, and solving application problems in complex environments. In addition, with the increasing demand for real-time and high efficiency in industrial production, future research will also focus on optimizing the HALCON algorithm and further improving the image processing efficiency by means of parallelized processing and hardware acceleration, in order to meet the real-time inspection needs of high-speed production lines. Overall, the technical advantages of HALCON provide reliable support for intelligent production and have broad application prospects.

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