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Overview and Applications of Image Processing

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Abstract. Currently, traditional manual inspection methods are inefficient and subjective. Compared with human visual measurement, machine vision measurement exhibits higher efficiency, greater flexibility in working hours, and immunity to fatigue. Meanwhile, it can be integrated with remote detection technologies such as X-ray, infrared, and ultrasonic, enabling the detection of non-visible objects and the execution of detection tasks in high-risk scenarios. The modern manufacturing industry is currently undergoing a transformation and industrial restructuring towards intelligence, and machine vision is therefore being used in a wide range of fields. This article describes in detail the components and functions of machine vision technology. In addition, this paper compares and summarizes the new algorithms in image pre-processing that have emerged in recent years. The results of this review also analyse the use of machine vision in different scenarios such as smart agriculture, public transport, industrial construction . Recognition of captured product images with the help of machine vision technology is of great significance in practical applications as it allows fast, accurate and non-destructive evaluation of their performance.

Keywords: machine vision, image preprocessing, deep learning, target detection, computer vision

1. Introduction

In recent years, robots have been widely used in different scenarios such as agriculture, machine production, road maintenance and daily life. The cooperative operation of various sensors is a crucial part of robot intelligence. A typical industrial machine vision application system includes a light source, an optical system, an image capture system, an image digitisation module, a digital image processing module, an intelligent judgement decision module and a mechanical control execution module [1]. Among them, machine vision technology is extremely important. Machine vision is mainly used by the camera to simulate the human visual function from the object to be observed to extract the appearance of the characteristics, and then use the computer to process the information, recognition and judgement, so as to achieve the purpose of measurement and detection and other operations. Machine vision measurement has the advantages of automation such as more efficient, high accuracy, convenience and expandability compared to manual. This study will summarise the components and functions of machine vision, outlining the practical use of machine vision in different scenarios such as agriculture, industry, public transport and warehousing and logistics. This paper analyses machine vision in the context of the literature and explores the

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optimisation of machine vision systems in recent years, with a view to bringing references to the future development and application of machine vision.

2. Components and functions of machine vision

2.1. Hardware subsystem

There are two main systems in the hardware system, the lighting system and the imaging system.

2.1.1. Lighting system

The main thing is to make the light source and the lighting scheme cooperate with each other, so that the light shines on the object to be observed with the most suitable lighting scheme. So as to highlight and enhance a feature of the object as much as possible, while reducing the interference in the image so that the image is easier to be detected and processed by the lens, so as to improve the recognition efficiency of the object in different positions and at different angles. Different light sources have different colours, luminous brightness, service life and energy consumption, and the lighting scheme suitable for different objects should be selected according to the position of different detection targets, the surface texture of the objects, the background in which the objects are located, and the features that the targets need to be captured.In machine vision systems, the most common types of light sources are halogen lamps, fluorescent lamps, xenon lamps and LED lamps. Among these light sources, LED light sources are widely used in modern machine vision systems by virtue of their diversity of colours, high brightness, extremely long service life, low heat generation, and very easy shaping.

2.1.2. Imaging system

The imaging system primarily comprises an optical lens, a CCD camera, and an image acquisition card.

As a core component of the camera, the optical lens is commonly referred to simply as "the lens" in practical applications.

The main role is similar to the lens in the human eye, can collect and focus the light into the camera chip, the final image imaging quality has a very big impact. In the selection of the lens according to the distance of the object, the need for fineness, the camera's viewing range and other requirements, choose the focal length and calibre of the appropriate lens.

CCD (Charge coupled device) camera and image acquisition card to complete the target object image acquisition and digitalisation, the main function of the CCD camera is to capture the optical signal into a digitised electrical signals, the specific choice of camera type should also be based on the type of object to be measured . According to the type of scanning and its use of devices can be divided into two types of surface array and line array. Area-array cameras capture a full-frame image in a single acquisition, resulting in images that offer high intuitive clarity for direct interpretation. Line array cameras obtain a complete image by scanning line by line and have a higher resolution [2]. Line scan cameras are further classified into interlaced and progressive scan [3].

Image acquisition card is the transmission port in the middle of the two links of image acquisition and image processing, and it has the advantage of having a high enough transmission speed and the ability to support multiple signal inputs at the same time to deliver the image signals. Meanwhile, to prevent data loss during transmission, image acquisition cards are typically equipped with 2MB on-board memory, which serves as a temporary data buffer for caching.

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2.2. Algorithmic subsystems

2.2.1. Edge detection algorithm

Sub-pixel edge detection can improve the precision and accuracy of image edge detection through three steps: sub-pixel interpolation, gradient measurement and edge enhancement.

Using sub-pixel interpolation technique to calculate the interpolation between image pixels can improve the image edge position detection to sub-pixel level and increase the accuracy of edge detection [4]. Subpixel interpolation is mainly classified into two types which are bilinear interpolation and bicubic interpolation. Bilinear interpolation by linear insertion operation and bicubic interpolation by cubic or polynomial interpolation operation can get more accurate edge features. Gradient computation can locate the image edge position and orientation more accurately. The image convolution operation calculates the sum of the intensity edges of each pixel in both horizontal and vertical directions to compare with the set threshold of the edge region, so as to detect the image edge region quickly. The Sobel algorithm can perform finer edge detection compared to Prewitt algorithm as it has stronger image noise suppression.

Finally, edge enhancement— a technique that sharpens image edges via filtering— typically employs filters such as the Laplacian filter and Gaussian filter.

2.2.2. Convolutional Neural Network (CNN) based on deep learning

Based on the powerful learning ability of deep learning, convolutional neural network uses the learning characteristics of neural networks, which can be more accurate and precise than traditional algorithms for image edge detection, and also more accurate details in the image are obtained. Through convolutional CNN achieves image feature abstraction through repeated convolution and pooling operations, followed by a classification process via fully connected layers. Additionally, integrated with pixel-level interpolation and regression modules, this algorithm demonstrates significant improvements over traditional approaches. The significant advantage is that there is no need to manually set the edge region threshold, which makes it easier to handle diverse and complex images.

2.2.3. Corner detection algorithm

Corner points are the intersection points of edge lines, that is, the extreme value points in the image, which are usually more prominent in various attributes, and they are the feature points that contain key information with obvious changes in the image. These key points are more stable in different environments, so they are more widely used in motion detection, video tracking and other dynamic environments. Corner detection algorithms can be categorized into three types—grayscale image-based, binary image-based, and contour curve-based—according to the target of detection [5]. Among these, grayscale image-based corner detection methods are further subdivided into gradient-based, template-based, and gradient-template hybrid approaches.

2.2.4. Texture analysis algorithms

Texture is a detailed feature that depicts the surface or structure of an object, and the texture features on an object do not change with the brightness or colour of the image. This technique plays a key role in analysing textures that are naturally occurring and distributed on the surface such as ore types, fish species classification and identification. Currently, the more effective texture image

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research methods mainly include statistical analysis, structural analysis, model analysis and signal processing analysis [6]. Typical statistical analyses include gray-level concurrence matrix (GLCM) and local binary patterns (LBP).

3. Image pre-processing

Image pre-processing can achieve the purpose of improving image quality, reducing the errors caused by the acquisition quality of different devices, reducing the impact of environmental lighting changes and noise interference, and enhancing the features, so that the accuracy and stability of the subsequent visual recognition system can be greatly improved.

There are many methods for image preprocessing, which can be mainly divided into two categories: function and realisation methods. According to different functions, it can be divided into denoising technology, image normalisation, image enhancement, image segmentation and so on.

3.1. Image denoising technology

Imaging system generated images due to external interference and other reasons mostly contain a variety of noise, such as salt-and-pepper, Gaussian, etc., which can cause blurred details, low contrast, blurred edges and other effects on the generated image. After denoising technique can improve the image quality while preserving the effective details. For salt-and-pepper noise and Gaussian noise, two targeted denoising techniques are available—median filtering and Gaussian filtering—each corresponding to one type of noise respectively.

3.2. Image enhancement

The main purpose of image enhancement is to make image features more visible. Commonly used techniques histogram methods, image sharpening methods and motion blur removal. Histogram-based methods are well-suited for images with simple backgrounds. They utilize techniques such as histogram equalization and probability density-based correction to enhance image contrast, adjust image brightness, and ultimately improve the recognizability of image details. The image sharpening method, on the other hand, achieves enhancement by detecting special structures, such as edge intersections, through a filter bank that is layered with the original image, but the disadvantage is that it is prone to high level noise in the superposition.

3.3. Image fusion stitching

Image fusion is a process of decomposing and reconstructing the obtained images. Multi-image fusion not only enables the acquisition of more effective image information but also eliminates redundant and repetitive data, thereby significantly enhancing overall image quality. Currently the most commonly used method is the wavelet transform in multi-resolution image analysis. It has a strong stability in the image processing process such as panning and fusion can be preserved unchanged, and can clearly retain the characteristics of the image edges.

3.4. Image segmentation

The main purpose of image segmentation is to detect and locate image defects, and then define some regions of special significance to facilitate targeted analysis. Common image segmentation methods include the threshold segmentation method, region growing method, watershed segmentation

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algorithm, graph-based segmentation method, and active contour-based segmentation method. The first two of these are currently the two most commonly used.

3.5. Image normalisation

Image normalisation is a process that allows different source images to be processed with a uniform feature base, which facilitates the extraction and comparison of subsequent image details. After this processing method can ensure that images from different acquisition devices, based on different shooting conditions can be consistent data latitude into the subsequent processing stage. The main methods are grey scale normalisation, colour normalisation and scale normalisation. The grey scale normalisation method adjusts the pixel values to avoid large differences in the data values affecting the subsequent calculations. Scale normalisation adjusts the target image to a certain scale to avoid recognition errors caused by different sizes and viewing angles of objects in the image at different distances.

4. Specific applications of machine vision

Machine vision systems can perceive more accurate and comprehensive information than the human eye. For instance, they can detect objects invisible to the naked eye through techniques such as ultraviolet or X-ray inspection. Another major advantage of machine vision is that it can rely on the characteristics of its non-contact observation, into the high-risk scene for detection, will not produce any casualties, in the safety of the greatly ahead of other methods. Therefore, machine vision is widely used in various fields.

4.1. Intelligent agriculture scene

The apple grading system based on machine vision has the efficiency and accuracy that cannot be matched by manual grading. The workflow of the system encompasses multiple stages, ranging from apple image acquisition and processing to final grading and output—with close coordination required between each step [7]. A high-resolution industrial camera is used with a reasonable lighting scheme to capture images with clear details. Apple image features from different lighting and backgrounds are extracted and processed by some technical means. Finally, the apple images are graded according to a unified standard. Combined with deep learning technology, the freshness of fruits and vegetables can also be detected [8].

4.2. Industrial construction field

In the detection of defects on the surface of parts, machine vision technology can assist in achieving contactless inspection. The system will quickly analyse the image of the surface of the parts, in order to achieve efficient and accurate detection, and can avoid the secondary damage that may be caused by manual inspection.It is now widely used in aerospace and other areas with high part requirements, providing stronger technical support for industrial part production. In recent years, some new lightweight Convolutional Neural Network (CNN) models have been developed, and MobileNet is one of the more well-developed ones, which significantly reduces the number of parameters and computation volume of the model through the introduction of deep separable convolution, and has the advantage of running in real time on conventional devices [9].

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4.3. Public transport infrastructure monitoring

Machine vision technology is also an emerging monitoring tool in the detection of highway slope displacements. The main advantage is that a camera can be used to continuously capture images of the structure and track and analyse moving objects. Compared with both traditional manual inspection and conventional automated monitoring methods, this approach offers higher real-time performance and accuracy. Additionally, it enables simultaneous real-time monitoring of multiple distinct locations. In addition, the hardware and software costs and data complexity of machine vision are lower than those of traditional methods, which not only reduces the economic burden, but also enables the system to continuously acquire real-time video data from the construction site, providing valuable information resources for subsequent analysis and decision-making [10].

Machine vision also plays a very important role in intelligent railway tunnel construction. Machine vision technology can remotely capture and process images of the internal and external environment of the tunnel to assist the construction personnel to control the tunnel structure in real time, to improve safety and quality of the project. At present, deep learning algorithms can be used to accurately classify and finely characterise feature information, and a hybrid TPE-GBRT prediction model has been constructed to achieve accurate prediction of the RMR indexes of enclosing rock grading [11].

5. Conclusion

In recent years, machine vision and its related technologies have advanced significantly, with their supporting software systems becoming increasingly comprehensive. Meanwhile, the enhancement of computing power has further boosted the processing speed of processors. However, China's machine vision technology remains less mature compared to that of foreign countries; some hardware and software components still need to be imported, which in turn results in relatively high costs for deploying such systems. However, the technology has a higher efficiency and accuracy compared to manual in practical use, which provides further support for the future demand for smarter and more convenient applications. The amount of literature used in this paper is limited, and future research could incorporate more literature for more comprehensive summaries and analyses.

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