Application of Microbiological Detection Based on Computer Image Analysis

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Abstract: Microorganisms play an important role in human society, and the analysis of microorganisms is of great significance. Traditional microbial detection methods based on microscopes have some defects, and more effective methods are needed to achieve rapid and accurate analysis. This paper studies the microbial detection methods based on computer image analysis technology, and introduces three main methods in detail, including methods based on classical image processing, traditional machine learning, and deep learning. The main implementation steps and shortcomings of various methods are analyzed. Finally, this paper points out the current challenges and research directions of microbial detection technology based on computer image analysis, and provides a theoretical basis for promoting microbial detection technology based on computer image analysis.

Keywords: Microbial Detection; Computer Image Analysis; Machine Learning; Deep Learning; Image Processing.

1. Introduction

Microorganisms are tiny organisms with independent life functions that can absorb energy, grow and reproduce on their own, and can exist in various ecosystems [1]. Microorganisms play an important role in human society. For example, some rhizobia can have a beneficial effect on plant health and growth, and can also inhibit pathogenic microorganisms [2]. Lactic acid bacteria can affect humans in many ways, such as regulating gastrointestinal flora, the normal operation of human metabolism, and inhibiting the reproduction of harmful bacteria [3]. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) can cause fever, malaise, dry cough, shortness of breath, and even death in severe cases [4]. It can be seen that the analysis of microorganisms is of great significance to humans. Microscopic observation is a common and important method in microbial analysis. For example, stereo scanning electron microscopy is used to analyze microorganisms in soil [5], aquatic bacteria are counted using improved epifluorescence technology based on microscopes [6], and microbial analysis is performed using environmental scanning electron microscopy [7]. However, these microscopic methods have some disadvantages. According to Locey et al., there are 1011 to 1012 species of microorganisms living on the earth [8]. Therefore, when researchers use this method for microbial analysis, they often have to consult a large amount of literature. Secondly, this type of professional method requires researchers to undergo long-term professional training, and the detection process takes a long time. For example, using traditional microscopy methods to count phytoplankton takes a very long time, and the work is boring and labor-intensive. In addition, the microorganisms to be analyzed are often large in magnitude. Microscopic methods are difficult to handle analytical problems with large data volumes, and large sample sizes will affect the accuracy of the operator's analysis [9]. In view of the shortcomings of the above microscopy method, a more effective method is needed to achieve fast and accurate microbial analysis. With the continuous development of science and technology, researchers have tried to apply computer image analysis technology to microbial detection and achieved good results. This paper studies the detection method of microorganisms, studies the principles of microbial detection methods based on computer image analysis technology, and introduces methods based on classical image processing, methods based on traditional machine learning, and methods based on deep learning, respectively, providing a reference for future research on microbial detection.

2. Microbial Detection based on Classical Image Processing

The microbial detection method based on classical image processing mainly includes four steps: preprocessing, segmentation, postprocessing and classification. Its main processing flow and common algorithms are shown in Figure 1.

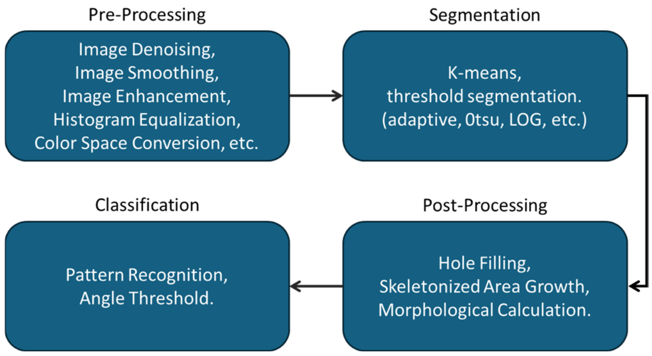

Figure 1. Processing flow and common algorithms of classical image processing

Preprocessing aims to improve image quality, reduce noise, and make the area of interest or target in the image clearer by adjusting parameters such as image contrast and brightness, thereby improving the effect of subsequent processing. Image segmentation is the process of dividing an image into multiple independent regions, aiming to distinguish the target of interest from the background. Threshold segmentation is the most widely used detection segmentation algorithm at present. The algorithm is simple to calculate and has high computational efficiency. Threshold segmentation sets one or more thresholds and intercepts pixels whose grayscale values are within the threshold range in the image to obtain the target in the image. The calculation process of the Otsu threshold is simple and has strong versatility [10]. However, when the target area is much smaller than the background area, the Otsu threshold cannot provide good segmentation results [11]. Post-processing steps can be used to remove noise caused by segmentation errors, refine segmentation results, repair breaks, etc. Classification extracts feature values that can represent the essential attributes of the target object from the image, matches the target object in the image with the reference pattern, and thus identifies and classifies the target object. The main classification methods currently include pattern recognition and angle threshold recognition. However, such methods are usually generally not robust, have high requirements for the accuracy of the segmentation step, and often cannot achieve practical application effects. Methods based on classical image processing have certain limitations. Such methods are highly dependent on expert knowledge and manually designed features, and have limited robustness. Moreover, as the amount of image data increases, the process of manually adjusting parameters and designing features becomes increasingly difficult. In addition, classical methods are difficult to capture high-level abstract features and cannot effectively mine the rich information contained in the data. Therefore, researchers have begun to try microbial detection methods based on machine learning and deep learning.

3. Microbial Detection based on Machine Learning

The traditional machine learning method introduces machine learning technology into microbial detection. Compared with the method based on classical image processing, this type of method can automatically learn feature representation and mine useful patterns from training data without manually designing features. Common traditional machine learning algorithms include support vector machine (SVM), decision tree, random forest, naive Bayes, etc. Microbial detection based on machine learning is similar to the method based on classical image processing. First, the image needs to be preprocessed and features such as color, texture, shape, etc. need to be manually extracted from the preprocessed image. The second step is to train the classifier. Using the labeled training data set, the extracted features are input into the machine learning algorithm to train the model. The trained model can be used in the classification and detection tasks of new microbial images. Among them, the most widely used classification model in microbial detection is SVM and its variants. SVM can effectively use smaller training samples, so that SVM can obtain higher classification accuracy on a smaller training set [12]. However, support vector machines are not suitable for solving multi-classification tasks [13]. In addition, support vector machines are sensitive to the choice of parameters and kernel functions, which means that different choices will have a great impact on the final classification accuracy of SVM [14]. Methods based on traditional machine learning can automatically learn feature patterns to improve detection performance. However, such methods still require manual design of low-level features and cannot directly learn feature representations end-to-end from the original image, which has certain limitations.

4. Microbial Detection based on Deep Learning

Deep learning is a data-based representation learning method that can automatically learn multi-level feature representations directly from raw data without the need for manual feature design. In recent years, microbial detection methods based on deep learning have achieved outstanding results. Convolutional neural network (CNN) is a classic deep learning model that performs well in the field of computer vision. Researchers apply CNN to microbial image detection to automatically learn features from images and classify them. For example, Tahir et al. proposed a CNN-based method for fungal detection and differentiation of different types of fungi [15]. In addition, they developed a new fungal dataset consisting of five different types of fungal spores and dirt. The results showed that the accuracy of this method was 94.8%. Panicker et al. proposed a CNN-based method for detecting tuberculosis in sputum smear microscopic images [16]. This method uses the Otsu threshold algorithm to binarize the image and applies CNN to determine the category of the region extracted from the first stage. The classification results show that the recall rate of this method is 97.13%, the accuracy rate is 78.4%, and the F-Score is 86.76%. Methods based on deep learning can automatically learn feature representation directly from raw image data without the need for manual feature design, and have stronger expressive power. These methods have shown superiority over methods based on classical image processing and traditional machine learning in multiple microbial detection tasks and have become the mainstream methods in this field. However, since deep models usually require a large amount of labeled data for training, the difficulty and time-consuming of data labeling have also become one of the constraints.

5. Conclusion

This paper reviews microbial detection methods based on computer image analysis technology, mainly including three types of methods based on classical image processing, machine learning, and deep learning. These methods have significantly improved the performance of microbial detection and have become the mainstream technology in this field. Although deep learning-based microbial detection methods have achieved remarkable results, they still face problems such as difficulty in data labeling, scarcity of data, and lack of interpretability, which still require further research. In the future, research on deep learning-based microbial monitoring technology will develop in the direction of designing more efficient network models, data enhancement strategies, and transfer learning with strong generalization capabilities to further improve detection performance. In summary, deep learning-based microbial detection technology is constantly developing and improving. Through continuous innovation and development, it is believed that this technology will bring more breakthroughs to the field of microbial analysis and make important contributions to promoting the sustainable development of human society.

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