Colony Image Edge Detection Algorithm Based on FCM and RBI-FCM Clustering Methods

Xu-Dong Li, Dong Wei*, Jie-Sheng Wang, Qing-Sheng Guo, Lin Chen

Abstract—**Traditional colony image research requires human visual observation and statistics, which results in the lower work efficiency and higher work intensity. Edge detection of colony image is an important basis of the study of colony images, but the traditional edge detection operators cannot meet the precision requirements of the detection results. In this paper, a colony image edge detection algorithm based on fuzzy c-means (FCM) clustering method and robust FCM integrating between-cluster information (RBI-FCM) clustering method was proposed to segment three typical colony images (mould, actinomycetes and bacteria). The edge detection results are compared with the classical image edge detector operators, such as Roberts operator, Prewitt operator, Sobel operator, LOG operator and Canny operator. Simulation results have verified the effectiveness of the adopted FCM and RBI-FCM clustering methods.**

Index Terms—**Colony image, Fuzzy clustering, Edge detection**

I. Introduction

Microorganisms are tiny organisms that humans cannot see or see clearly with the naked eye and need to be observed through a microscope. With the exploration of nature, microbial technology is derived from the microbial level. The study of microbial technology often depends on the study of microbial images [1]. The study of microbial images can be divided into two levels: macro-colony image and micro-individual image. A colony is a microbial cell cluster that can be seen with the naked eye on a macro level after a large number of microscopic single microbial individuals multiply. It has been used as an important testing method and research object in food safety, drug safety, environmental pollution and medical effect. In the evaluation of the pollution and freshness of food, medicine and other products, the determination of the number of colonies can effectively tell whether the hygiene of the product meets the evaluation standard [2]. In medicine, the effect of oral disinfection on halitosis in patients with periodontitis can be studied by colony test [3]. In industry and agriculture, antagonistic antibacterial screening of sewage treatment and agricultural pests and diseases is achieved through colony experiments. All the research on colonies is due to the study of colony images. As more and more attention is paid to the colony images, the work intensity of the researchers is increasing. To a large extent, the work intensity comes from the low efficiency and high energy consumption of the traditional research methods. That is to say observation on the colony images through the human eye, statistical and analysis work consumed by the labor costs. So the digital image processing technology based on computer vision is introduced into the research of colony images, which can solve this problem perfectly, improve the work efficiency and reduce the researchers' work intensity. The research on digital image technology of colony images is bound to influence the innovation and development of related fields.

The edge detection of colony images is the basic work of digital processing technology of colony images, which provides support for image segmentation, object recognition, shape extraction and image analysis. Image edge is the boundary between the object and the background in an image, which is one of the most basic feature of digital images and also an important previous stage of image analysis. The accuracy of detection will directly lead to the accuracy of computer understanding of the target images in machine vision. Only the higher image edge detection accuracy can provide a strong guarantee for the later image analysis or video analysis. The representation of image edge is mainly the abrupt change of gray level in the Pixel area of an image, that is to say the gray level value occurs step. At present, the commonly used image segmentation methods mainly include the region-based segmentation method, the edge-based segmentation method, the level set-based segmentation method, the neural network-based segmentation method, the fuzzy theory-based segmentation method, and the wavelet transform-based segmentation method.

Traditional edge detection operators include Prewitt [4], Canny [5] , Sober[6], Roberts[7], and so on. These are called edge detection differential operators. Differential operators can be divided into two categories, one is the first-order differential operator, the other is the second-order differential operator. The first-order differential operator includes Prewitt, Canny, Sober and Roberts, while the second-order differential operator includes Laplace operator, LOG operator [8], and so on. But the traditional edge detection

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method has some defects, such as sensitivity to noise, target location blur, poor robustness, easy to be affected by physical factors and so on. There are adaptability difficulties in practical application.

According to the characteristics of colony images, Zhou et al. proposed the maximum class-between-variance method to binary the collected colony images, and divide the colony with distance transformation and watershed algorithm, then count the colony, analyze the species, shape and size of colony [9]. Men et al. Studied the counting of heterotrophic colonies by using image processing method, and the errors of automatic counting under different dilution of samples were carried out statistical analysis. The iterative threshold is used to realize the binarization of the colony image, and the adhesion colony is cut by the method of distance transformation combined with watershed [10]. The edge detection of colony images is the important foundation of colony image research, but the traditional edge detection operators can not satisfy the precision requirement. The segmentation method based on fuzzy theory is to use coherent knowledge of fuzzy theory to cluster the target images, which is suitable for image segmentation with uncertainty and unclear [11].

A colony image edge detection algorithm based on FCM and RBI-FCM clustering method was proposed to segment three typical colony images. Simulation results have verified the effectiveness of the adopted FCM and RBI-FCM clustering methods.

II. Colony Image Edge Detection Based on Fuzzy Clustering Algorithms

A. Fuzzy C-Means Clustering Algorithm

K-Means clustering algorithm was proposed by E. Ruspin, and then J. C. Dunn [12] and J. C. Bezdek [13] developed K-Means clustering algorithmm into the Fuzzy C-Means (FCM) clustering algorithm. FCM clustering algorithm optimizes the objective function and carries out the clustering according to the membership value of each group in clustering process, that is to say FCM clustering algorithm is a fuzzy and unartificial process. The mathematics principle of FCM clustering algorithm is described as follows. The most common fuzzy cluster analysis function is defined as:

$$J_m(U,P) = \sum_{i=1}^{c} \sum_{x_k \in X} (\mu_{ik})^m (d_{ik})^2 \quad \text{s.t.} U \in E_f \tag{1}$$

where, U is the membership matrix, P is the matrix center of each cluster, d_{ik} is the distance between i-th sample and k-th sample, m is the fuzzy coefficient. d_{ik} can be calculated by:

$$d_{ik}^2 = \| x_k - P_i \|_A = (x_k - P_i)^T A (x_k - P_i) \tag{2}$$

where, A represents the weight. Obtaining the clustering optimum is to get $\min\{J_m(U, P)\}$ under the condition of $\sum_{i=1}^{c} \mu_{ik} = 1$, that is to say:

$$\min\{J_m(U, P)\} = \sum_{k=1}^{n} \min\{\sum_{i=1}^{c} (\mu_{ik})^m (d_{ik})^2\} \tag{3}$$

Therefore, the above problem can be understood as: under the constraint of membership degree $\sum_{i=1}^{c} \mu_{ik} = 1$, $\min\left(\sum_{i=1}^{c} (\mu_{ik})^m (d_{ik})^2\right)$. The implementation procesof FCM clustering algorithm can be described as follows.

Step 1: Randomly initialize the partition matrix U, cluster center P_i, and the distance norm d_{ik}.

Step 2: Compute the cluster center P_i.

Step 3: Update the partition matrix U.

Step 4: Judge whether the termination condition is satisfied or not. If the condition is not satisfied, go to Step 2, otherwise output the optimum results.

B. Robust Fuzzy C-means Clustering Algorithm Integrating Between-cluster Information

The robust FCM integrating between-cluster information (RBI-FCM) clustering method was introduced into the clustering analysis algorithm based on the concept of fuzzy partition [14]. RBI-FCM clustering algorithm optimizes the function to get the membership relationship between the center of each cluster and different samples. Through the different cluster center sample value, and all of the center are compared one by one, and then divided into groups of each class. The membership degree of each center to each class is optimized, and the samples are divided into different classes by the center. The FCM clustering algorithm can be modeled as:

$$J(u_{ij}, v_i) = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m \left\| x_j - v_i \right\|^2 \tag{4}$$

$$\sum_{i=1}^{c} u_{ij} = 1, j = 1,2,\ldots,n \tag{5}$$

where, m>1 is the fuzzy coefficient, c is the number of clusters, v_i is cluster center, j is the sample point, u_{ij} is the membership degree. FCM clustering algorithm adopts fuzzy coefficient to consider the relationship between data clusters, so it is easy to be affected by noise and the actual clustering effect will be affected. However, RBI-FCM clustering algorithm can effectively reduce the internal fragmentation of data clusters, improve the stability of data clusters and reduce the influence of noise. On the other hand, it can solve the sensitivity problem of unbalanced distribution and obtain relatively satisfactory clustering results. The optimization function is defined as follows.

$$J(u_{ij}, v_i) = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m \left\| x_j - v_i \right\|^2 + \sum_{i=1}^{c} \sum_{j=1}^{n} \beta_j u_{ij} \left(1 - u_{ij}^{m-1}\right) \left\| x_{j-} v_i \right\|^2 \tag{6}$$

where, m is the fuzzy coefficient, c is the number of clusters. The clustering center V is selected randomly through the samples. The maximum iteration number T_{max} is set. The error threshold of the objective function is also set through the given non-negative u parameter to initialize.

Update the membership matrix through Eq. (6) and perform the (t+1) step, where u_{ij} is a set of hyperfunctions, which can be mathematically transformed to obtain:

$$minJ(u_{ij},v_i) = \sum_{i=1}^{c}\sum_{j=1}^{n}(1-\beta_j)u_{ij}^{m}\|x_j - v_i\|^2 + \sum_{i=1}^{c}\sum_{j=1}^{n}\beta_j u_{ij}\|x_j - v_i\|^2 \tag{7}$$

The auxiliary function is set up by Eq. (7) update the cluster center.

$$L(u_{ij},v_i) = \sum_{i=1}^{c}\sum_{j=1}^{n}u_{ij}^{m}\|x_j - v_i\|^2 + \sum_{i=1}^{c}\sum_{j=1}^{n}\beta_j u_{ij}\left(1 - u_{ij}^{m-1}\right)\|x_j - v_i\|^2 - \sum_{j=1}^{n}\lambda_j\left(\sum_{i=1}^{c}u_{ij} - 1\right) \tag{8}$$

Carry out a partial derivation of the cluster v_i and let the result be zero so as to obain:

$$v_i = \frac{\sum_{j=1}^{n} u_{ij}^{m}x_j + \sum_{j=1}^{n}\beta_j u_{ij}\left(1 - u_{ij}^{m-1}\right)x_j}{\sum_{j=1}^{n} u_{j=1}^{m} + \sum_{j=1}^{n}\beta_j u_{ij}\left(1 - u_{ij}^{m-1}\right)} \tag{9}$$

First set the fuzzy parameter *m* and the number of clusters *c*, objectively select the center of each cluster, and then set the largest iteration number, as well as the number of convergence of function error. Secondly, transform the membership degree by Eq. (7) and update the cluster center by Eq. (8) and (9). Then $t=t+1$. Finally repeat the above operations until *t* reaches its maximum value.

III. Simulation Experiment and Result Analysis

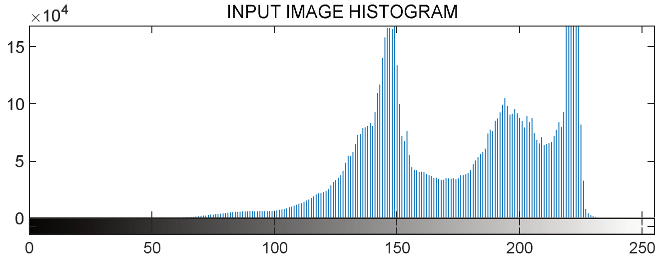
Three typical colonies (mould, actinomycetes and bacteria) were selected for carry out the edge detection simulation experiments based on the FCM and RBI-FCM clusteirng methods, and Matlab was used as the simulation software.

A. Segmentation Results and Analysis of Mold Colony Images

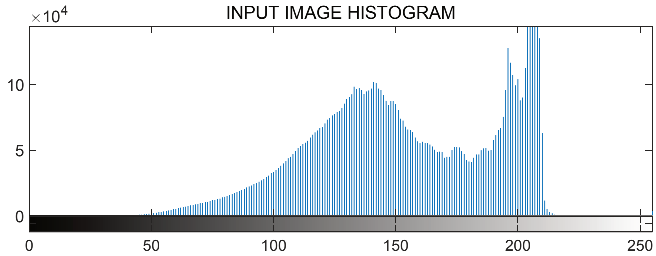
For the image segmentation effect of mold colonies, the specific images are shown in Fig. 1. Two typical mold colony images shown in Fig. 1 (a) and (b) are selected as experimental objects. Fig. 2 is the grayscale histogram of the analyzed colony images. There is a very conspicuous trough on the colony histogram. The left side of the histogram belongs to the black background value, and the right side is the area background value of the research object. The required image segmentation can be obtained through this numerical value. In Fig. 3, the colony images are denoised by adopting the mean filtering method. The image denoised results are very good and the sharp edges are preserved. The concrete step is to select eight grayscale values around each point and sort them according to the order of size, so as to obtain the grayscale value of the target point. Fig. 4 shows the distribution of black-and-white image after using each segmentation algorithm. From the colony image analysis, the colony gray value is relatively close, so the image is processed optically to show the colony outline. In this paper, the target is separated by adjusting the spectrum, saturation and lightness of the images.

(a) (b)

Fig. 1 Images of mold colony.

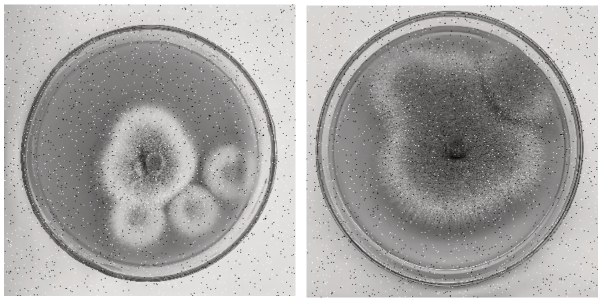


(a)



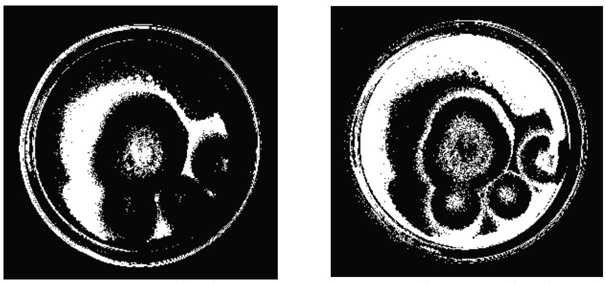
(b)

Fig. 2 Image histogram.



(a) (b)

Fig. 3 Colony denoising image.



Spectrum-treated colony Saturation-treated Colony

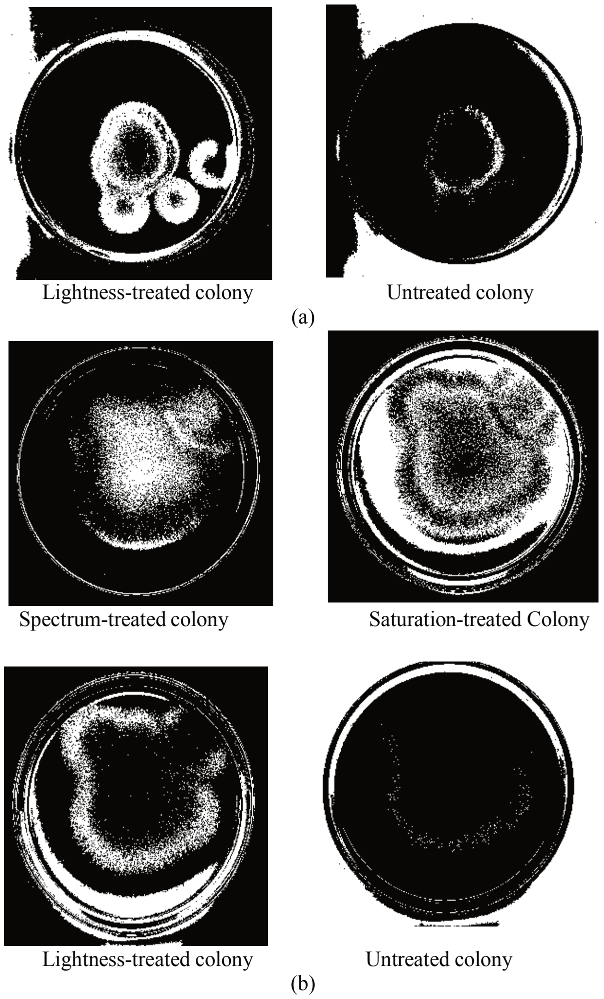
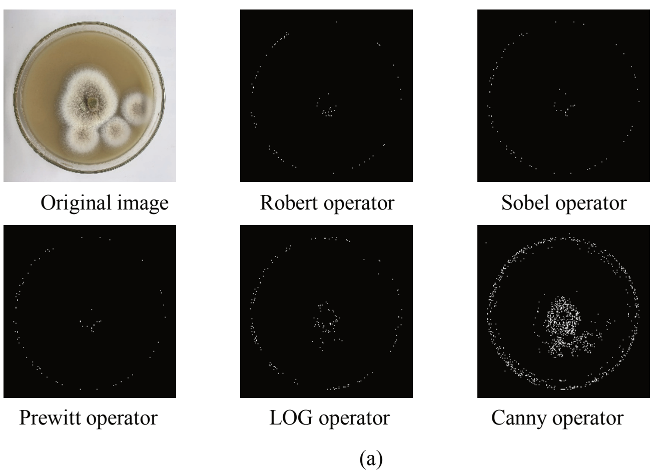


Fig. 4 Optical image segmentation.

As shown in Fig. 5, five edge detection operators (Robert operator, Sobel operator, Prewitt operator, LOG operator and Canny operator) are used on colony images. According to the segmentation edges, the cracks of the segmentation edge are retained. Fig. 6 shows the super pixel color image fast segmentation results based on FCM clustering method, where bright color region is the identified colony region. Fig. 7 shows the image edge detection results based on RBI-FCM clustering method. The RBI-FCM clustering method is to shift the colony image through the fuzzy membership degree so as to improve the contrast of colony images and thus reduce the sample's fuzzy degree.



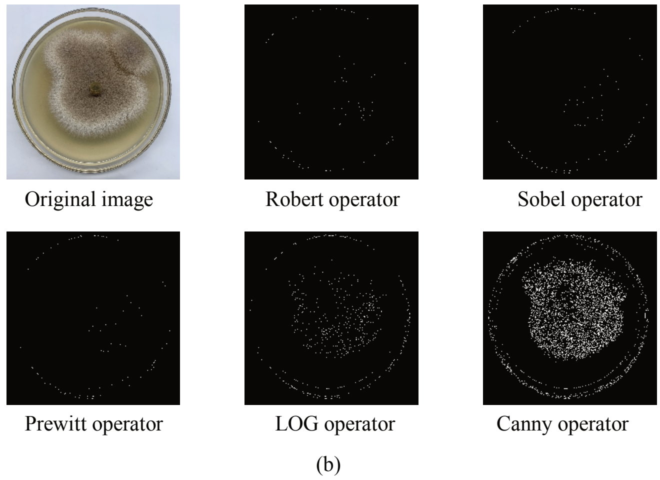
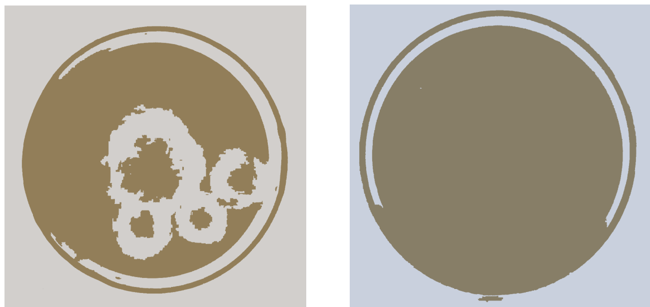
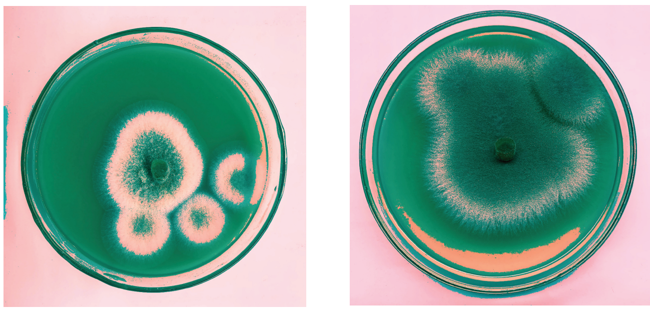


Fig. 5 Image edge detection.



(a) (b)

Fig. 6 Image edge detection based on FCM clustering method.

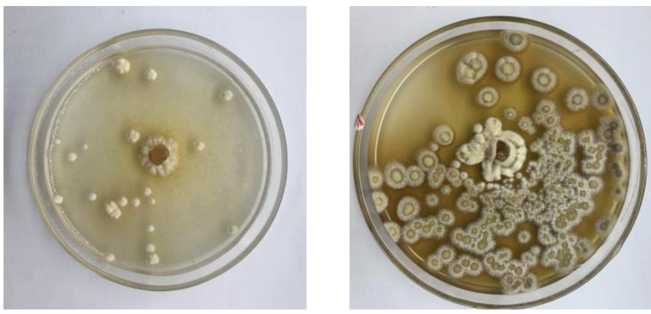


(a) (b)

Fig. 7 Image edge detection based on RBI-FCM clustering method.

B. Segmentation Results and Analysis of Actinomycete Colony Images

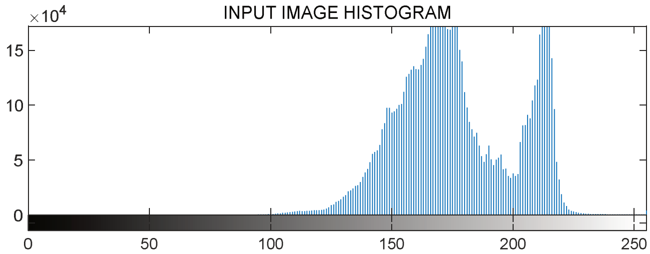
For the image segmentation effect of actinic colonies, the specific images are shown in Fig. 8. Two typical actinic colony images shown in Fig. 8 (a) and (b) are selected as experimental objects.



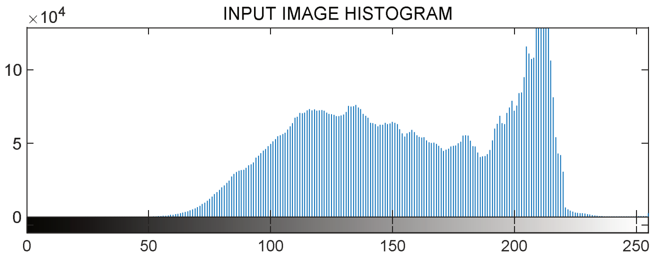
(a) (b)

Fig. 8 Images of actinomycete colony.

Fig. 9 is the grayscale histogram of the analyzed colony images. There is a very conspicuous trough on the colony histogram. The left side of the histogram belongs to the black background value, and the right side is the area background value of the research object. The required image segmentation can be obtained through this numerical value. In Fig. 10, the colony images are denoised by adopting the mean filtering method. The image denoised results are very good and the sharp edges are preserved. The concrete step is to select eight grayscale values around each point and sort them according to the order of size, so as to obtain the grayscale value of the target point. Fig. 11 shows the distribution of black-and-white image after using each segmentation algorithm. From the colony image analysis, the colony gray value is relatively close, so the image is processed optically to show the colony outline. In this paper, the target is separated by adjusting the spectrum, saturation and lightness of the images.

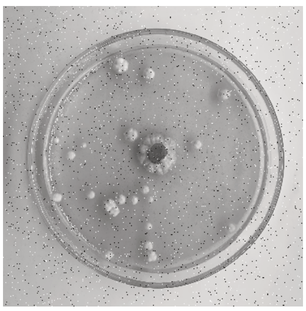


(a)



(b)

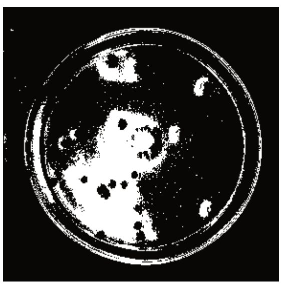
Fig. 9 Image histogram.



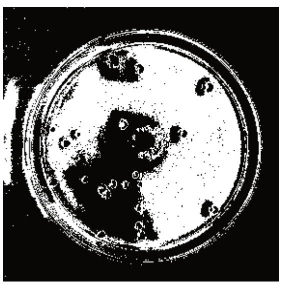
(a)

(b)

Fig. 10 Colony denoising image.



Spectrum-treated colony



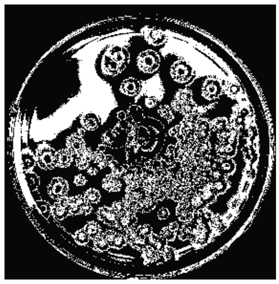
Saturation-treated Colony

Lightness-treated colony

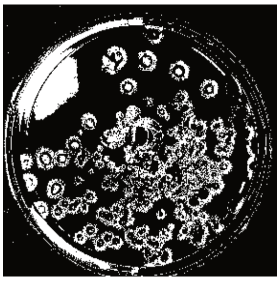
Untreated colony

(a)

Spectrum-treated colony



Saturation-treated Colony



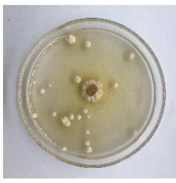
Lightness-treated colony

Untreated colony

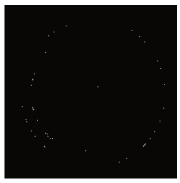
(b)

Fig. 11 Optical image segmentation.

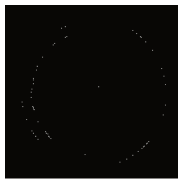
As shown in Fig. 12, five edge detection operators (Robert operator, Sobel operator, Prewitt operator, LOG operator and Canny operator) are used on colony images. According to the segmentation edges, the cracks of the segmentation edge are retained. Fig. 13 shows the super pixel color image fast segmentation results based on FCM clustering method, where bright color region is the identified colony region. Fig. 14 shows the image edge detection results based on RBI-FCM clustering method. The RBI-FCM clustering method is to shift the colony image through the fuzzy membership degree so as to improve the contrast of colony images and thus reduce the sample's fuzzy degree.



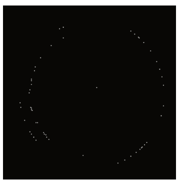
Original image



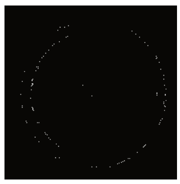
Robert operator



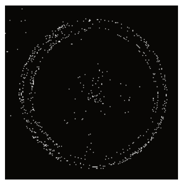
Sobel operator



Prewitt operator

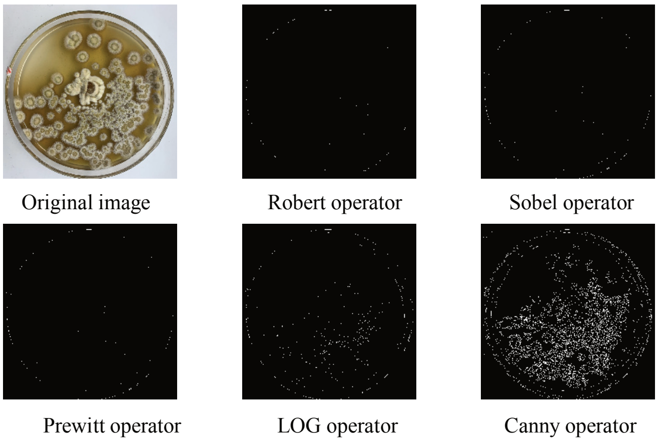


LOG operator



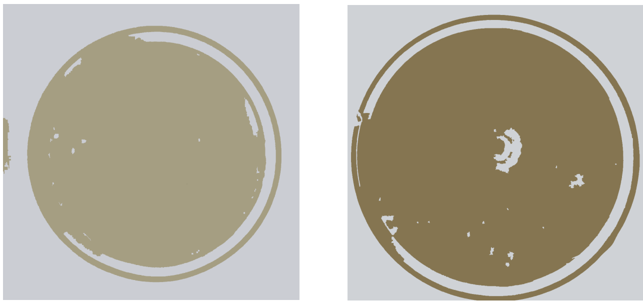
Canny operator

(a)



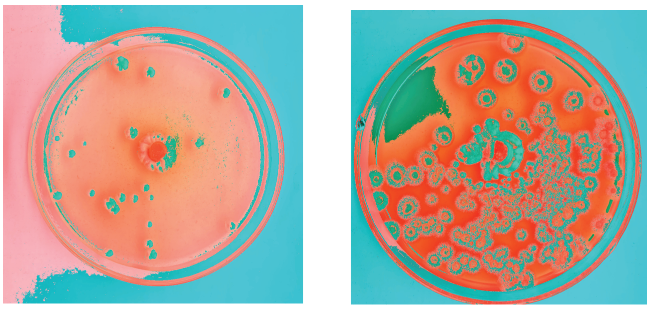
(b)

Fig. 12 Image edge detection.



(a) (b)

Fig. 13 Image edge detection based on FCM clustering method.



(a) (b)

Fig. 14 Image edge detection based on RBI-FCM clustering method.

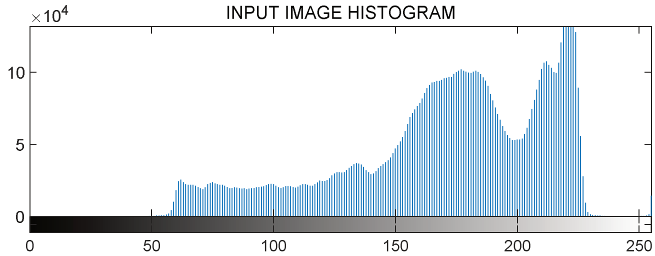
C. Segmentation Results and Analysis of Actinom.ycete Colony Images

For the image segmentation effect of bacterial colonies, the specific images are shown in Fig. 15. Two typical bacterial colony images shown in Fig. 15 (a) and (b) are selected as experimental objects.

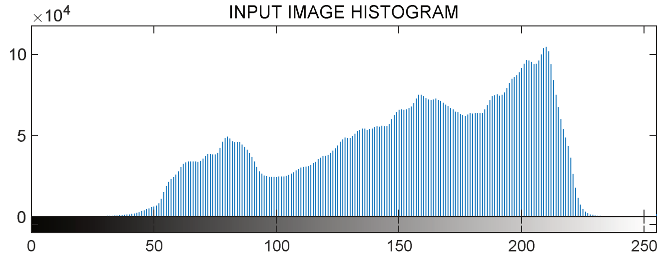
(a) (b)

Fig. 15 Bacterial colony images.

Fig. 16 shows a gray histogram of an analysis of the colony image. The histogram shows a very prominent wave trough. The values on the left side of the histogram are in a black background, and the values on the right side are the regional background values of the subject. This can be used to get the image segmentation value. In Fig. 17, the colony images are denoised by adopting the mean filtering method. The image denoised results are very good and the sharp edges are preserved. The concrete step is to select eight grayscale values around each point and sort them according to the order of size, so as to obtain the grayscale value of the target point. Fig. 18 shows the distribution of black-and-white image after using each segmentation algorithm. From the colony image analysis, the colony gray value is relatively close, so the image is processed optically to show the colony outline. In this paper, the target is separated by adjusting the spectrum, saturation and lightness of the images.

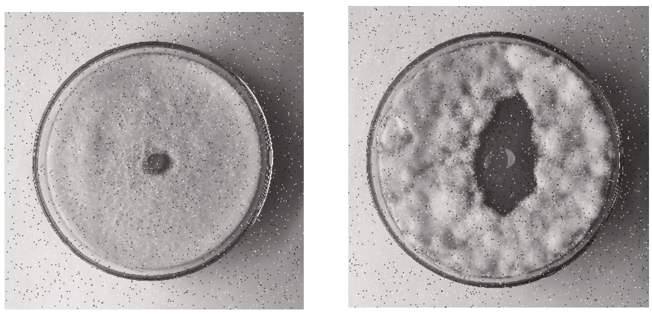


(a)



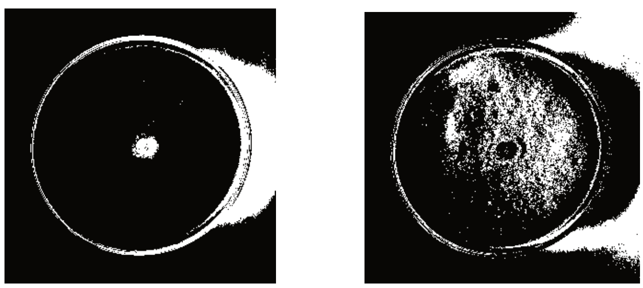
(b)

Fig. 16 Image histogram.

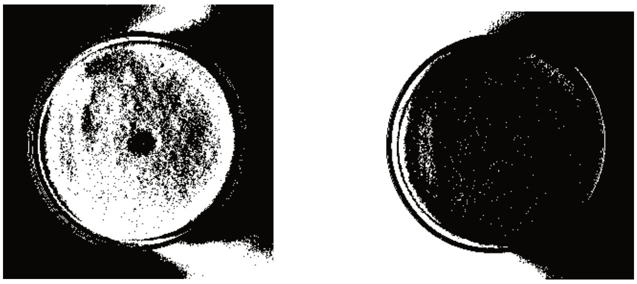


(a) (b)

Fig. 17 Colony denoising image.

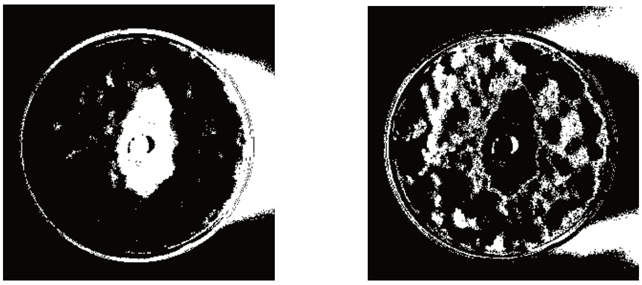


Spectrum-treated colony Saturation-treated Colony

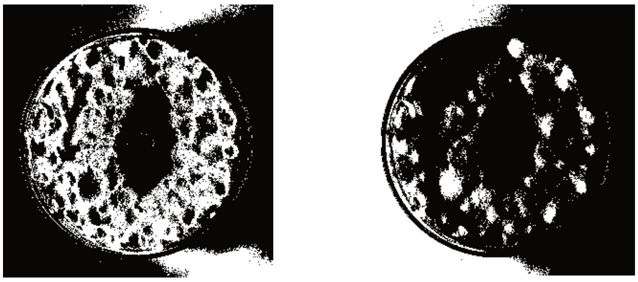


Lightness-treated colony Untreated colony

(a)



Spectrum-treated colony Saturation-treated Colony

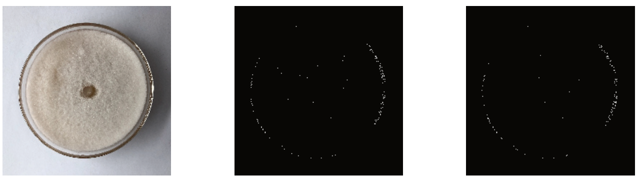


Lightness-treated colony Untreated colony

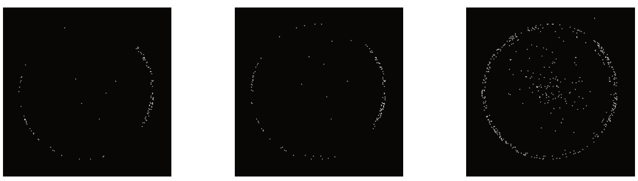
(b)

Fig. 18 Optical image segmentation.

As shown in Fig. 19, five edge detection operators (Robert operator, Sobel operator, Prewitt operator, LOG operator and Canny operator) are used on colony images. According to the segmentation edges, the cracks of the segmentation edge are retained. Fig. 20 shows the super pixel color image fast segmentation results based on FCM clustering method, where bright color region is the identified colony region. Fig. 21 shows the image edge detection results based on RBI-FCM clustering method. The RBI-FCM clustering method is to shift the colony image through the fuzzy membership degree so as to improve the contrast of colony images and thus reduce the sample's fuzzy degree.



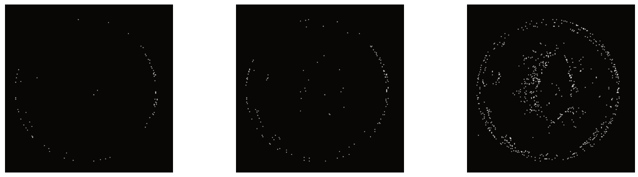
Original image Robert operator Sobel operator



Prewitt operator LOG operator Canny operator

(a)

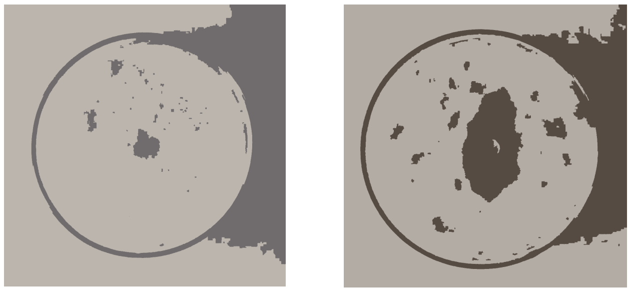
Original image Robert operator Sobel operator



Prewitt operator LOG operator Canny operator

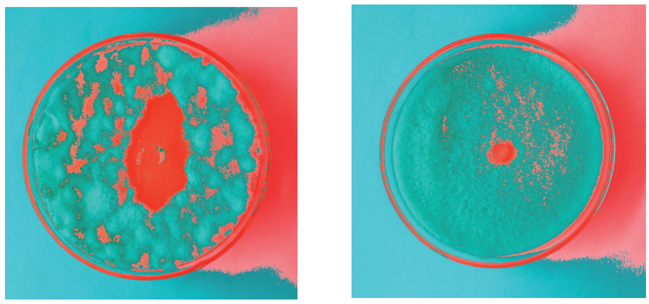
(b)

Fig. 19 Image edge detection.



(a) (b)

Fig. 20 Image edge detection based on FCM clustering method.



(a) (b)

Fig. 21 Image edge detection based on RBI-FCM clustering method.

It can be seen from the above edge detection results that each algorithm has different segmentation results and its suitable segmentation range. Relatively speaking, FCM segmentation algorithm has a good segmentation effect in various image segmentation, and does not have a large error. Considering the actual segmentation range and the distribution after segmentation, FCM segmentation algorithm is inferior to RBI-FCM segmentation algorithm on color images. These two algorithms have different segmentation regions and segmentation effects.

IV. CONCLUSIONS

In this paper, FCM clustering algorithm and RBI-FCM clustering algorithm are used to detect the edges of three colonies with different shapes. These two algorithms have very good segmentation effect in colony images. FCM clustering algorithm introduces the fuzzy factor, which makes it vulnerable to noise and outliers. So the clustering effect is not practical enough. The RBI-FCM clustering algorithm can perform detailed classification between each cluster, and reduce the interactive operation between each data through the cluster segmentation process to express the separable characteristics of different data adjacent to each other. Simulation experiment results show that the RBI-FCM clustering algorithm has stronger robustness than FCM clustering algorithm, and it can reduce the high feedback characteristic of FCM clustering algorithm to step difference and unbalanced sampling, and obtain the better segmentation results.

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