

Brightness-based Threshold-Weighted OTSU Method for Image Segmentation

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Keywords: TW-OTSU, Image Segmentation, Weighting Coefficient based on Gray Level

Abstract: In order to solve the problem that the OTSU method is less effective for segmenting low brightness images, this paper proposes the brightness-based threshold-weighted OTSU (TW-OTSU) method. A threshold weighting coefficient of segmentation threshold based on the average gray level of images is introduced, a mapping relationship between the weighting coefficient of segmentation threshold and the average gray level is created. It is taken as the final segmentation threshold that the segmentation threshold calculated by the OTSU method is weighted with the gray level value, which is corresponding to the peak in the foreground of an image gray level distribution as the final segmentation threshold. The experiments show that the TW-OTSU method improves not only solves the problem of poor the segmentation effect of OTSU method for low brightness images, but also the comprehensive performance advantage of the algorithm in terms of segmentation accuracy and running time is obvious.

1. Introduction

Image segmentation is the a process of dividing an image into different connected regions based on the features of the image, so that the pixel points within the region meet the consistency of a specific region[1,2]. Among the many image segmentation methods, the threshold-based image segmentation method is the earliest and most widely used, and the implementation principle is simple and fast[3]. Japanese scientist Nobuyuki Otsu[4] He proposed an unsupervised threshold segmentation method, also known as the "maximum inter-class variance method", later referred to as the OTSU method, which sets a threshold to divide the image into foreground and background, so that the maximum inter-class variance of the two parts is used as the final segmentation threshold. This method as good effect on the segmentation of the image with independent foreground and background grayscale peaks and the two peaks are far away from each other. But the effect of the segmentation of the image with two peaks close to each other or non-both peaks is inadequate.[5-7] The OTSU method has a weak ability to deal with image noise.

In response to the problems of OTSU, scholars have proposed different improvement methods. To solve the problem of poor segmentation effect of OTSU method on single-peak images, Ng [8] et al. proposed the Valley-Emphasis(VE) method, which adds a segmentation threshold gray probability

parameter to the OTSU objective function, and the smaller the gray probability, the larger the gain of the objective function, ensuring that the threshold segmentation point is in the valley of the grayscale map, but VE starts to fail in the foreground when the background occupies a relatively small amount. To solve this problem, Fan[9] et al. proposed an improved VE method that uses the grayscale information of the valley neighborhood instead of the grayscale of a single valley point, called Neighborhood Valley-Emphasis (NVE); Yuan[10] et al. improved on the OTSU method and proposed the weighted object variance (WOV) method, which was experimentally shown to have a better segmentation effect compared with the OTSU, VE, NVE and ME[11] methods. The OTSU method has also been specifically improved by scholars in the segmentation tasks for different material images. To improve the accuracy of crack detection, Hoang[12] proposed a minimum-maximum gray level discrimination (M2GLD) method as a preprocessing method for OTSU, and experiments showed that the method improved the accuracy of crack detection; Qiao[13] et al. proposed an improved OTSU algorithm for image segmentation of PCBs based on the OTSU algorithm, considering the different effects of factors such as the distance between foreground and background and various types of cohesion on image segmentation, and the results were better than the OTSU method.

In order to solve the problem that the OTSU method is ineffective in segmenting images with noise, Jianzhuang Liu[14] et al. proposed the two-dimensional OTSU method, considering both the grayscale distribution of pixels and the average grayscale of their neighboring pixels, and extended the OTSU method to the case of two-dimensional histogram, and the experiments showed that the performance of the method was much higher than the original one-dimensional OTSU method when dealing with noisy images. However, the two-dimensional OTSU algorithm is too computationally intensive, so He[15] et al. improved the two-dimensional OTSU method by directly building a linear intercept histogram from the two-dimensional information of the image and then finding the optimal intercept threshold from the one-dimensional OTSU, thus the method is not only less computationally intensive than the original two-dimensional OTSU, but also more resistant to noise. To further improve the computational efficiency and noise immunity of the two-dimensional OTSU, Xiao[16] et al. improved the original two-dimensional OTSU method and proposed a new OTSU thresholding method based on set mapping and trapezoidal region intercept histogram which not only has better performance in computational efficiency but also can achieve a balance between detail preservation and noise removal in image segmentation.

In addition, the experiment finds that the OTSU method is less effective in segmenting images with low brightness, and it is easy to misjudge some impurities and disturbances as foreground, resulting in segmentation errors. In this paper, for a class of image segmentation problem with large image size, little noise and low brightness, after considering the balance problem of efficiency and effectiveness, the information of image brightness is incorporated into the adjustment strategy of OTSU method threshold on the basis of one-dimensional OTSU method to solve the problem of poor effect of existing OTSU method on low brightness image segmentation. The contributions of this paper are as follows.

- ① The brightness-based threshold-weighted OTSU method is proposed, which can effectively solve the problem of poor segmentation of low brightness images by OTSU.
- ② Introduced a threshold weighting coefficient based on the average gray level of the image, created a mapping relationship between the threshold weighting coefficient and the average gray level, and achieved a more optimal selection of the image segmentation threshold.

The rest of this paper is organized as follows: Chapter 2 introduces the OTSU method and the problems it encounters in image segmentation; Chapter 3 describes the proposed and implementation of this paper's method(brightness-based threshold-weighted OTSU method, TW-OTSU); Chapter 4 conducts experimental validation, and eight image segmentation methods are selected for comparison

with this paper's method to verify the effectiveness of this paper's method; finally, Chapter 5 gives the conclusion.

2. Problem Description

In industrial production, when taking images of objects with strain gauges, flexible circuits and other substrates of light-transmitting materials, in order to enhance the contrast between the foreground and background of the image, the backward light source imaging is usually used, i.e., the light source and the camera are placed on both sides of the object. Appropriate enhancement of light intensity can remove the small size of the substrate speckle impurities, but the light intensity should not be too strong, too strong light will intensify the effect of light diffraction, corrosion of the image foreground edge, the loss of image authenticity, so the selection of light intensity to achieve a balance between the removal of substrate impurities and retain the image edge details. However, it is difficult to reach a balance, and in order to retain the original details of the image, the image segmentation algorithm inevitably has to deal with some images with low brightness. In the case of low brightness, the contrast between image foreground and impurities is low, and the OTSU method cannot accurately segment the impurities into background, and segmentation errors will occur.

The literature[17] states that OTSU thresholds tend to separate larger classes so that the two classes remain of similar size; the literature[18] argues that OTSU computed thresholds will favor components with larger size or larger class variance. Xu[19] gives a further explanation and theoretical proof of the conclusion of the literature[17] and [18]: the OTSU threshold is equal to the mean value of the average grayscale of the two classes segmented by this threshold, and when the intra-class variance of the two classes differs significantly, the OTSU threshold will favor the class with the larger variance. Thus when the image brightness is low, the contrast between foreground and interference is low, the grayscale range of the background is larger, and the intra-class variance is larger, so the OTSU threshold will be biased toward the background.

According to the above analysis, the change of the same image brightness will cause the change of image grayscale distribution, but the traditional OTSU method does not consider this problem when calculating the segmentation threshold, so the segmentation effect for low brightness images is poor. Based on this, this paper proposes a weighted image brightness maximum interclass variance method to improve the OTSU method by incorporating the changes in image grayscale distribution caused by changes in image brightness into the OTSU method.

3. Brightness-based Threshold-Weighted OTSU Method(TW-OTSU)

3.1 Improvement ideas

Through the problem analysis in part 2, it is found that the image segmentation threshold calculated by OTSU is often larger than the ideal segmentation threshold, and the difference between it and the ideal threshold decreases as the brightness increases, and the OTSU threshold is the same as the ideal threshold after the brightness reaches a certain value. As [figure 1] shown, the red dashed line indicates the segmentation threshold of OTSU method T_{otsu} , and the green dashed line indicates the ideal segmentation threshold T_{final} , the ideal threshold should be closer to the foreground part of the image than the threshold calculated by OTSU method, i.e., the grayscale peak on the left side, and the grayscale value corresponding to the peak of the foreground grayscale distribution T_{left} used to represent the left side grayscale peak component, and it is conjectured that the ideal segmentation threshold is weighted by the threshold calculated by OTSU and the grayscale value corresponding to

the peak of the foreground grayscale distribution T_{left} obtained.

$$T_{final} = (1 - \alpha)T_{left} + \alpha T_{otsu} \quad (1)$$

Where α is called the threshold weighting coefficient and satisfies $0 \leq \alpha \leq 1$.

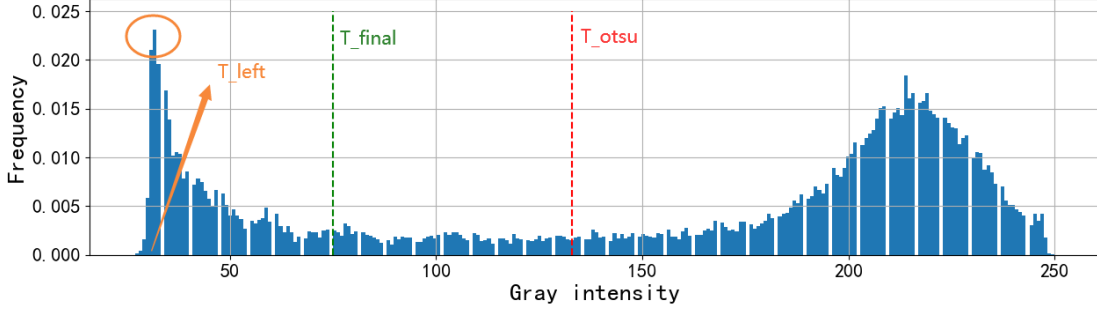


Figure 1 Position of thresholds in the histogram

According to the previous analysis, the threshold weighting coefficient α should be a factor that is positively correlated with the image brightness. When α is close to 1, the final ideal segmentation threshold is mainly determined by the threshold value calculated by the OTSU method; when α is close to 0, the final ideal segmentation threshold is mainly determined by the gray value corresponding to the peak in the foreground of the image grayscale distribution. This inference is also consistent with the phenomenon that the OTSU method is more effective in segmenting high-brightness images and less effective in segmenting low-brightness images. The following study investigates how to obtain the threshold weighting coefficients for images of different brightness α .

3.2 Threshold weighting coefficient acquisition method

The above mentioned threshold weighting coefficient is positively correlated with the image brightness, but for an image, it is not possible to directly know from it the intensity of the light source, the size of the camera aperture, and the exposure time during the image capture, so the average grayscale of the image needs to be used as a measure of the image brightness. Let the size of an image be $M \times N$ pixels and the gray value of the pixel point at (x, y) be $g(x, y)$, then the brightness of the image b is defined as:

$$b = \frac{1}{M \cdot N} \sum_{y=0}^{M-1} \sum_{x=0}^{N-1} g(x, y) \quad (2)$$

In order to obtain the relationship between image brightness and threshold weighting factor, multiple image data with different brightness levels are required. Sixty images with uniformly distributed brightness levels in the range of [20,200] were taken and their brightness were calculated according to the Eq. (2) Calculate their brightness. At least 20 images are selected from them by uniform sampling, and manual image segmentation is performed to determine the ideal segmentation threshold for each image. Then the OTSU segmentation threshold of each image is calculated using the OTSU method. Finally, the grayscale distribution of each image is obtained, and the grayscale value corresponding to the peak in the foreground of the grayscale distribution of each image is calculated by a round-robin comparison method.

Let the OTSU segmentation threshold of the i th image be T_{otsu_i} , the peak corresponding to the foreground peak of the grayscale distribution be T_{left_i} , and the ideal segmentation threshold be T_{f_i} ,

then by Eq.(1) deformation, the threshold weighting coefficient is obtained as α_i :

$$\alpha_i = \frac{T_{f_i} - T_{left_i}}{T_{otsu_i} - T_{left_i}} \quad (3)$$

According to the above steps, the threshold weighting coefficients and image brightness parameters were obtained for each image. With the image brightness b as the independent variable and the threshold weighting coefficient α as the dependent variable, a scatter plot was plotted on coordinate paper to determine the function structure, and then least squares was fitted to obtain the following relationship between α and b as a function of:

$$\alpha = f(b) \quad (4)$$

3.3 Algorithm flow

After obtaining the relationship between the threshold weighting coefficient and the image brightness according to the method mentioned in 3.2, the final segmentation threshold can be calculated using the Eq.(1) and the flow chart of the algorithm is shown in Figure 2. For images of the same material, the step “obtain the relationship between the threshold weighting coefficient and the image brightness” is performed only once, and the calculated function $\alpha = f(b)$ can be used directly in the subsequent image segmentation.

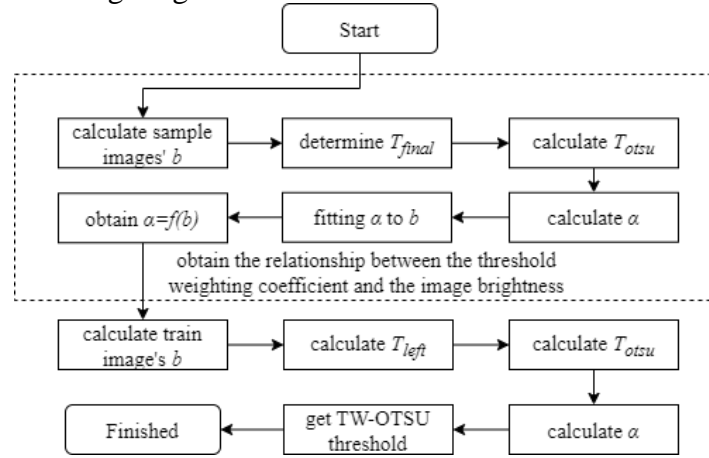


Figure 2 Flow char of TW-OTSU algorithm

4. Experimental Results and Analysis

The following experiments are conducted to obtain the threshold weighting coefficients and segmentation effect comparison experiments with strain gauge images as an example. The strain gauge images were taken by a strain gauge smart detection device, and the computer environment was a Core i9-9900k CPU with 32G RAM, using PyCharm compiler, and all programs were written in Python.

4.1 Get the Threshold Weighting Coefficient

According to the method in 3.2, the strain gauge images with different brightness are obtained as Figure 3. The parameters required for each image are calculated, and the threshold weighting

coefficient of each image can be obtained by Eq.(3).

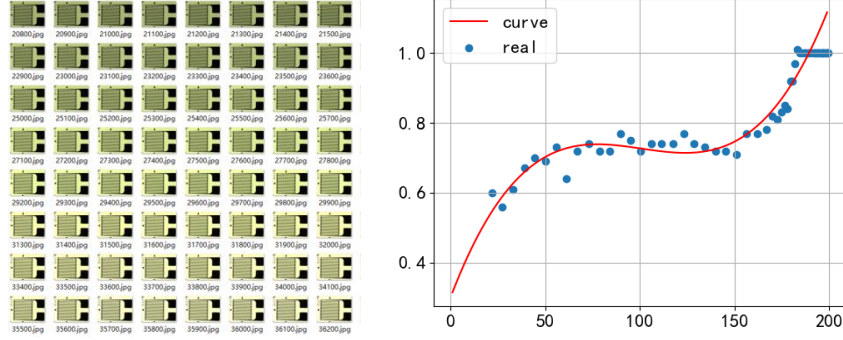


Figure 3 (left) Images of strain gauges with different brightness; (right) Cubic fitting

A scatter plot of α and b on coordinate paper is found to be a good fit for the cubic function, and let α be related to b as:

$$\alpha = C \cdot b^3 + D \cdot b^2 + E \cdot b + F \quad (5)$$

The least squares fit gives: $C=4.94702 \times 10^{-7}$, $D=-0.00015$, $E=0.01428$, $F=0.30046$.

4.2 Image segmentation experiment

In order to verify the effectiveness of this method, eight image segmentation methods are selected for comparison in this paper. They are: ① conventional OTSU method(OTSU)[4]; ② Range Constrained OTSU method (RC-OTSU)[19]; ③ Weighted Object Variance (WOV) [10]; ④ Minimum maximum gray level discrimination (M2GLD)[12]; ⑤ Valley Emphasis Method (VE)[8]; ⑥ Neighborhood Valley Emphasis (NVE)[9]; ⑦ Maximum entropy method(ME)[11]; ⑧ Two-dimensional OTSU (2D-OTSU)[14].

The experiments consisted of the device taking 580 images of the same strain gauge monolith with different brightness (different from the sample images), with brightness numbers ranging from 2000 to 60000. the regions containing interference were selected, and the image segmentation was performed using the eight comparison methods mentioned above with the method in this paper, with the segmentation effect and the algorithm running time as the index. Three effect images were selected for demonstration, and one of them was selected to draw a grayscale histogram in relation to the position of each threshold value, and finally a table was drawn to count the average time spent on the experiment.

By comparing the original images of the three brightness levels, it can be seen that the filament-like objects in the middle of the circuit are interfering and will not cause a short circuit in the circuit, so they should be classified as the background part. In the two experiments shown in Figure 4 and Figure 5, only the RC-OTSU method and the method in this paper can segment correctly and classify this part as the background part, while the rest of the methods make obvious errors. For the experiment shown in Figure 6, the results obtained by all methods except the OTSU can be considered as qualified. The gray level distribution of the strain gauge image of experiment 2 and the position relationship of each segmentation threshold are shown in Figure 7. Through this group of experiments, it is found that only the RC-OTSU method and our method can complete accurate image segmentation for strain gauge images of different brightness, but by Table 1 it is known that the RC-OTSU method takes about 1.7 times more time than ours.

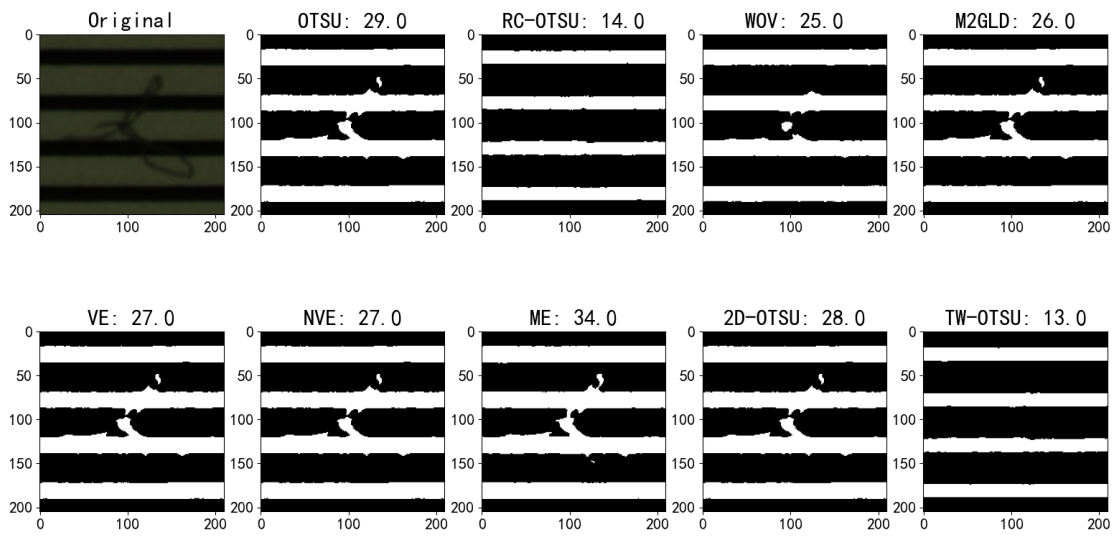


Figure 4 Experiment-1, Brightness index-8600

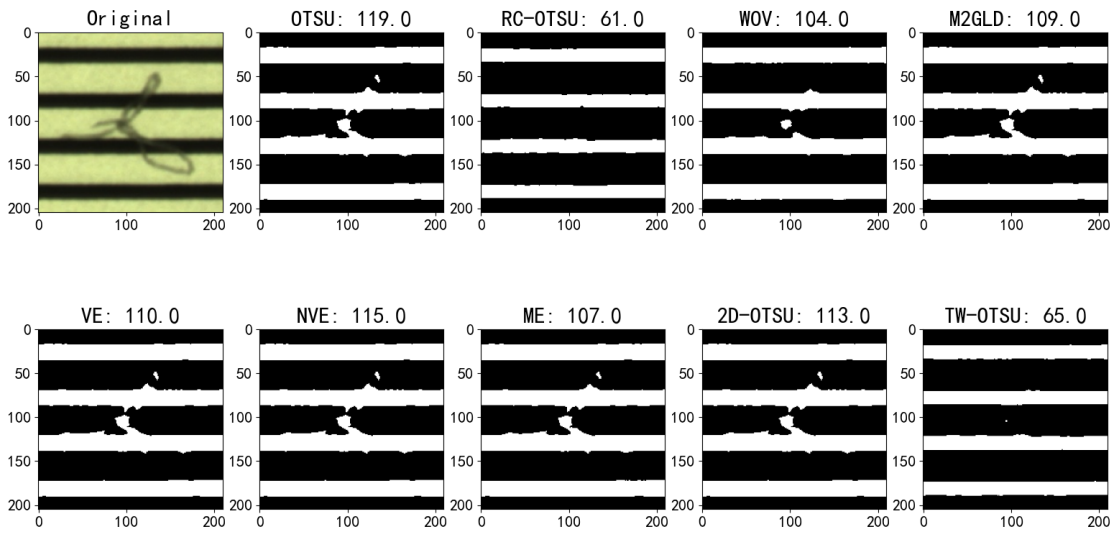


Figure 5 Experiment-2, Brightness index-35100

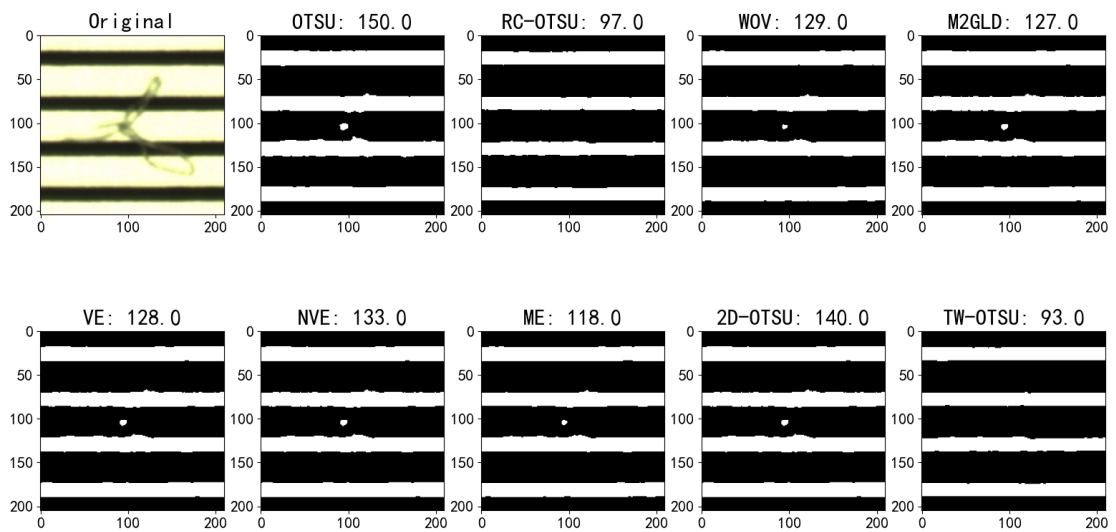


Figure 6 Experiment-3, Brightness index-56600

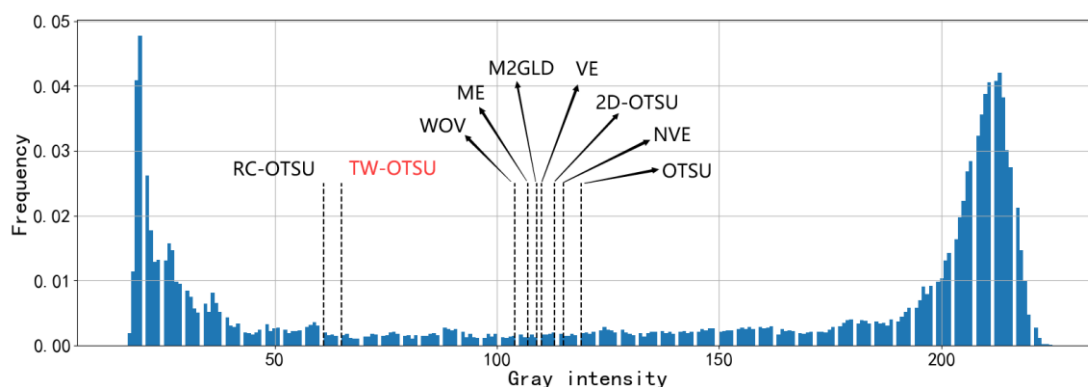


Figure 7 Histogram of exp2 with thresholds of all methods

Table 1 Average Running Time

	Running Time/s	Relative
OTSU	0.101	94.39%
RC-OTSU	0.184	171.96%
WOV	0.103	96.26%
M2GLD	0.371	346.73%
VE	0.104	97.20%
NVE	0.105	98.13%
ME	0.115	107.48%
2D-OTSU	0.265	247.66%
TW-OTSU	0.107	100.00%

5. Conclusions

In response to the poor segmentation effect of the traditional OTSU method on low brightness images, a brightness-based threshold-weighted OTSU method (TW-OTSU) is proposed in this paper. The threshold weighting coefficient is introduced, and the gray value corresponding to the peak of the image foreground gray distribution is weighted with the segmentation threshold of the OTSU method as the improved segmentation threshold, and the threshold weighting coefficient based on the average grayness of the image is introduced, and the mapping relationship between the threshold weighting coefficient and the average grayness of the image is created. The experimental results show that the TW-OTSU method not only solves the problem of poor segmentation effect of the OTSU method in dealing with low brightness images, but also the comprehensive performance advantage of the algorithm in terms of segmentation accuracy and running time is obvious.

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