Study on Automatic Threshold Selection Algorithm of Sensor Images

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Abstract

The threshold selection of sensor images has great influences on the detection accuracy of the mass center, while which will directly affect the recovery of the wave-front detection. Through introducing several principles and algorithms of the threshold segmentation, based on the detection accuracy of the mass center with relatively multiple base points of images, it has been demonstrated that for lattice images with large contrast, there is no much difference in the standard deviations of solving mass centers by four algorithms, however, the OTSU Algorithm based on gray extension obtain the smallest deviation, therefore, for bitmap images, regarding to the binary threshold selection, in this paper, it adopts the OTSU Algorithm based on gray extension, and then solves the center of mass through conducting the binarization. In the end of this paper, it points out the OTSU Algorithm based on gray extension is a better method for the threshold segmentation.

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1. Introduction

Sensors have been widely used in the self-adaptive optics system, the detection accuracy of the mass center is a key indicator of measuring the performance of which, and the threshold selection of images has great influence on its detection accuracy. The image segmentation is the most fundamental problem in the discipline of the image processing, while the segmentation based on thresholds is one of the most fundamental difficulties in the image segmentation, of which the difficulty lies in the selection of thresholds. The current threshold selection methods are discussed, implemented and compared in this paper mainly from the Bimodal Algorithm, the Iterative Algorithm, the OTSU Algorithm and the OTSU Algorithm based on gray extension.
2. Image segmentation

The image segmentation is a process dividing a digital image into a non-overlapping and connected set of pixels, one of which corresponds to the background, and the others correspond to each object in the image. One difficulty of the image segmentation lies in: before dividing, it is not certain to be able to determine the number of the image area.

The image segmentation is the most fundamental problem in the discipline of the image processing, while the segmentation based on thresholds is one of the most fundamental difficulties in the image segmentation, of which the difficulty lies in the selection of thresholds. It has been proved that whether the selection of thresholds is appropriate or not, it plays a decisive role in the effect of segmentations. Due to the basic nature of the threshold selection for the image segmentation, the following contents of this paper discusses, implements and compares some currently popular threshold selection algorithms mainly from the Bimodal algorithm, the Iterative algorithm, the OTSU Algorithm and the OTSU Algorithm based on gray extension. Although the multi-threshold segmentation can further improve the quality of the image segmentation, for it is only concerned with the processing of segmentation techniques, there is no essential difference in the single-threshold segmentation. Thus this paper will not discuss the multi-threshold segmentation, but only considers the case of the single-threshold segmentation.

2.1 The Bimodal Algorithm

The principle of the Bimodal Algorithm is extremely simple: it considers that the image is formed by the foreground and the background; in the gray histogram, the foreground and the background both form peaks; the lowest peak valley between two peaks is where the threshold of the image locates.

2.2 The Iterative Algorithm

The Iterative Algorithm is based on the idea of the approximation, of which steps are as follows:

a) Solve the maximum and the minimum gray values of images, respectively denoted as Zmax and Zmin, so that the initial threshold \( T_0 = (Z_{max} + Z_{min}) / 2 \);

b) According to the threshold \( T_k \), images are divided into the foreground and the background, and respectively solve their average gray of \( Z_{O} \) and \( Z_{b} \);

c) Solve the new threshold \( T_{k+1} = (Z_O + Z_B) / 2 \);

d) If \( T_k = T_{k+1} \), the obtained value is the threshold; otherwise return to b) to use the Iterative computation.

The image segmentation effect of the threshold obtained from iterations is good. The threshold based on iterations enables to distinguish where the main areas locate between the foreground and the background of images, but does not have good degree of distinctions in the subtle area of images.

2.3 The OTSU Algorithm

The Otsu Algorithm has been proposed by Otsu in 1979; it denotes the image as Image, \( t \) as the segmentation threshold of the foreground and the background, the ratio of the foreground points in the image as \( w_0 \), and the average gradation as \( u_0 \); the ratio of the background points in the image as \( w_1 \), and the average gradation as \( u_1 \). The total average gradation of the image \( \bar{u} = w_0 * u_0 + w_1 * u_1 \). The traversing from the minimum gray to the maximum gray is denoted as \( t \), when \( t \) makes the value of \( g = w_0 * (u_0 - u_2) + w_1 * (u_1 - u_2) \) be the maximum, \( t \) is the optimal segmentation threshold. The Otsu Algorithm can be understood as follows: this formula is actually the between-class variance, and the two parts of the foreground and the background segmented by the threshold \( t \) constitute the whole image, while the foreground takes the value as \( u_0 \), its probability as \( w_0 \), the background value as \( u_1 \), the probability as \( w_1 \),
and the total average value as $u$, according to the definition of the variance, then the formula is obtained. For the variance is a kind of measurement of the gradation distribution uniformity, the larger the variance value is, the greater the differences between the two parts constituting the image will be; when part targets are wrongly segmented as backgrounds or part backgrounds are wrongly segmented as targets, it will all result in smaller differences between two parts, therefore the maximum segmentation of the between-class variances means the minimum probability of wrongly segmentations. The calculation amount of directly applying the Otsu Algorithm is larger, thus when it can be implemented, it is to use the equivalent formula $g = w_0 * w_1 * (u_0 - u_1)$.

The threshold selected by the Otsu Algorithm is very ideal, and is relatively good in the performances in all cases. Although it is not the optimal segmentation in many cases, the segmentation quality usually has a certain degree of guarantee, which can be said to be the most stable segmentation. It can be known from the above, the Otsu Algorithm is a more general segmentation algorithm. Under the inspiration of its ideology, many similar threshold assessment algorithms have been further proposed.

### 2.4 Gray Extension Algorithm – An Improved Otsu Algorithm

The Otsu Algorithm has been widely used, but it has been found that the fatal flaw of which is when the difference between the target and the background gradation is not apparent, there will be unbearable large black areas, or even the loss of the whole image information. To solve this problem, the enhanced Otsu algorithm of gray extension has been proposed. In fact, the principle of this method is based on the Otsu Algorithm, by increasing the gray level to enhance the gray difference between the foreground and the background so as to solve the problem. The gray-level increased method is to multiply the original gray level with the same coefficient, thus expanding the gray level, especially when the multiplied coefficient is 1, it is the prototype of the Otsu Algorithm; therefore, the Otsu Algorithm can be seen as a special case of this approach. For the background and the foreground of the lattice image detected by the Hartmann-Shack sensor are not obvious, and the overall occupied area of the foreground is small, it is not to use the Bimodal Algorithm and Iterative Algorithm, instead in this paper it chooses the improved OTSU algorithm.

### 3. Methods To Improve The Detection Accuracy Of The Mass Center

Design a template larger than the sub-facula, place it in the upper-left corner of the segmentation area, and find out the most brightened dot within the template. Move the template in turn to find out several most brightened dots. Compare each module with the most brightened dot as the center and the brightness ratio of the surrounding dots with the same size, and find out the most brightened dot with the largest ratio. Take this most brightened dot as the center, select a rectangular area with larger size than the approximate size of the facula, and within this region use the threshold method and the first moment formula to calculate the mass center of the facula.

The selection method of the mass center detection window due to its usually relatively well-distributed background noises, is generally adopted with the threshold method to reduce the errors they produce, that is to minus a certain thresholds from the readout signals of CCD and set negative values to zero. However, as there is a certain degree of fluctuations in the well-distributed noises, even the use of the threshold approach can not completely eliminate this part of noises. Therefore, as the size of the mass center detection window is increased, the mass center detection errors will be increased as well. In addition, when the facula cannot fully stay within the mass center detection window, the mass center detection errors will be increased. Subsequently, the better the size of the mass center detection window matches with the distribution area of the facula, the smaller the mass center detection errors will be.

The steps for the method of multi-solving mass center are as follows:

1. Solve the corresponding location of the maximum value within each sub-aperture, that is the location where the most brightened dot of each facula is. In the actual experiments, the influence of noises makes the location of the maximum value within each sub-aperture be possible to have more than one, at this time, it needs to determine the real location of the most brightened dot: firstly, for the facula picture,
regarding the entire sub-aperture area as the detection window, solve the mass center locations of each facula by the first moment method, and then according to this traditional algorithm initially calculate the surrounding area of mass center locations, which is certain to be the area covered by the facula within each sub-aperture; secondly, regarding the initially calculated mass center locations as the center, select an area with appropriate size, and solve the maximum value within this small area, which is certain to be the location for the maximum value of the entire sub-aperture area.

g) Calculate the mass center locations of each facula within the determined detection window by the first moment method. Use this method to optimize the facula detection window, which shows all the facula are located within the window, and the window size is closer to the facula size; the detection error of the mass center is smaller.

As the facula image obtained from the actual Hartmann sensor is very irregular, in which not only there are several locations for the most brightened dots, but also usually multiple peaks and valleys are contained. In the aspect of improving the calculation accuracy of the mass center, only depending on the optimization of the detection window is limited. It must adopt method of combining the optimization detection window with the other methods to improve the accuracy.

According to the existing problems in the HS wavefront sensor and the analysis on the variation range of the mass center, it can be known that the sub-aperture size is much larger than the variation range between two frames of the mass center. Therefore, it has proposed a new method to use the variation range of two adjacent sampling intervals in the mass center to calculate the location of the mass center. The method uses the known location of the previous frame of mass center and the variation range of the mass center, in such range to calculate the location for this frame of mass center to achieve the dynamic tracking measurement for the location of the mass center.

The algorithm has established the technology to solve the mass center under random observed scene, and displayed the relationship of the minimum mean square error existed between the two sub-window images (one of which is the reference image). Comparisons of the facula image and the referred facula image by related algorithms, and the values used to estimate are all around the most suitable place, as the signal for the most suitable place is the strongest with the largest proportion, which causes related algorithms to be insensitive to noises, greatly reducing the effects of noises on the calculations of the mass center, and insensitive to the distortions of the background light and most facula. This algorithm is too complicated to meet the speed requirement of image restorations.

4. Evaluating Indicators For Methods Of Solving The Mass Center

General optical system often uses optical transfer function (OTF) to evaluate its quality, when the error source is the random self-adaptive optic system, although the statistical average of the optical transfer function can be used to evaluate, the wider application is to use the Strehl Ratio to evaluate the quality of the self-adaptive optic system.

The complex amplitude of any point on the distorted wavefront can be expressed as:

$$E(\rho) = A(\rho)e^{i\varphi(\rho)}$$  \hspace{1cm} (1)

In which $A(\rho)$ is the wavefront amplitude, $\varphi(\rho)$ as the wavefront phase, by the far-field Fraunhofer diffraction theory, this point can be solved; the light intensity of the imaging focal spot after passing the ideal imaging system on the system optical axis is:

$$I = \frac{1}{\lambda^2 F^2} |A(\rho)e^{i\varphi(\rho)}|^2$$  \hspace{1cm} (2)
In which $F$ is the focal length of the imaging system. If the wave front is the ideal plane wave, then $\Phi(\rho) = 0$ is existed, at this time the light intensity of the imaging focal spot on the system optical axis is:

$$I_0 = \frac{1}{\lambda^2 F^2} |A(\rho)|^2$$  \hspace{1cm} (3)

The Strehl Ratio is defined as the ratio of the peak value light intensities between the imaging focal spots of the distortion wavefront and the ideal wavefront, that is,

$$SR = \frac{I}{I_0} = \frac{|A(\rho)e^{j\phi(\rho)}|}{|A(\rho)|}$$  \hspace{1cm} (4)

It conducts the McLaughlin series expansion on the above equation, and only ignores the higher order terms more than the second order, then the above equation can be simplified as:

$$SR = 1 - \sigma^2$$  \hspace{1cm} (5)

In which $\sigma^2$ is the phase variance of the distortion wavefront.

If the phase of the distortion wavefront conforms to the Gaussian distribution, then equations (6-10) can be further expressed as:

$$SR = e^{-\sigma^2}$$  \hspace{1cm} (6)

It can be seen from the above expressions that the Strehl Ratio depends only on the wave front phase difference, and is very sensitive to the phase difference, so it is very suitable for measuring the quality of the self-adaptive optic system.

When evaluate the pros and cons of the methods solving the mass center, it can use the Strehl method to evaluate it, but the solution on the mass center is only an important step in the self-adaptive optics, moreover it must calculate through the follow-up steps, thus in this paper it uses the mass center standard deviation of the basis point image as the criteria to evaluate the method. For the distortion of the basis point image is smaller, while in theory, the standard deviation of the mass center in the basis point should be zero, so that it can meet the requirements of the mass center in the basis point, the smaller the standard deviation in the method of solving the mass center, the more effective the mass center detection is indicated.

5. The Mass Center Detection And Its Experiments

The lattice image of the distorted wavefront due to uneven distributions of light intensities, the mass center detection is greatly influenced by thresholds; in this paper after comparing several methods of selecting binary thresholds, it proposes the Otsu method of gray extension is the best method to process the lattice images. As the contrast ratio of the lattice image is not strong and the lattice imaging area is small, the Bimodal Algorithm is unable to determine its peak and valley; instead the threshold must be determined by the gray extension.

There is no much difference in the aspect of solving the standard deviation of the mass center by using the Bimodal Algorithm of gray extension, the Iterative Algorithm and the OTSU Algorithm, however, the points of the maximum or the minimum value on the curve are different, and their maximum standard deviations are all around 0.34 (both at X Axis and Y Axis). So for this image, the above 3 methods do not meet the requirements of images to solve the mass center. After using the Bimodal Algorithm of gray extension, at X Axis, the maximum standard deviation for the mass center is 0.158, while the maximum value in Y Axis is 0.1, which is respectively 50% or 30% of the previous 3 methods (0.34). Thereby, for this image using the OTSU Algorithm of gray extension is the best way.

Since the imaging area of the original lattice images has larger gray level and strong contrast of the foreground and the background, when the gray extension is not performed, the peak and valley can be determined. As it needs to be compared with the previous results, this paper has still carried out the extensions, and in the extended gray level, there is a clear peak and valley.
For the standard deviations of the mass center in the lattice images with strong contrast solved by the Bimodal Algorithm of gray extension, the Iterative Algorithm, the OTSU Algorithm, and the OTSU Algorithm of gray extension in X Axis and Y Axis are not large, there is no much difference in the four algorithms for solving the lattice images with strong contrast.

In the lattice images with strong contrast, although there is no much difference in solving the standard deviations of the mass center by various algorithms, the standard deviation calculated by the OTSU Algorithm based on gray extension at X Axis and Y Axis is the minimum, indicating that this is the optimal method.

In the lattice images with small contrast, there are much differences (0.8-0.9) in solving the standard deviations of the mass center by using the Bimodal Algorithm, the Iterative Algorithm and the OTSU Algorithm, while the maximum solved standard deviation of the mass center by using the OTSU Algorithm based on gray extension is about 0.23, therefore this method is the best one.

**TABLE I.** The Comparing of Maximum Standard Deviations of the Mass Center Solved by Several Algorithms

<table>
<thead>
<tr>
<th></th>
<th>Bimodal Algorithm of Gray extension</th>
<th>Iterative Algorithm</th>
<th>OTSU Algorithm</th>
<th>OTSU Algorithm of Gray extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Standard Deviations at X Axis and Y Axis (1)</td>
<td>0.3482</td>
<td>0.3334</td>
<td>0.3363</td>
<td>0.1588</td>
</tr>
<tr>
<td></td>
<td>0.3415</td>
<td>0.3366</td>
<td>0.3296</td>
<td>0.1000</td>
</tr>
<tr>
<td>Maximum Standard Deviations at X Axis and Y Axis (2)</td>
<td>0.3476</td>
<td>0.3300</td>
<td>0.3332</td>
<td>0.3007</td>
</tr>
<tr>
<td></td>
<td>0.3480</td>
<td>0.3335</td>
<td>0.3310</td>
<td>0.3101</td>
</tr>
<tr>
<td>Maximum Standard Deviations at X Axis and Y Axis (3)</td>
<td>0.8213</td>
<td>0.9228</td>
<td>0.8853</td>
<td>0.2382</td>
</tr>
<tr>
<td></td>
<td>0.8232</td>
<td>0.7592</td>
<td>0.7914</td>
<td>0.1689</td>
</tr>
</tbody>
</table>

Evaluating the pros and cons of the mass center quality can also use the method of the signal-to-Noise ratio to represent; the signal to noise ratio uses the formula:

\[
\text{SNR} = \frac{(X_1 - X_2)}{N}
\]  

(7)

In which X1 is the target gray average within all sub-apertures, and select the facula-centered 7 pixels x 7 pixels. X2 is the background gray average within all sub-apertures, and N is the mean square deviation of the background gray level.

Table 2 is the comparing of the maximum standard deviations for the mass center in the sub-apertures of another 5 frames of images separately solved by the previous 4 algorithms; it can be seen from the table, as the SNR decreases, the maximum standard deviation solved by the OTSU Algorithm of gray extension is smaller than the other 3 algorithms, indicating that this is a better method of solving thresholds.

**TABLE II.** The comparing of maximum STD used four threshold determinations

<table>
<thead>
<tr>
<th>SNR of Image</th>
<th>The Max. of STD at X Axis and Y Axis</th>
<th>Two-Peak Method (after gray extension)</th>
<th>Iterative Method</th>
<th>OTSU (after gray extension)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0691</td>
<td>X</td>
<td>0.3482</td>
<td>0.3334</td>
<td>0.3363</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>0.3415</td>
<td>0.3366</td>
<td>0.3296</td>
</tr>
<tr>
<td>1.8048</td>
<td>X</td>
<td>0.3476</td>
<td>0.3300</td>
<td>0.3332</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>0.3480</td>
<td>0.3335</td>
<td>0.3310</td>
</tr>
<tr>
<td>0.4393</td>
<td>X</td>
<td>0.8213</td>
<td>0.9228</td>
<td>0.8853</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>0.8232</td>
<td>0.7592</td>
<td>0.7914</td>
</tr>
<tr>
<td>0.2022</td>
<td>X</td>
<td>0.8131</td>
<td>0.7919</td>
<td>0.7952</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>0.8658</td>
<td>0.8654</td>
<td>0.8735</td>
</tr>
</tbody>
</table>
6. Conclusion

It can be seen from the above analysis, the current methods of solving the mass center generally are the bimodal method, the iterative method, OTSU method and the OTSU method based on gray extension (strictly speaking, which should be the method of threshold selection, here generally called the method of solving the mass center); for the lattice images with smaller contrast, using the OTSU method of gray extension to solve thresholds, conducting the binarization on images, and then solving the mass center, the calculated standard deviations are smaller, only accounting for about 30% of other methods; it can be seen from the above analysis that for the lattice images without distortion, as the effects of optical adjustments, etc. factors, there is a certain deviation with the reference position, however, this deviation should be small to be negligible; subsequently for the several methods, it uses the evaluation method of unifying standard deviations of the mass center, and each method that solves the minimum standard deviation of the mass center is the best method.

References