Application of a New Segmentation Algorithm in Submarine Manganese Nodule Statistics

Qing-wen CAI\textsuperscript{1,2} and Yu-liang LIU\textsuperscript{1,2,∗}

\textsuperscript{1}Key Laboratory of Submarine Geoscience, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China

\textsuperscript{2}School of Naval and Architecture and Mechatronics Engineering, Zhejiang Ocean University, Zhoushan, 316022, China

\textsuperscript{∗}Corresponding author

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Abstract. To solve the problem of particle overlapping in the statistics of submarine manganese nodules, a new algorithm is proposed in this paper. According to the natural round nucleus shape of manganese nodule particle, a substitution circle is used to replace the particle approximately. Firstly, the centroid of particle obtained by calculating is regarded as the center of the substitution circle. Then, the distance between the circle’s center and the boundary of the particle is obtained, and the distance plus to a modified constant as the radius of the substitution circle. Finally, the intersection points of two substitution circles are looked upon as the pair of segmentation points, and the manganese nodule particles is segmented by connecting a line between the pair of segmentation points. From experiments results, it’s shown that the accuracy of statistics is over 98% after processed by the new algorithm, which proved the proposed algorithm is effective.

Introduction

Manganese nodules, including manganese, titanium and other rare elements, have a huge market in many fields such as aviation, aerospace, electronic information and so on. Manganese nodules are abundant especially on seabed and the corresponding exploration from seabed usually requires the help of underwater robots \cite{1}. According to the pictures taken by underwater robots, the size, quantity and distribution condition of manganese nodule particles can be obtained. However, there are overlapping phenomenon between or among manganese nodule particles, which will bring troubles to the statistics and further affects the mining. Therefore, many attentions have been payed to the study of image segmentation of submarine manganese nodules in the recent years.

Scholars around the world have proposed some algorithms for segmenting overlapping particles especially in the medical field \cite{2-6}, including classical watershed segmentation algorithm and its improved versions, segmentation algorithm based on concave point detection and those based on bottleneck detection, etc. Classical watershed segmentation algorithm \cite{4} often gives rise to the problem of over-segmentation or under-segmentation. Marker-controlled watershed \cite{5} can solve the above problems, but for some objects with serious overlapping or strange shape, the detection of marker is also a huge challenge. The algorithm proposed in \cite{6} has a good segmentation result but with a large amount of computation, so it is unsuitable to the overlapped problem of manganese nodule particles requiring rapid processing of large amounts of data. Literature \cite{7} proposed a segmentation algorithm, which splits the manganese nodule particles by detecting bottleneck and ellipse fitting. But this algorithm is not good at dealing with a large number of complex overlapping particles.

In this paper, a new segmentation algorithm is proposed according to the natural round shape of manganese nodules. The operation steps as follows. The first step is Euclidean distance transformation of binary image obtained by preprocessing. The second step is extended maximum value transformation of the image, obtaining the extend maximum value region of manganese nodule particles. In the third step, we need calculate centroid of extend maximum value region, and
use it as center of the substitution circle. The distance between center of the circle and the boundary of the particle plus a modified constant as radius of substitution circle. In the fourth step, obtained splitting points pair by calculating intersection points of substitution circle of two overlapped particles. Finally, segment the overlapping particles by connecting the splitting points pair. The algorithm simulation experiment is carried out using MATLAB and the effectiveness of the proposed algorithm is verified.

Summary of Proposed Segmentation Algorithms

In this section, the proposed algorithm is described. The idea is to replace a manganese nodule particle with a circle of appropriate size. This circle is called substitution circle in other parts of this paper. The center of substitution circle is centroid of manganese nodule particle. The distance between the centroid and the boundary of the particle plus a modified constant as radius of substitution circle. By controlling the radius, we can guarantee the substitution circle of two overlapped manganese nodule particles intersect each other, next calculate the intersection as the pair of splitting points, finally we achieve segmentation by connecting the splitting points.

Determination of the Substitution Circle

Center of Substitution Circle. A binary image of overlapped manganese nodules can be obtained by denoising, binarization and other preprocessing steps. Where the binarization is as follows,

\[
f(x, y) = \begin{cases} 
1 & \text{object} \\
0 & \text{background} 
\end{cases} 
\]  

(1)

In order to obtain substitution circle center of each manganese nodule particle, it is necessary to mark each particle independently.

First, the distance transformation of connected regions is carried out. Suppose that a connected region \(T\) is \(T = \{P_1, P_2, ..., P_n\}\), where \(n\) is the number of pixels on the region and \(f(P_i) = f(x_i, y_i) = 1\). The minimum boundary contains the entire connected region is \(B = \{Q_1, Q_2, ..., Q_m\}\), where \(m\) is the number of pixels on the boundary and \(f(Q_j) = f(X_j, Y_j) = 0\). The distance between pixel \(P_i\) and the nearest boundary pixel \(Q_j\) in the connected region is:

\[
d_i = \sqrt{(x_i - X_j)^2 + (y_i - Y_j)^2}
\]

(2)

Let \(F(P_i) = d_i\), the closer to the center, the larger \(F(P_i)\) is. Set the maximum point of \(F(P_i)\) in the region to be \(P_{\text{max}}\), the extended maximum value transform region by threshold \(H\) is:

\[
E = \left\{ PE_i \mid F(PE_i) \in A \right\} \quad E \subseteq T
\]

(3)

Among that, \(A = [F(P_{\text{max}}) - H, F(P_{\text{max}})]\). The selection of threshold \(H\) should make all manganese nodules particles labeled as far as possible.

The extended maximum value transform region \(E\) is located in the center of the particle, like \(P_{\text{max}}\), so the centroid of manganese nodules can be replaced by centroid of \(E\). Assumed that \(E = \{PE_1, PE_2, ..., PE_{\xi}\}\) and \(\xi\) is the number of pixels on the \(E\), and \(f(PE_i) = f(XE_i, YE_i) = 1\). Set centroid of \(E\) be \(P_c = (x_c, y_c)\) the calculation of centroid as follows

\[
x_c = \left( \sum_{k=1}^{\xi} XE_k \right) / \xi \quad y_c = \left( \sum_{k=1}^{\xi} YE_k \right) / \xi
\]

(4)

The result is shown in Figure 1.
Radius of Substitution Circle. Let initial radius be $r = F(P_c)$. The boundaries of manganese nodules are irregular so the substitution circle cannot contain the entire manganese nodule particle if let the initial radius be the radius of the substitution circle, which will cause that the intersection points cannot be found, further perhaps leading to segmentation failure. To avoid such a case, we introduce a modified constant $K$ and let the final radius is $R = r + K$.

The selection of the $K$ requires that substitution circle be able to contain the entire manganese nodule particle without making the substitution circle too large. In this paper, we use a diameter $D$ of the circle with the same area as $E$ as the modified constant $K$.

$$K = D = 2\sqrt{\frac{\xi}{\pi}} \quad (5)$$

Wherein $\xi$ is the area of $E$, i.e., the number of pixels on $E$.

Calculation of the Splitting Points Pair

To obtain the splitting points pair we need calculate the intersection of intersecting substitution circle first, then determine the splitting points pair by rounding. We refer to method from [8] and the calculation process is as follows.

Suppose two substitution circles intersected as Figure 2, we set the center of substitution circle which located in lower left be $O_1 = (x_1, y_1)$, intersection points are $A = (x_a, y_a)$ and $B = (x_b, y_b)$ make a line $O_1C$ which through point $O_1$. Then we set the angles $\angle AO_1O_2 = \alpha$, $\angle O_1O_2C = \beta$, $L = |O_1O_2|$, according to cosine theorem and geometric relation expression, we get

$$\alpha = \arccos \frac{R_1^2 - R_2^2 + L^2}{2R_1L}, \quad \beta = \arcsin \frac{y_2 - y_1}{L}, \quad \left(\beta \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]\right) \quad (6)$$

Further we get

$$\begin{align*}
  x_a &= x_1 + R_1 \cdot \cos(\alpha + \beta) , & y_a &= y_1 + R_1 \cdot \sin(\alpha + \beta) \\
  x_b &= x_1 + R_1 \cdot \cos(\alpha - \beta) , & y_b &= y_1 + R_1 \cdot \sin(\alpha - \beta) 
\end{align*} \quad (7)$$

The intersection points $A = (x_a, y_a)$ and $B = (x_b, y_b)$ are obtained and get splitting points pair by rounding.
Calculation of the Splitting Line

After obtaining the splitting points pair, selecting the appropriate pixels to form an approximate line as the splitting line by calculating. The calculation process as follows,

Set $\Delta x = x_a - x_b$, $\Delta y = y_a - y_b$, if $\Delta y$ satisfies $\Delta y > \Delta x$, the value of $x$ and $y$ will exchange. According to the two-point straight line equation, we can get the equation

$$y = \frac{\Delta y}{\Delta x} (x - x_b) + y_b, \quad x \in [x_b, x_a]$$

(8)

Because the coordinates of the pixel on the digital image are positive integers, $y$ need be rounded.

Experimental Verification

In order to verify the proposed algorithm, we selected four manganese nodule images with different number and overlapping degree to carry out the experiment. The images’ preprocessing and binarization have been finished. The particle’s area is approximately calculated by the number of pixels that make up the particle, and a segmentation threshold is set for classification and statistics. Comparing the results of classification and statistics with the real data, the statistical accuracy is obtained and used to represent the effect of new algorithm.

The four images are processed by the proposed algorithm, and the results are shown in Figure 3. It can be seen that the splitting result of this algorithm is thorough and correct, and the detailed statistical results are shown in Table 1.

![Figure 3](image)

**Figure 3.** Experimental results. The images in the first row are original binary ones and those in the second row are split results diagrams by proposed algorithm: (a) single region and simply overlapped. (b) single region and complicatedly overlapped. (c) multiple regions and simply overlapped. (d) multiple region and complicatedly overlapped.

<table>
<thead>
<tr>
<th>Image</th>
<th>real number of small particles</th>
<th>real number of big particles</th>
<th>number before separation</th>
<th>small particles after separation.</th>
<th>big particles after separation</th>
<th>correct segmentation rate</th>
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<tr>
<td>a</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>b</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>100%</td>
</tr>
<tr>
<td>c</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>10</td>
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</tr>
<tr>
<td>d</td>
<td>40</td>
<td>40</td>
<td>10</td>
<td>41</td>
<td>39</td>
<td>98%</td>
</tr>
</tbody>
</table>

Table 1. Detailed results of the segmentation and statistics.
Conclusion

To solve the overlapping problem in manganese nodules statistics, a new algorithm is proposed according to natural round shape of manganese nodules. The algorithm achieves target object splitting conveniently based on the search of splitting points and the construction of splitting line. First, the center and radius of substitution circle of target object are calculated by distance transform and extended maximum value transformation. Then we use cosine theorem to calculate intersection points of intersecting substitution circles, and obtain splitting point pair. Final, connect the splitting point pair to achieve splitting of overlapped manganese nodules. In order to prove the effectiveness of the proposed algorithm, we made statistics on the size and number of manganese nodules on the basis of segmentation processing. The statistical accuracy is not less than 98%, which proves the new algorithm is effective. The new algorithm achieves segmentation by simply connecting a line, and it has the advantages of concise principle and fast calculation speed. We also find the new algorithm has an error in the statistics of real size. In order to get more accurate statistical results, it is necessary to correct the area after splitting and this is just the next plan of our own.

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