Otsu Image Threshold Segmentation Method Based on Seagull Optimization Algorithm

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Abstract. In this paper, a two-dimensional Otsu image threshold segmentation method based on Seagull optimization is proposed. The Seagull algorithm is used to calculate the threshold points of two-dimensional Otsu image segmentation and segment the image. The algorithm makes full use of the seagull migration operator of global search and the seagull attack operator of simulated local search. Simulation results show that the algorithm not only improves the speed, but also improves the segmentation accuracy.

1. Introduction
Image segmentation refers to extracting the required target from the image, so as to separate the background from the target. At present, the threshold segmentation methods mainly include maximum variance between classes, projection threshold method of two-dimensional gray histogram, minimum cross entropy method, minimum error threshold method under the assumption of normal distribution and so on. The method of maximum variance between classes divides the plane into two parts by calculating the threshold $T$, one part is the set whose threshold is lower than $T$, and the other part is the set whose threshold is higher than $T$, thus obtaining the binary image. The method of maximum variance between classes is widely used in image segmentation because of its simple calculation method and high speed.

In recent years, with the rapid development of artificial intelligence, more and more intelligent optimization algorithms provide new ideas for image segmentation, such as particle swarm algorithm, wolf swarm algorithm, pigeon swarm algorithm, firefly algorithm, genetic algorithm, etc. Compared with the direct use of maximum variance between classes or clustering method, the accuracy, operation speed and convergence speed of image segmentation have been improved to a certain extent. Swarm intelligence algorithm can effectively solve nonlinear optimization problems. Because of its fast convergence speed, simple algorithm principle and high efficiency, it has attracted many researchers’ attention and has been widely used. Therefore, this paper aims at the new swarm intelligence algorithm-Seagull Optimization Algorithm, and combines Otsu method to apply it to image segmentation. Experiments show that this algorithm can achieve better image segmentation.

2. Seagull Algorithm
Seagulls are the most common seabirds, which often move in pairs or small groups, or fly in the air. Seagull, an animal with strong attack power, often hovers in the air to find and attack prey with wisdom. Seagulls will migrate between different regions with seasonal changes in order to find the most abundant food and provide enough energy. When seagulls migrate, they often attack migratory birds. When they
attack, the group makes a spiral natural movement shape. Therefore, the two most important characteristics of seagulls are migration and aggression. The migration and prey attack behavior of seagulls are similar to the optimization objective function, and the optimal solution is searched in a given search space.

2.1. Migration
The migration process of seagulls is equivalent to global search, and the best seagull location is found according to the solutions in the migration rules. In the process of migration, seagulls need to meet the following three conditions:

1) Avoid collisions
When migrating, the position of each seagull is different. In order to avoid the collision between neighbors (other seagulls), the additional variable \( A \) is used to calculate the new seagull position.

\[
C_s(x) = A \times P_s(x)
\]  (1)

\( C_s(x) \) indicates the new position of seagull, which does not conflict with other seagulls. \( P_s(x) \) represents the current position, \( x \) represents the current iteration times, \( A \) represents the movement behavior of seagulls in the search space, and the range of \( A \) is \([0, f_c]\).

\[
A = f_c - (x \times (f_c / MAX_{iteration}))
\]  (2)

\( f_c \) can control the frequency of variable \( A \), and its value decreases linearly from 2 to 0.

2) Optimum position and direction
Approaching to the best position: Seagulls will move to the best position during migration.

\[
M_s(x) = B \times (P_{bs}(x) - P_s(x))
\]  (3)

\( M_s(x) \) indicates the direction of the best position, and \( B \) is the random number responsible for balancing the global and local search.

\[
B = 2 \times A^2 \times r_d
\]  (4)

\( r_d \) is a random number in the range of \([0,1]\).

3) Close to the best position
Close to the best position: the seagull moves towards the best position and reaches the best position.

\[
D_s(x) = |C_s(x) + M_s(x)|
\]  (5)

\( D_s(x) \) is the new position (best position) of seagull.

2.2. Attack
The attack behavior of seagulls is equivalent to local search. Seagulls keep their height with their wings and weight during migration, and constantly change their angles and speeds to attack. In the process of attacking prey, keep spiral motion. The motion behavior in the spatial \( x, y \) and \( z \) planes is described as follows:
In which \( r \) is the radius of the spiral and \( \alpha \) is a random value in the range of \([0, 2\pi]\). \( u \) and \( v \) are the correlation constants of spiral shape, and \( e \) is the base of natural logarithm.

The attack position of seagulls is calculated by formula (10).

\[
P_s(x) = D_s(x) \times x \times y \times z \times P_{se}_{(x)}
\]  

(10)

\( P_s(x) \) represents the attack position of seagulls, that is, the optimal solution of search space.

3. Two-dimensional Maximum Variance between Classes (two-dimensional OTSU)

Because the performance of image segmentation with noise interference is degraded by one-dimensional gray histogram, based on the one-dimensional histogram, a two-dimensional gray histogram is constructed by introducing the neighborhood average gray value of the image, which considers both the pixel information and the spatial information of the image. Two-dimensional maximum variance between classes method uses the gray value of pixel and the average gray value of neighboring pixels to calculate the threshold. In the two-dimensional gray histogram (fig. 1), if \((s, t)\) is the threshold point of segmentation, the two-dimensional histogram is divided into four blocks, as shown in fig. 1.

**Figure 1.** Two-dimensional gray histogram

In most cases, there are obvious differences between the image background and the pixels near the target’s boundary. The corresponding 2D histogram is the target \( (C_0) \) and the background \( (C_1) \) in the upper area of the diagonal, and the area away from the diagonal \( (C_2 \text{ and } C_3) \) is the edge or noise.

Let \( P(C_0) \) represent the probability of target \( C_0(s,t) \) and \( P(C_1) \) represent the probability of background \( C_1(s,t) \). Then

\[
P(C_0) = \sum_{i=0}^{t} \sum_{j=0}^{t} p_{ij} = P_0(s,t)
\]  

(11)
The mean vectors corresponding to the target and the background are

$$\mu_0 = (\mu_{00}, \mu_{01})^T = \left( \frac{\sum_{(i,j) \in C_0(s,t)} ip_{ij}}{P_0(s,t)}, \frac{\sum_{(i,j) \in C_0(s,t)} jp_{ij}}{P_0(s,t)} \right)^T$$

(13)

$$\mu_1 = (\mu_{10}, \mu_{11})^T = \left( \frac{\sum_{(i,j) \in C_1(s,t)} ip_{ij}}{P_1(s,t)}, \frac{\sum_{(i,j) \in C_1(s,t)} jp_{ij}}{P_1(s,t)} \right)^T$$

(14)

The total mean vector on the two-dimensional histogram is

$$\mu_T = (\mu_{T0}, \mu_{T1})^T = \left( \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} ip_{ij}, \sum_{i=0}^{L-1} \sum_{j=0}^{L-1} jp_{ij} \right)^T$$

(15)

The areas $c_2$ and $c_3$ represent the boundary information of the target and the background. The boundary information far from diagonal is usually ignored, that is, the probability of regions $i = s+1, ..., L-1$ and $j = 0, ..., t$ or $i = 0, ..., s$ and $j = t+1, ..., L-1$ is about 0, $p_{ij} \approx 0$.

So $P_0(s,t) + P_1(s,t) \approx 1$.

$$\mu_t \approx P_0(s,t) \mu_0 + P_1(s,t) \mu_1$$

(16)

The dispersion matrix between classes is expressed as:

$$S_B = P_0(s,t)[(\mu_0 - \mu_T)(\mu_0 - \mu_T)^T] + P_1(s,t)[(\mu_1 - \mu_T)(\mu_1 - \mu_T)^T]$$

(18)

Using the trace of $S_B$ as the dispersion measure between classes:

$$tr(S_B) = P_0(s,t)[(\mu_{00} - \mu_{T0})^2 + (\mu_{01} - \mu_{T1})^2] + P_1(s,t)[(\mu_{10} - \mu_{T0})^2 + (\mu_{11} - \mu_{T1})^2]$$

(19)

The optimal threshold $(s^*, t^*)$ is determined by formula (20):

$$(s^*, t^*) = \arg \max_{0 \leq s, t \leq L-1} [tr(S_B(s,t))]$$

(20)

Two-dimensional OTSU algorithm is composed of image pixel gray value and neighborhood average gray value, which can improve the accuracy of threshold calculation and the anti-noise ability of the algorithm, but it has a large amount of calculation. Trace $tr(S_B(s,t))$ of $S_B$ is calculated at any point $(s, t)$, and the cumulative sum of corresponding items is repeatedly calculated from the origin $(0, 0)$ for both mean vector and probability. Therefore, in this paper, OTSU uses the fast recursive algorithm proposed...
by Jing Xiaojun et al. [1] to calculate the distance measure between target and background to get the best threshold. The fast recursive algorithm can reduce the computation time and the required space.

Other \( \mu_i(s,t) = \sum_{i=0}^{k} \sum_{j=0}^{k} P_{ij} \), \( \mu_j(s,t) = \sum_{i=0}^{k} \sum_{j=0}^{k} P_{ij} \). There is a fast recursive algorithm formula:

\[
P_0(s,0) = P_1(s-1,0) + p_{s0} \tag{21}
\]

\[
P_0(s,t) = P_0(s,t-1) + P_0(s-1,t) - P_0(s-1,t-1) + p_{st} \tag{22}
\]

\[
\mu_i(s,0) = \mu_i(s-1,0) + s \times p_{s0} \tag{23}
\]

\[
\mu_i(s,t) = \mu_i(s,t-1) + \mu_i(s-1,t) - \mu_i(s-1,t-1) + s \times p_{st} \tag{24}
\]

\[
\mu_j(s,0) = \mu_j(s-1,0) + s \times p_{j0} \tag{25}
\]

\[
\mu_j(s,t) = \mu_j(s,t-1) + \mu_j(s-1,t) - \mu_j(s-1,t-1) + s \times p_{st} \tag{26}
\]

4. Image Segmentation Technology Based on Seagull Algorithm

Seagull algorithm is proposed by Dhiman G et al. [2], which simulates the process of seagulls searching for food in nature to find the optimal solution. Seagull algorithm, as a new iterative optimization method, takes the position of each seagull as the spatial solution, and the position of the richest food as the optimal solution. Seagulls constantly migrate and attack to find rich food.

Seagull algorithm calculation steps are as follows:

1. Parameter initialization. Set the maximum iteration times \( \text{MAX}_{\text{iteration}} \), frequency variable \( f_c \), correlation constants \( u \) and \( v \), \( r_x \) and \( \theta \) of spiral shape.

2. Calculate the additional variable A (Formula 2) and the random number B (Formula 4), which is responsible for balancing the global and local factors.

3. According to the fitness function formula (formula 19-26), the fitness value \( P_s(x) \) of each seagull and the position \( C_s(x) \) of seagull (formula 1) are solved.

4. Compare the migration position of seagulls with the fitness function solved in step (3), so as to find a better position \( P_{bs}(x) \). According to the initial position and better position of seagulls, get the direction \( M_s(x) \) (formula 3) and the best position \( D_s(x) \) (formula 5) of the better position, and update the fitness value and the best position of seagulls.

5. According to the attack radius \( r \) of seagull, the attack position coordinates are calculated, and the new position \( P_s(x) \) of seagull is updated according to the position, attack radius, attack direction coordinates and the best position of seagull (formula 10).

6. Repeat steps 3, 4 and 5 to update the seagull position. If the best position is found to stagnate and no longer change, the process is terminated, otherwise, go to step 3 and continue to execute until the maximum number of iterations is reached.

7. The optimal threshold \( P_s(x) \) is used to segment the image.

5. Experimental Results and Analysis

In order to verify the rationality of this algorithm, experiments are carried out on lena, lake and cameraman images, and the resolution of the images is 512×512. The experimental environment is
Windows 7 operating system and the program running software is Matlab2016b. Parameters are set as follows: frequency variable $f_c = 2$, correlation constants of spiral shape $u = 1$, $v = 1$, $\text{Max}_\text{iterations} = 200$, $r_j$ is a random number in the range of $[0, 1]$ and $\theta$ is a random angle value of $(0, 2\pi)$, where the dimension of search space is 2.

Otsu algorithm and Seagull algorithm are used to segment the image, and the segmentation effect is shown in Figure 2.

![Original image](image1.png)  ![Two-dimensional Otsu algorithm](image2.png)  ![This algorithm](image3.png)

**Figure 2.** Image segmentation result

From the image segmentation results in Figure 2, it can be seen that the segmentation results of this algorithm are more noise-resistant than those of Otsu algorithm, for example, lena image and cameraman image segmentation have some improvements. In addition, the running time of this algorithm in lena image segmentation is about 5s, while the time of two-dimensional Otsu algorithm is more than 7s. Relatively speaking, the time has also been improved, and the time has been shortened in the segmentation of lake and cameraman images.
6. Summary
In this paper, Seagull algorithm is used for image segmentation. Three images are segmented in the experiment, and otsu algorithm is used to verify the superiority of this algorithm. Generally speaking, these two algorithms can show the contour of the segmented image. However, this algorithm has certain advantages in anti-noise and time. Experimental results show that Seagull algorithm can not only obtain the equivalent segmentation results of two-dimensional otsu algorithm, but also has shorter operation time. Therefore, applying Seagull algorithm to image segmentation can effectively improve the optimization ability and shorten the running time. In image segmentation, this algorithm has better practical value.

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