Image Segmentation Method with Maximum Entropy Optimized by Wolf Pack Algorithm

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Abstract. In order to improve the accuracy and efficiency of image segmentation, the wolf pack algorithm is introduced into the maximum entropy image segmentation method. The wolf pack algorithm is applied to the calculation of the maximum entropy threshold, and the image segmentation is realized by finding the optimal threshold. Simulation results show that this method can quickly and accurately find the segmentation threshold, obtain better segmentation accuracy, and improve the image segmentation effect to a certain extent.

Keywords: Image segmentation, Maximum entropy, Wolves algorithm, Threshold selection.

1. Introduction
Image segmentation is an important image technology, which is the basis of image processing and image recognition. Image segmentation has been widely used in practice, such as satellite images, medical images, facial recognition, military and agricultural engineering, etc. Image segmentation is to extract meaningful features from an image, so as to obtain interesting objects. There are many kinds of image segmentation algorithms, among which the classical algorithms are edge-based image segmentation, such as sobel operator, roberts operator, prewitt, Laplace and canny. Region-based segmentation methods include traditional algorithm combined with genetic algorithm, region growing algorithm, region splitting and merging algorithm, watershed algorithm, and graph-based segmentation algorithm.

As a new optimization method, swarm intelligence optimization algorithm is widely used in various fields because of its simplicity and effectiveness. Swarm intelligence optimization algorithm uses swarm intelligence to search cooperatively, so as to find the optimal solution in the solution space. By simulating the foraging behavior of insects or animals in nature, these groups search for food in a cooperative way, communicate with each other constantly, and find more food faster. Commonly used swarm intelligence algorithms include ant colony algorithm, particle swarm optimization algorithm, flora optimization algorithm, frog leaping algorithm, firefly algorithm, cuckoo algorithm, wolf pack algorithm and so on. In order to improve the image segmentation effect, this paper proposes an image segmentation method based on maximum entropy optimized by wolf pack algorithm. Firstly, the threshold objective function of the maximum entropy method is calculated, then the wolf pack algorithm is used to calculate the objective function, and the optimal segmentation threshold of the image is obtained. Finally, the image is segmented according to the threshold.
2. Related Theory

2.1. Maximum entropy method
Information entropy refers to the value of information in information dissemination. The higher the probability of information appearing, the wider it spreads. Mathematically, it is described as the occurrence probability of certain information. The calculation formula of system information entropy is that the probability of each event in the system is multiplied by the log probability, and then all the events are added up to take a negative number.

Image information entropy is the average amount of information contained in an image. The larger the entropy, the more uniform the interior of the image, and the threshold corresponding to the maximum entropy of the image is the threshold of image segmentation. Two-dimensional entropy of an image is a feature binary composed of gray distribution feature information and neighborhood gray mean.

Let \((i, j)\) represent a binary group, where \(i\) represents the gray value of the pixel and \(j\) represents the neighborhood gray average. \(f(i, j)\) is the frequency of occurrence of binary \((i, j)\), and there are:

\[
p_{ij} = f(i, j)/N^2
\]

\(p_{ij}\) is the pixel with gray level \(i\) and the proportion of neighborhood

\[
H = - \sum_i \sum_j p_{ij} \log p_{ij}
\]

\(H\) is the information entropy of the image

The threshold \(q(0 <= q < L-1)\) is used to divide the image into background \(C_0\) and target object \(C_1\).

The estimated probability density function can be expressed as:

\[
\begin{align*}
&C0: \left(\frac{p(0)}{P_0(q)}, \frac{p(1)}{P_0(q)}, \frac{p(2)}{P_0(q)}, \ldots, \frac{p(q)}{P_0(q)}, 0, \ldots, 0\right) \\
&C1: \left(0, \ldots, 0, \frac{p(q+1)}{P_1(q)}, \frac{p(q+2)}{P_1(q)}, \ldots, \frac{p(L-1)}{P_1(q)}\right)
\end{align*}
\]

Among them \(P_0(q) = \sum_{i=q}^q p(i) = P(q)\) and \(P_1(q) = \sum_{i=q+1}^{L-1} p(i) = 1 - P(q)\).

\(P_0(q)\) and \(P_1(q)\) represent the cumulative probability of pixels in the area corresponding to background \(C_0\) and target object \(C_1\).

The entropy corresponding to the image background and target is:

\[
\begin{align*}
H_0(q) &= - \sum_{i=0}^{q-1} \frac{p(i)}{P_0(q)} \log \frac{p(i)}{P_0(q)} \\
H_1(q) &= - \sum_{i=q+1}^{L-1} \frac{p(i)}{P_1(q)} \log \frac{p(i)}{P_1(q)}
\end{align*}
\]

Total entropy of image is: \(H(q) = H_0(q) + H_1(q)\).

Calculate the total entropy of the image under each threshold, and find the maximum entropy, which is the image segmentation threshold. Using exhaustive method to calculate the image entropy for each threshold is heavy and time-consuming. Therefore, this paper proposes to use wolf pack algorithm to solve the best threshold by using maximum entropy method.

2.2. Wolves algorithm
There are many kinds of wolf pack algorithms. It was first proposed by Liu et al. in 2011, which simulates the behavior of wolves in nature and abstracts the wolf pack activities into three intelligent behaviors: search, siege and update. In 2013, Wu Husheng and others graded wolves based on three
kinds of intelligent behaviors and proposed a new algorithm for wolves. In this paper, the algorithm proposed by Wu Husheng and others is adopted. The wolf pack algorithm mainly has two criteria and three intelligent behaviors. Two of them are "the winner is king" and "the strong survive". The three behaviors are wolf hunting, wolf summoning and fierce wolf siege.

In the algorithm, wolves are divided into three categories according to their grades:

Head Wolf: The most intelligent and fierce wolf among wolves is the leader of wolves. The role of the head wolf is to lead the wolves to develop in a more robust direction. The internal competition of the wolves makes the head wolf constantly updated, and the head wolf is always the strongest wolf among the wolves. The wolf does not perform the three behaviors until the wolf is replaced by other stronger wolves. In image segmentation, the wolf is the pixel with the best fitness function.

Wolf detection: when wolves are looking for prey, instead of moving out as a whole, they choose stronger wolves except the head wolf to wander, and the wolf detection searches in the direction with better function value until the head wolf is updated or reaches the maximum iteration times.

Fierce Wolf: After the wolf is summoned, the fierce wolf will approach the wolf with a larger step size. During the attack, if the objective function value of the fierce wolf is found to be greater than that of the wolf, the position of the wolf will be updated; otherwise, the fierce wolf will continue to attack until it enters the siege range.

In addition, after catching prey, wolves are not evenly distributed, but distributed from strong to weak, that is, first distributed to the first wolf to catch prey, and then distributed to the weak wolf.

Several rules of wolf pack algorithm:

(1) Rules of wolf production

In the initial solution space, the artificial wolf with the best objective function value is the head wolf; In the iterative process, after each iteration, the objective function of the optimal wolf is compared with the position of the head wolf in the previous iteration. If it is better, the head wolf position is updated. If there are multiple identical solutions, one solution is randomly selected as the head wolf position. The wolf does not perform the three behaviors, and directly enters the iteration until the wolf is replaced by other wolves.

(2) Wandering behavior

\[ s \_sum \] artificial wolves (except the head wolf) with the best objective function value are selected as the wolf detection, \[ s \_sum \] is a random integer between \[ n / (\alpha + 1), n / \alpha \], and \[ \alpha \] is the wolf detection scale factor. Record the objective function value of the current wolf detection, and then the wolf detection travels in \( h \) directions (the walking step is \( step_h \)), and the position of the wolf detection in the \( p \) direction is:

\[ x'_i = x_i + \sin(2\pi * \frac{P}{h}) * step_h \]

Calculate the function value of the wolf in each direction, select the direction with the largest function value and greater than the current function value, update the transition state of the wolf, and repeat the wandering behavior until the maximum number of wandering times is reached or the function value of a certain wolf is greater than that of the head wolf, then send out the summoning behavior instead of the head wolf and update the position of the head wolf.

(3) Summon behavior

The wolf sends out a summoning behavior, and the fierce wolf (individual wolf except the wolf and the scout wolf) approaches the wolf position with a larger attack step \( step_h \). At the \( i \)-th iteration of Ferocious Wolf, its position is:

\[ x_i(k+1) = x_i(k) + step_h * (g_k - x_i(k))/|g_k - x_i(k)| \]

\( g_k \) is the position of the \( k \)th wolf, and \( x_i(k) \) represents the current position of the artificial wolf.

During the attack, if the fierce wolf is better than the head wolf, the fierce wolf replaces the head wolf and gives a calling behavior. Otherwise, the fierce wolf continues to attack until the distance from the wolf is less than the siege distance, which is converted into the siege behavior.
(4) Siege behavior
When the fierce wolf is close to the head wolf, it will jointly explore the wolf into siege and capture it. If the objective function value of the artificial wolf is better than that of the head wolf in the siege process, the summoning behavior will be issued instead of the head wolf. Otherwise, the position of the artificial wolf remains unchanged. For the \( k \) generation wolves, the prey position is \( G_k \), and the siege behavior formula is:

\[
x_i(k + 1) = x_i(k) + \lambda * step_c * |G_k - x_i(k)|
\]

In the formula, \( \lambda \) is a random number uniformly distributed in the interval of \([0,1]\). \( step_c \) is the attack step size.

3. Maximum Entropy Method based on Wolf Pack Algorithm
(1) Algorithm initialization. Initialize wolf pack size, spatial dimension, maximum iteration times, wolf exploration scale factor, update scale factor, distance determination factor, step size factor, search range, wandering step size, attack step size, siege step size, siege distance, exploration direction, etc.
(2) Initialize the position of wolves, and arrange them in descending order of fitness function, with the first wolf.
(3) Calculate the number of wolf scouts according to the wolf scout scale factor.
(4) The wolf began to swim. In the process of traveling in the direction of H, among the \((h+1)\) objective functions, select the direction with the largest objective function value and greater than the current objective function. If the current objective function value of wolf detection is greater than that of wolf, update the information of wolf and call out. If it is not found, the wolf will continue to swim until the maximum number of trips is reached, and the wolf will summon at its original position.
(5) When the fierce wolf hears the call of the wolf, he approaches the wolf quickly with the attack step. If the attack is in progress, if the objective function value of the fierce wolf is greater than that of the head wolf, it will call instead of the head wolf and exit the current cycle. Otherwise, continue to attack until the siege distance is reached.
(6) After reaching the siege distance, the fierce wolf and the scout wolf round up the prey (the head wolf is regarded as the prey) according to the siege step. If the function value of the artificial wolf is greater than that of the head wolf during the round-up, the position of the head wolf is updated until the prey is captured.
(7) Reorder the objective function values in wolves, update wolves, and randomly generate new artificial wolves to replace wolves with smaller objective function values.
(8) Judging whether the objective function value meets the end condition or whether the algorithm reaches the maximum number of times, if yes, ending, and calculating the optimal threshold. Repeated execution is not satisfied until the conditions are met.
(9) According to the threshold value.

4. Experiment and Analysis
In order to verify the improvement of wolves algorithm on the selection of maximum entropy threshold, two images are tested in this paper, and the segmentation results are shown in Figure 1. The wolf pack size is 20, the spatial dimension is 2, the maximum number of iterations is 500, the maximum number of walks is 20, the wolf detection scale factor is 4, the update scale factor is 6, the distance determination factor is 600, the search range is \([1, 256]\), and the step factor is 1000. The walking step is the search range divided by the step factor, the attacking step is twice as long as the walking step, the siege step is half as long as the walking step, and the exploring direction of wolf exploration is 10. The wolf pack algorithm is used for 100 repeated experiments on the image, and the number of times that the optimized maximum entropy of the wolf pack algorithm and the basic maximum entropy method get the same results is counted. The test results are shown in Table 1.
Table 1. Experimental results.

| Image | Maximum entropy method | Maximum entropy optimization by wolf pack algorithm |
|-------|-------------------------|---------------------------------------------------|
|       | Frequency | Threshold | Frequency | Threshold |
| 1     | 256       | 126       | 100       | 100       |
| 2     | 256       | 90        | 100       | 99        |

The basic maximum entropy method in the table uses the exhaustive method to calculate the maximum entropy of each threshold. Each experiment needs to calculate the threshold 256 times, and the optimal value of each image is obtained 126 times and 90 times respectively. However, the algorithm in this paper only needs 100 threshold attempts to get the optimal value in each experiment, and every image gets the optimal threshold value 100 times and 99 times respectively. Therefore, the wolf pack algorithm can effectively improve the basic maximum entropy method and has stability.

Figure 1. Segmentation effect.

5. Summary
In view of the disadvantages of the basic maximum entropy method, such as heavy computational workload and long segmentation time, an image segmentation method based on wolves algorithm to optimize maximum entropy is proposed. The basic idea is to calculate the objective function obtained by the maximum entropy method with the wolf pack algorithm, optimize the objective function to obtain the optimal threshold, and finally segment the image with the optimal threshold. Experimental results show that the wolf pack algorithm, as a global search method, can improve the speed and execution efficiency of image segmentation by introducing it into the threshold selection of the maximum entropy objective function, and has good robustness, so it has great application potential in the field of image processing.
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