Grid-search wolf pack optimization algorithm for two-dimensional OTSU image segmentation

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Abstract. Compared with One-Dimensional OTSU, Two-Dimensional OTSU includes the relationship about the pixels of the image and improves the anti-noise ability of the algorithm. However, as a result of too much computation caused by considering the relationship about pixels of the image to be processed, Two-Dimensional OTSU always takes much time. To keep the good performance of original Two-Dimensional OTSU as well as reduce the time spent; this paper proposes Grid-Search Wolf Pack Optimization Algorithm (GSWA) for Two-Dimensional OTSU Image Segmentation. Firstly, it is based on the thought of adaptive shrinking grid search chaos wolf optimization algorithm with adaptive standard-deviation updating amount (ASGS-CWOA) that traditional wolf pack optimization algorithm was improved to enhance its performance, which includes Grid Search and Opposite-Middle Raid(OMR). Grid Search can enhance the wolf pack's summon and siege capability. Moreover, discrete step-size was adopted to adapt to discrete solution space of Image-Segmentation. Experimental results indicate that GSWA-OTSU not only reduces the segmentation time, but also takes the segmentation quality into account.

1. Introduction

Image segmentation is based on some specific similarity criteria, which divides the image into a number of non-overlapping regions with special properties. In the same region, it satisfies certain similarity criteria of texture, grayscale, colour, etc. In different regions, the image characteristics are significantly different. The common methods used in image segmentation are Threshold method [1], watershed [2], multi-scale morphological method [3], fuzzy clustering [4], deep learning-based image segmentation [5] and Bayesian [6,7].

In the paper [9], the authors proposed a new wolf swarm algorithm by Yang and others in 2007.The wolf swarm algorithm has been developed and improved continually, and is also used in many fields, such as: in the paper [10], the authors proposed a method for the chaotic systems. In the paper [11], the authors proposed a method for path planning. In order to solve a problem in mathematical field, the authors of paper [12] proposed a method. In the paper [13], the authors proposed a new method that adds a radius and a parameter to the old method. In order to increase the ability of hunting, the authors of paper [14] proposed a method that the action of the wolves is obeying the command of the leader wolf. In order to solve the electrical problem, Gupta and Saurabh [15] proposed a method. For the purpose of solving the global optimization problems, Jitkongchuen et al. [16] proposed a method. A new wolf pack algorithm to solve problems was proposed in paper [17] by Saurabh and Gupta. Yao et al. [18] proposed a new wolf pack algorithm which is applied to solve the uncertain bi-level knapsack problem.

Summarizing the research results of predecessors, especially the paper [19], this paper proposes a grid search wolf optimization algorithm. This paper uses this improved wolf group algorithm combined with two-dimensional OTSU algorithm. This algorithm not only can ensure the quality of image segmentation, but also can make the running time shorter.

2. Related works

2.1. OTSU

OTSU method is an important threshold method [8] which proposed by Scholar OTSU in 1979. OTSU threshold method is an automatic, nonparametric, unsupervised threshold selection method, which is based on discriminant measure criterion. When the discriminant measure criterion gets maximum, we get the best threshold. OTSU is global threshold selection method which widely used due to its high efficiency and simplicity.

One-dimensional OTSU is a simple method, which requires a grey level histogram. However, the histogram can't show obvious troughs and peaks in practical applications because of the noises and other factors. So One-Dimensional OTSU doesn't achieve good segmentation effect.

2.2. Two-dimensional OTSU

Since one-dimensional OTSU did not achieve perfect segmentation, two-dimensional OTSU method was proposed. The main method of the two-dimensional OTSU algorithm is to apply the pixel gray value and the average gray value of the pixel neighbourhood. The two-dimensional histogram containing the gray level of the pixel and its neighbourhood mean is designed, and the optimal threshold is obtained by the two-dimensional histogram to realize the automatic threshold selection.

2.3. Wolf Pack algorithm

*2.3.1. Original wolf pack algorithm.*Inspired by the group intelligence algorithm, the wolf group algorithm appeared. The specific process of original wolf group algorithm is: predatory wolf send several wolves to search for prey, wolves continue to search for prey by smell; then, when the prey is discovered, the wolf closes to the prey as soon as possible and summons companion through howling to lurk the prey in all directions; next, when the time is proper, the wolves catch the prey; in addition, the prey is distributed to the wolves according to their contribution, and the weak wolf will be eliminated.

2.3.2. ASGS-CWOA. In the paper [14], the authors proposed a new wolf pack algorithm which named Leader wolf algorithm. When the wolf pack prepares to get food, the wolves which have the better ability of siege will compete to be the leader wolf. The wolves of the pack except the leader wolf will obey the rules which made by the leader wolf. This system is good to the survival of the wolf pack in the harsh environment.

The COWA is proposed which originated from Leader wolf algorithm. The improvements of the COWA are as follows:

First, the chaos optimization is introduced to the algorithm. The equation of logistic map is following, which is from [20].

$$Chaos_{k+1} = \mu * Chaos_k * \left(1 - Chaos_k\right) \qquad Chaos_k \in [0,1] \tag{1}$$

Second, a new search which includes migration step size and siege step size is introduced to the algorithm. The new search step size is adaptive variable. For the step size of siege, CWOA adopts an adaptive adjustment factor α into the improved equation following.

$$step\_a_{new} = \alpha * step\_a_0 \ , \alpha = 1 - \left(\frac{t-1}{T}\right)^2 \tag{2}$$

And the latter is about the step size of siege. The equation is following.

$$step\_c_{new} = step\_c_0 * rand(0,1) * \left[1 - \left(\frac{t-1}{t}\right)^2\right] \tag{3}$$

In the paper [19], the ASGS-COWA is proposed which originated from COWA.

The new ideas of the algorithm are as follows:

The first of the innovations is ASGS. In the migration of the wolf pack, the wolf can choose any directions for its step. In the LWPS and CWOA, the wolf only chooses a direction in the H dimensions, and a point is generated. If the wolf chooses a better direction, the algorithm convergence speed will be increased. As shown in figure 1 and figure 2, there are (2*k+1) points generated in H dimensions, which reflect the neighbourhood range of the current position. The each point of the grid is got by the following equation:

$$[k, x_{ih-new}] = x_{ih} + step\_a_{new} * k (k = -K, -K+1, ..., 0, ..., K-1, K; i = 1, 2, ..., Q; h = 1, 2, ..., H) \quad (4)$$

So a point from the grid can be got by the following equation:

$$x_{i-new} = \{[k, x_{i1-new}], [k, x_{i2-new}], ..., [k, x_{iH-new}]\} (i = 1, 2, ..., Q; k = -K, -K+1, ..., 0, ..., K-1, K) \quad (5)$$

There are $(2*K+1)^H$ points produced in the grid during any migration which will be new position of the searching wolf, and the position with best fitness will be chosen as the leader wolf's position. As the step_anew become smaller, the searching grid becomes smaller and smaller. Grid search which has $(2*K+1)^H$ points is better than an isolated point in each iteration. This means is good to find the optimal threshold in the local neighbourhood which includes $(2*K+1)^H$ points.

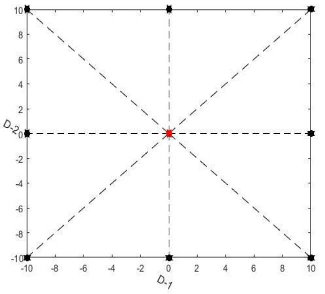

Figure 1. Locations of searching wolves (dimension=2)

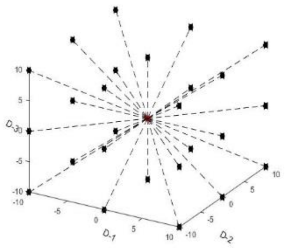

Figure 2. Locations of searching wolves (dimension=3)

Figure 1 shows the range of locations of searching wolves in ASGS-CWOA when dimension is 2 [19]; Figure 2 shows the range of locations of searching or competing wolves in ASGS-CWOA when dimension is 3, where step_a = 10 or step_c = 10 and K = 1 [19].

This strategy is also introduced into the process of siege. But the different is that the siege step size is shorter than the migration step size. In the end, the wolf with the best fitness will be chose of the neighbourhood range points.

The second of the innovations is OMR. When the leader wolf send the signal of summon, the other wolves try to close to the leader wolf as soon as possible and find the preys on the way. The OMR is about the opposite position of the current position relative to the leader wolf. Its position is calculated by the following equation:

$$X_{id-opposition} = 2 * X_{1d} - X_{id} \quad (i = 1, 2, ..., Q; d = 1, 2, ..., D) \quad (6)$$

To get the better position, we can change the current position to the opposite position based upon the fitness of opposite position is better than the fitness of the current position. If the wolves don't get the better position, the wolves except the leader wolf get the new position by the following equation.

$$\begin{aligned}&X_{i-m\_d}=(X_{i\_d}+X_{1\_d})/2,\\&X_i=Bestfitness([X_{i\_1},X_{i\_2},...X_{i\_(D-1)},X_{i\_D}],[X_{i\_1},X_{i\_2},...X_{i\_(D-1)},X_{i-m\_D}],...[X_{i-m\_1},X_{i-m\_2},\\&...X_{i-m\_(D-1)},X_{i-m\_D}])\\&(i=1,2,...Q;d=1,2,...D)\end{aligned} \tag{7}$$

3. OTSU based on grid search wolf pack algorithm

3.1. Improvement of traditional wolf pack optimization algorithm

In the algorithm ASGS-COWA, the Adaptive Shrinking Grid Search (ASGS) is proposed. In the process of migration and siege, the step size is getting smaller and smaller, and the step size may become decimal. This method is suitable for solving complicate problems. When we solve the problem of image segmentation, the gray level is from1 to 256, and there is no decimal case, so we don't need to use the adaptive variable step size strategy to generate the gird.

Based on the aforementioned thoughts of grid search, the GSWA is proposed. In the migration of the wolf pack, the wolf can choose any directions for its step. As shown in figure 1 and figure 2,there are (2*k+1) points generated in H dimensions, which reflect the neighbourhood range of the current position, where K represents the number of points taken in the same direction of each dimension. The each point of the grid is got by the following equation:

$$[k,x_{ih-new}]=x_{ih}+step\_a*k(k=-K,-K+1,...,0,...,K-1,K;i=1,2,...,Q;h=1,2,...,H) \tag{8}$$

So a point from the grid can be got by Eq.(5).

During the process of any migration, the position with best fitness from the grid including $(2*K+1)^H$ points will be selected as new position of the searching wolf, and at the end of the migration, the wolf with best fitness will be successful to compete to be the leader wolf of the wolf pack.

There are $(2*K+1)^H$ points generated in the grid during any migration which will be new position of the searching wolf, and the position with best fitness will be selected as the leader wolf's position. The searching grid will not be smaller because the step_a is the same. The process of migration is also used the gird search strategy.

3.2. Steps of GSWA-OTSU

The steps of the GSWA algorithm are as follows:

A. Initialization of population

Set parameters: N, D, range_min, range_max, T, step_a, step_b, step_c.

N is the total number of wolf pack, D is the dimension of solution space, [range_min ,range_max] is the ranges of solution space , T is the maximum number of iterations, step_a is the initial step size for migration, step_b is the initial step size for summons, step_c is the initial step size for siege. And the N wolves are generated by Eq.(9).

$$x_{id}=range\_\min+rand(0,1)*(range\_\max-range\_\min)\ (i=1,2,...,N;d=1,2,...,D) \tag{9}$$

Where, rand (0, 1) is a random number distributed uniformly in the interval [0, 1]; x_{max} and x_{min} are the upper and lower bounds of the search space respectively.

B. Migration

In order to show the neighbourhood space of the current position, a grid with H dimensions which has $(2*K+1)^H$ points gets by Eq.(5).In the end, the position with best fitness will be selected as the leader wolf's position.

C. Summon

When the leader wolf send the signal of summon, the other wolves try to close to the leader wolf as soon as possible and find the preys on the way. In this process, we can use the innovation OMR of the

ASGS-COWA.

D. Siege

The wolves except the leader wolf wait for opportunities to move where the prey can't see. Select the middle point of the current wolf position and the best wolf position is got by the following equation:

$$x_{i-m\_d} = (x_{i\_d} + x_{1\_d})/2 \tag{10}$$

Based on the middle point, the GSWA was used to generate a grid with H dimensions by Eq. (5).

Comparing the fitness of the opposite position and the fitness of the current position, we can get the better position of the current position in the grid. Comparing the fitness of the best position and the fitness of the current position, we can get the better position of the current position in the grid.

The wolf with best fitness will be chosen as the leader wolf at the end of each siege.

E. Regeneration

Following the wolf's survival rules, the food will be distributed according to the wolf's hunting ability, and the wolves with weak hunting ability will be eliminated. The same amount of wolves should be generated along with the weaker wolves has been removed.

F. Loop

The iteration won't stop until the exit condition is ok. Go to B if the exit condition is not ok. Once the loop stops, the global optimal value is found through the best fitness.

3.3. Steps of GSWA-OTSU

Convert an image to M*N points. The gray level is L. The gray level of the neighbourhood smooth image G(X,Y) is also L, and the value of each pixel i in the image and the neighbourhood average gray value j are calculated to form a binary group (i, j).

The steps of the GSWA-OTSU algorithm are described below.

A. Initialization of population

Set parameters: N, D=2, range_min=1, range_max=256, T, step_a, step_b, step_c.

N is the total number of wolf pack, D is the dimension of solution space, [range_min ,range_max] is the ranges of solution space , T is the maximum number of iterations, step_a is the initial step size for migration, step_b is the initial step size for summons, step_c is the initial step size for siege. And the N wolves are produced by Eq.(9).

B. Migration

In order to show the neighbourhood space of the current position, a grid with H dimensions which has $(2*K+1)^H$ points gets by Eq.(5). In the end, the position with best fitness will be selected as the leader wolf's position.

C. Summon

When the leader wolf send the signal of summon, the other wolves try to close to the leader wolf as soon as possible and find the preys on the way. In this process, we can use the innovation OMR of the ASGS-COWA.

D. Siege

The wolves except the leader wolf wait for opportunities to move where the prey can't see. Choose the middle point of the current wolf position and the best wolf position is got by Eq.(10).Based on the middle point, the GSWA was used to generate a grid with H dimensions by Eq.(5).

If the fitness of the best position which in the grid is better than the best wolf position, change the best wolf position to the best position in the grid. If the fitness of the best position which in the grid is better than the current position, change the current position to the best position in the grid.

The wolf with best fitness will be chosen as the leader wolf at the end of each siege.

E. Regeneration

Following the wolf's survival rules, the food will be distributed according to the wolf's hunting ability, and the wolves with weak hunting ability will be eliminated. The same amount of wolves should be generated along with the weaker wolves has been removed.

F. Loop

The iteration won't stop until the exit condition is ok. Go to B if the exit condition is not ok. Once the loop stops, the global optimal value is found through the best fitness.

G. Calculate the segmentation threshold

According to the position of the best wolf, the best segmentation threshold is got by equation:

$$Threshold = (bestwolf(i) + bestwolf(j))/2 \quad (i = 1, j = 2) \tag{11}$$

4. Experimental and experimental analysis

As shown below, the two pictures are the experimental objects.

Figure 3. Female picture.

Figure 4. Elephant picture.

In order to make the results of the GSWA-OTSU algorithm more convincing, one-dimensional OTSU and two-dimensional OTSU image segmentation algorithm are selected for comparison experiments under the same conditions.

(a) (b) (c) (d)

Figure 5. (a) shows the original grey female picture; (b) shows the picture which processed by one-dimensional OTSU; (c) shows the picture which processed by two-dimensional OTSU; (d) shows the picture which processed by GSWA- OTSU.

It can be seen from the comparison of various algorithms in the above figures that the two-dimensional OTSU algorithm is clearer than the one-dimensional OTSU algorithm because of the addition of the neighbourhood average grey value. The upper left and upper right corners of the figure 5(c) are more clearly contoured, and the female's hair is handled more clearly. It can be seen from the figure6(c) that the outlines of swamps and elephants are handled more clearly.

(a) (b) (c) (d)

Figure 6. (a) shows the original grey elephant picture; (b) shows the picture which processed by one-dimensional OTSU;(c) shows the picture which processed by two-dimensional OTSU; (d) shows the picture which processed by GSWA- OTSU.

Comparing the figure 5(c) and figure 5(d), figure 6(c) and figure 6(d), we can see that the GSWA-OTSU algorithm has no significant difference in image segmentation quality from the traditional two-dimensional OTSU method.

5. Results and Discussion

From table 1, we can see the running time of the one-dimensional OTSU, two-dimensional OTSU and GSWA-OTSU. The unit is seconds. Comparing the running efficiency of the algorithm, the average time of the one-dimensional OTSU segmentation algorithm is about 0.0002-0.0009 seconds, the average running time of the two-dimensional OTSU algorithm is about 43.1-44.1 seconds, and the algorithm of this paper is about 13.8-18.7 seconds. The GSWA-OTSU algorithm takes about 32% of the time of the traditional two-dimensional OTSU method, and the running time is greatly reduced. The image segmentation quality of the two two-dimensional OTSU algorithms has no obvious difference. When the female image and the elephant image are segmented, the outlines of the female and the elephant are better extracted. Although the one-dimensional OTSU algorithm takes less time, its image segmentation quality is poor. Under the premise of efficiency and quality, the GSWA-OTSU algorithm proposed in this paper is an ideal segmentation method.

Table 1. Running time of the three methods

method time	One-dimensional OTSU	Two-dimensional OTSU	GSWA-OTSU
Female image	0.00092	44.1363	13.791395
Elephant image	0.00021	43.0967	18.73625

Although GSWA-OTSU algorithm performs well in terms of time, this algorithm is not good enough in some aspects. For example， the segmentation quality still needs to be improved. If the segmentation edge is clearer, it is good for the follow-up work.

6. Conclusion

This paper proposes an improved two-dimensional OTSU segmentation method, which greatly improves the segmentation speed compared to the traditional two-dimensional OTSU segmentation method. It’s core procedure are initialization the wolf group in the image pixel area, migration, summon, capture the prey, hand out the food and update the wolf pack. The optimal two-dimensional segmentation threshold of the grey image is finally got by the fitness function.

Experiments show that compared with the one-dimensional OTSU algorithm and the traditional two-dimensional OTSU algorithm, the GSWA-OTSU algorithm takes the image segmentation quality and segmentation speed into account. The outlines of the segmented images are more clearly. This segmentation method lays a good foundation for the follow-up work. And, the proposed GSWA-OTSU segmentation method is an effective image segmentation method.

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