Color Image Segmentation using Multilevel thresholding-Cooperative Bacterial Foraging Algorithm

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Abstract—Multilevel thresholding is of great importance in the fields of image segmentation techniques. This paper proposes multilevel thresholding for color image segmentation using cooperative bacterial foraging algorithm (CBFA), which combined bacterial chemotaxis, cell-to-cell communication, and an adaptive foraging mechanism to extend original bacterial foraging algorithm. The superiority of the proposed algorithm can reach a higher quality adequate segmentation and reduce the CPU processing time, which is demonstrated by comparing with other algorithm.

Keywords—Color image segmentation; Bacterial Foraging Algorithm (BFA); Cooperative Bacterial Foraging Algorithm (CBFA)

I. INTRODUCTION

Color image segmentation is one of the most important basic steps for images analysis and acquired, which can determine the quality of the final result in image processing. Color images contain luminance, hue, saturation, etc, and which have more information than gray images. There are many different types for image segmentation, such as clustering, texture analysis, region based split and merging and histogram thresholding, etc. In all of them, the thresholding method is widely used for the segmentation of images due to its simplicity, accuracy and robustness. The key of the thresholding method is efficiently selecting the optimal thresholding to group pixels within meaningful regions, where each pixel share visual characteristics in the color image. Usually, the recursive programming techniques are developed to reduce the order of magnitude of computing the multilevel thresholds and further the Nature Inspired Algorithm is used to minimize the cross entropy[1].

In this paper, the novel cooperative bacterial foraging algorithm (CBFA) is applied to find the optimal threshold values by applying two enhanced manipulated steps, namely a cell-to-cell communication and a self-adaptive foraging strategy, which is extended by the classical BFA algorithm.

The proposed method which is tested that the Multi-level thresholding method based on Cooperative Bacterial Foraging Algorithm cooperative bacterial foraging algorithm (CBFA) for color image segmentation is considered as an optimization problem is more stable and can execute faster than the other evolutionary algorithms[2].

II. COLOR IMAGE SEGMENTATION

A. The conversion of color space

The color image is characterized in three primary color components included red, green and blue or in all their possible combinations.

In order to eliminate the high correlation among the R, G, and B components of the color image, this can be converted to HSV spaces, which represent hue, saturation, and value. HSV spaces describe the color natural and intuitive, where H represents different colors, S represents the color shades, and V represents lightness or darkness. The conversion formula of RGB and HSV is shown in Eq. (1):

\[
S = 1 - \frac{3}{R + B + G} \left[ \min(R, G, B) \right]
\]

\[
H = \cos^{-1} \left( \frac{(R - G) + (R - B)}{2 \sqrt{(R - G) + (R - B) + (G - B)}} \right)
\]

\[
R = 0 \text{ or } R > G, \quad G > B > G, \quad H = (2\pi - H)
\]

\[
V = \frac{R + B + G}{3}
\]

B. Multi-level thresholding for image segmentation

The segmentation process is considered as an optimization problem, in the same time, treating the optimal multilevel thresholding problem as an n-dimensional optimization problem and determining n optimal thresholds for the given image, where the aim is to maximize the objective function[3]. So the problem of n-level thresholding is reduced to an optimization problem to search for the thresholds t_i. In order to obtain proper segmentation, multiple threshold values should be selected which can be configured as multi-level optimization problem [4].
There are multiple objects or even specific features in the given image, the pixels of it would be divided into n classes. Assuming \( t_i \) to generic n-level thresholding (j=1…n-1). The optimal threshold is regarded as the objective function and the variance which is maximized is generally using Eq. (2):

\[
\sigma_B^2 = \sum_{j=1}^{n-1} W_j (\mu_j - \mu_T)^2
\]  
(2)

Where a specific class is represented by j in such a way, the probability of occurrence and mean of class j are assumed as \( w_j \) and \( \mu_j \), which can be defined as Eq. (3)

\[
w_j = \sum_{i=t_{j-1}+1}^{t_j} p_i, \mu_j = \sum_{i=t_{j-1}+1}^{t_j} \frac{i p_i}{w_j}, (1 < j < n)
\]  
(3)

The purpose is obtained the maximization of the objective functions using Eq. (4):

\[
\phi^* = \max \sigma_B^2(t_i)
\]  
(4)

In order to elevate the stability of the algorithm, the standard deviation can be evaluated by the standard deviation, which is defined as Eq. (5):

\[
STD = \sqrt{\frac{\sum_{i=1}^{n} (\sigma_i - \mu)^2}{N}}
\]  
(5)

Assuming \( \sigma_i \) as the best fitness value of the ith run of the algorithm, \( \mu \) as the average value of \( \sigma_i \), and N as the repeated times of each algorithm [5][9].

Using the proposed approach to each component of a color space of the given image, and then the final segmentation results should be obtained by the Combination of the results in some way.

III. MODIFIED BACTERIAL FORAGING ALGORITHM

A. The traditional bacterial foraging algorithm (BFA)

There are four actions in the traditional bacterial foraging algorithm (BFA), including chemo taxis, swarming, reproduction and elimination-dispersal[6].

a) Chemotaxis

This process is the first step, swimming and tumbling via flagella can be achieved. The rotation of flagella of each bacterium decides whether it should move in a predefined direction (swimming) or altogether in different directions (tumbling) in the entire lifetime.

b) Swarming

During this process of reaching toward the best food location, swarming is the optimum path that the bacterium searched, and try to produce an attraction signal to other bacteria and congregate into groups, which have concentric patterns of groups with high bacterial density.

c) Reproduction

Reproduction is the process makes the population of bacteria constant that the least healthy bacteria die and the other healthiest bacteria each split into two bacteria in the same location.

d) Elimination and dispersal

Elimination-dispersal is the process that the bacteria in a local region may be killed or a group may be dispersed into a new location in the environment due to some other influence [7].

B. Modified bacterial foraging algorithm

The modified bacterial foraging algorithm constructs the model applying two steps, one is self-adaptive foraging strategy, and the other is cell-to-cell communication[8].

In each chemotactic step, the adaptive chemotactic step-size \( C_i \) controls the swim amplitude taken by the ith bacterium towards a desired direction, which is specified by the cell-to-cell communication based tumble direction \( D_i \):

\[
X_i(t) = X_i(t-1) + C_i(t-1)D_i(t-1)
\]  
(6)

Where \( X_i \) is the position of the ith bacterium, \( t \) is the chemotactic generation counter from 1 to max-generation, \( i \) is the bacterium’s ID counter from 1 to S, \( S \) is the colony size. The parameter values of the adaptive chemotactic step-size \( C_i \) changes using the dynamic adaptive strategy, which is expresses as follows[9]:

\[
C(i) = \frac{J_i(X)}{J_i(X) + \alpha}
\]  
(7)

Where \( J_i(X) \) is the fitness function value of the ith bacterium, \( \alpha \) is a user-defined positive constant. \( D_i \) is an additional direction component to each bacterium. Then in the modified model, at the tth iteration the direction is computed as:

\[
D_i(t) = kD_i(t-1) + \phi_1R_1X_{pi} - X_i(t-1) + \phi_2R_2X_{gi} - X_i(t-1)
\]  
(8)

Where \( k \) is the weight for the previous direction of the ith bacterium, which represents how the bacterium trusts its own status at present location, \( X_{pi} \) is the best position where this bacterium had been, \( X_{gi} \) is the overall global best position ever achieved by the bacterial colony, \( \phi_1 \) and \( \phi_2 \) are the learning rates that control the influence levels of cognitive and social components to make different swimming directions, \( R_1 \) and \( R_2 \) are random numbers uniformly distributed in \([0, 1]\).

In this Modified bacterial foraging algorithm, each bacterium adjusts its tumble angle according to the personal historical experience and the bacterial colony social knowledge. This cell-to-cell communication based cooperation may provide bacteria with more accurate information about the search because it is the whole colony that engaged in searching the solution space not just the single bacterium.
IV. COLOR IMAGE SEGMENTATION ALGORITHM BASED ON MULTILEVEL THRESHOLDING-CBFA

The proposed approach can be directly applied to each component of a color space, and then the results can be combined in some way to obtain the final segmentation results.

1. Processing Phase for vector image

The segmentation procedure can be summarized by the following steps in Table I.

| TABLE I. THE SEGMENTATION PROCEDURE |
|-------------------------------------|
| 1. Input the parameters of CBFA, set the boundaries of the threshold values. |
| 2. Set the positions of the threshold values randomly for a population of bacteria. |
| 3. For each bacterium in the population, evaluate the objective value using Eq. (2). |
| 4. According to Eq. (6), modify the positions of the threshold values for all the bacteria using tumbling/swimming process. |
| 5. Perform reproduction and elimination-dispersal operation. |
| 6. Reach the maximum number of chemotactic, reproduction and elimination-dispersal steps, then go to Step 7. Otherwise, go to Step 4. |
| 7. The Optimal threshold is used for image segmentation. |

The flowchart of CBFA process is given in Fig. 1.

(2) Color image segmentation Phase

The segmentation procedure can be summarized by the following steps in Table II.

| TABLE II. COLOR IMAGE SEGMENTATION PHASE |
|------------------------------------------|
| 1. HSV space can be converted by the RGB image. |
| 2. Get the corresponding segmentation image at the three vectors by using CBFA. |
| 3. Combine the three vector results, and then get the final segmentation image. |

The Algorithm flowchart of color image segmentation is given in Fig. 2. The RGB image is converted to HSV space, so that the relevance of each component should be eliminated through the H, S, V vectors, it can get the corresponding separated image by using the new algorithm based on multi-level thresholding-CBFA, so we can get the result that the three vectors merged into the final image segmentation.

V. EXPERIMENT RESULT

We implement the traditional Bacterial Foraging Algorithm and the Cooperative Bacterial Foraging Algorithm based on multi-level thresholding for color image segmentation in MATLAB.

Two images named “Desert” and “Hydrangeas” are used for conducting our experiments, which are tested to evaluate the performance of the proposed algorithm.

The control parameters that are the number of runs of each algorithm is set to 50, and the number of bacteria is set to 20.

First, we execute the traditional Bacterial Foraging Algorithm and the Cooperative Bacterial Foraging Algorithm on partitioning the two test images. It shows the selected thresholds, computation time and quantitative standard for evaluating in Fig 3 and Fig 4. We tested the other color image named “Hydrangeas” with the same way, the results are shown in Fig 5 and Fig 6. It reveals that the segmentation results of
the conducted experiments show that the proposed method yields adequate segmentations.

Fig. 3. The result of segmentation with 2, 3, 4 thresholds with BFA of ‘Desert’ (a) Original (b) (c) (d) The result of segmentation with 2, 3, 4 thresholds

Fig. 4. The result of segmentation with 2, 3, 4 thresholds with CBFA of ‘Desert’ (a) Original (b) (c) (d) The result of segmentation with 2, 3, 4 thresholds

Fig. 5. The result of segmentation with 2, 3, 4 thresholds with BFA of ‘Hydrangeas’ (a) Original (b) (c) (d) The result of segmentation with 2, 3, 4 thresholds

Fig. 6. The result of segmentation with 2, 3, 4 thresholds with CBFA of ‘Hydrangeas’ (a) Original (b) (c) (d) The result of segmentation with 2, 3, 4 thresholds

From the standard deviation and CPU processing times are brought in Table III and Table IV, we can see the corresponding between the Cooperative Bacterial Foraging Algorithm and the Cooperative Bacterial Foraging Algorithm. The latter method has the least the standard deviation values in comparison, which is the more stable. The Cooperative Bacterial Foraging Algorithm (CBFA) has been proven in the literature to require less CPU processing time for image to find multi-level thresholds in comparison to the former method, especially for higher threshold numbers. The results illustrate that the Cooperative Bacterial Foraging Algorithm is more efficient to solve the problem than the traditional Bacterial Foraging Algorithm, in particular, when we face the problem of the multi-level of segmentation, which can find the better thresholds with more stability in less CPU processing time.

| Test image  | Thresholds | STD of BFA | STD of CBFA |
|-------------|------------|------------|-------------|
| Desert      | 2          | 0.5974     | 0.2912      |
|             | 3          | 1.7732     | 0.3579      |
|             | 4          | 2.1779     | 0.9818      |
| Hydrangeas  | 2          | 0.7824     | 0.5087      |
|             | 3          | 1.2319     | 0.6457      |
|             | 4          | 2.2287     | 1.2887      |

| Test image  | Thresholds | Computational time of BFA | Computational time of CBFA |
|-------------|------------|---------------------------|----------------------------|
| Desert      | 2          | 3.1231                    | 3.0781                     |
|             | 3          | 3.7629                    | 3.3848                     |
|             | 4          | 4.0061                    | 3.5517                     |
| Hydrangeas  | 2          | 3.2549                    | 3.1008                     |
|             | 3          | 3.7129                    | 3.3891                     |
|             | 4          | 4.2021                    | 4.0837                     |
VI. CONCLUSION

In this paper, a novel method for image segmentation based on the Cooperative Bacterial Foraging Algorithm is presented for solving the problem for delineating multilevel threshold values, and which can overcome the disadvantages of the traditional Bacterial Foraging Algorithm. The performance of the proposed algorithm has been tested with various standard test images and compared with traditional Bacterial Foraging Algorithm.

Results shown that the Cooperative Bacterial Foraging Algorithm is better than the other algorithms, not only in terms of solution quality, but also in computation efficiency and stability, specifically when the image segmentation of the multi-level is processed, the novel method for image segmentation based on the Cooperative Bacterial Foraging Algorithm can show better performance to find the better thresholds with more stability in less CPU processing time.

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