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A cooperative honey bee mating algorithm and its application in multi-threshold image segmentation

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ABSTRACT

Multilevel thresholding has been one of the most popular image segmentation techniques; however, most of these techniques are time-consuming. This paper proposes a cooperative honey bee mating-based algorithm for natural scenery image segmentation using multi-level thresholding (CHBMA) to save computation time while conquering the curse of dimensionality. The characteristics of natural scenery images are random, imprecise, complicated, and noisy. The locations of interest points in them are not regular. Our proposed algorithm, which is based on honey bee mating algorithms (HBMA) and cooperative learning, considerably enhances the search capability of the algorithm. In the algorithm, we adopt a new population initialization strategy to make the search more efficient, and this strategy works in accordance with the characteristics of multilevel thresholding in an image; the thresholding is arranged from a low gray level to a high gray level. Extensive experiments have demonstrated that our proposed algorithm can deliver more effective and efficient results than state-of-the-art population-based thresholding methods. Thus, our algorithm can be applied in complex image processing, such as automatic target recognition.

1. Introduction

Image segmentation is an important and basic operation for the analysis of images to separate objects from their background or distinguish an object from objects that have distinct gray levels. For intensity images, there are four popular image segmentation approaches: thresholding techniques, edge-based methods, region-based techniques, and connectivity-preserving relaxation methods [3,32]. Among these four approaches, the image thresholding techniques are widely used in many image processing applications, such as optical character recognition, automatic visual inspection of defects, detection of video changes, moving object segmentation and medical image applications [19], due to their simplicity, robustness and accuracy [23,25].

The image thresholding methods can also be classified generally into parametric and nonparametric approaches. In parametric approaches, the gray-level distribution of each class has a probability density function that is usually assumed to obey a Gaussian distribution. Additionally, there is always a need to find an estimate of the parameters of the

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distribution to fit the given histogram data in parametric approaches [17,31,28]. Hence, such approaches are time-consuming and computationally expensive.

Nonparametric approaches find the thresholds in an optimal manner based on some discriminating criteria such as the between-class variance, entropy, or other features. These criteria are easy to extend to multilevel thresholding. However, the amount of thresholding computation significantly increases with this extension. To overcome this problem, some multilevel thresholding techniques that are based on Intelligent Optimization Algorithms (IOA) have been proposed and proven effective in recent years.

Hammouche et al. [12] proposed a fast multilevel thresholding technique based on GA and a wavelet transform-based technique to reduce the time computation. However, it is less efficient to determine the threshold number automatically. Lai et al. [18] proposed a clustering-based approach using a hierarchical evolutionary algorithm for medical image segmentation. The threshold number in the given image does not need to be known in advance, but is initialized randomly. Ye et al. [29] proposed a particle swarm optimization algorithm (PSO) to optimize Otsu's criterion. The experimental results of this algorithm show that a PSO algorithm can yield very encouraging results in terms of the quality of solutions found and the processing time required, compared with Otsu. Yin [30] first developed a recursive programming technique that stored the results of preceding tries as the basis for the computation of succeeding ones. Then, a PSO algorithm was used for searching the optimal thresholds based on the recursive programming technique. Gao et al. [9] proposed the quantum-behaved PSO by employing a cooperative method to conquer the curse of dimensionality. It also shortens the computation time of the traditional OTSU method and has comparable or even superior search performance for many hard optimization problems, with faster and more stable convergence rates. Tao et al. [27] proposed a fuzzy entropy method incorporating the Ant Colony Optimization algorithm (ACO), which has better search performance than the one based on GA. Bhattacharyya et al. [5] proposed a multilevel method using a self-supervised multilayer self-organizing neural network and a supervised pyramidal neural network. The central idea of the method is to incorporate the contextual image information into the thresholding process. Chen et al. [26] proposed two low-complexity variants of Fuzzy C-means Clustering with spatial constraints for image segmentation by using kernel methods, and the two variants aimed at simplifying the computation of parameters. Gong [11] proposed a fuzzy energy functional based variational image segmentation model with an edge indicator integrated regularization. This method is insensitive to initialization and provides a general scheme for introducing fuzzy logic to region-based partial differential equation approaches. Horng [14] proposed a multilevel thresholding method based on the technology of the Honey Bee Mating Algorithm (HBMA) by using the maximum entropy criterion. The HBMA may also be considered as a typical swarm-based approach for optimization. In this paper, Horng also analyzed the convergence behavior and selected three other methods to be implemented on several real images for comparison. Chander et al. [7] proposed a new variant of PSO for image segmentation, which made a contribution in adapting the 'social' and 'momentum' components of the velocity equation for the particle move updates. The authors also proposed an iterative scheme based on Otsu's method to obtain initial thresholds. This iterative scheme showed a linear growth of computational complexity. Jiang et al. [15,16] proposed an automatic parameter selection technique based on stratified sampling and Tabu Search. This technique can automatically determine the appropriate threshold number and values for image segmentation. Inspired by the balance of competition and diversity in ecology, Gao et al. [10] presented a PSO algorithm with an intermediate disturbance searching strategy (IDPSO), which can enhance the global search ability of particles and increase their convergence rates. The IDPSO algorithm was applied to a multilevel image segmentation problem, and it showed that an IDPSO-based method was more effective than some IOA-based methods, and it shortened the computation time of the traditional threshold-based segmentation methods. Cuevas et al. [8] explored the use of the Artificial Bee Colony (ABC) algorithm to compute threshold selection for image segmentation. In their algorithm, an image's 1-*D* histogram is approximated through a Gaussian mixture model whose parameters are calculated by the ABC algorithm. The ABC method shows fast convergence and low sensitivity to initial conditions. Additionally, it mitigates complex time-consuming computations commonly required by gradient-based methods.

Over the past decade, Swarm Intelligence, which is a sub-field of IOA, has been widely applied to engineering optimization problems and has achieved very satisfactory results. Ant Colony Algorithm [13] and Particle Swarm Optimization are the two most popular approaches in swarm intelligence. HBMA [2] is inspired by the mating process of real honey bees, and it is a typical swarm-based approach for optimization. The HBMA has been adopted to search for the optimal solution in some applications, such as clustering, market segmentation and benchmark mathematical problems.

However, for the PSO, updating the position of the particle as a whole item has the problem of the curse of dimensionality. The performance of the PSO deteriorates as the dimensionality of the search space increases, as described in [4]. HBMA also has the problem of the curse of dimensionality because the broods are updated as a whole item. To solve this problem, a new HBMA with a cooperative method (called CHBMA here) is proposed in this paper. The cooperative method is specifically applied to conquer the "curse of dimensionality" by partitioning the search space of a high-dimensional problem into one-dimensional subspaces. Then, the broods in CHBMA make a contribution not only as a whole item but also in each dimension. A measure that is based on the entropy criterion is employed to evaluate the performance of CHBMA.

The images that we have chosen in the experiment are images of natural scenery. The characteristics of natural scenery images are random, imprecise, complicated, and noisy. The locations of interest points in them are not regular. Combining the honey bee mating algorithm with the cooperative learning method can result in high-quality handling of imprecise and noisy image information. The experimental results indicate that CHBMA can produce effective, efficient and smoother segmentation results in a comparison with several previously developed methods.