Applied Soft Computing 11 (2011) 5205–5214

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

SAR image segmentation based on Artificial Bee Colony algorithm

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ARTICLE INFO

Article history:
Received 14 December 2010
Received in revised form 26 March 2011
Accepted 15 May 2011
Available online 20 May 2011

Keywords:
SAR image
Image segmentation
ABC algorithm
Grey entropy

ABSTRACT

Due to the presence of speckle noise, segmentation of Synthetic Aperture Radar (SAR) images is still a challenging problem. This paper proposes a fast SAR image segmentation method based on Artificial Bee Colony (ABC) algorithm. In this method, threshold estimation is regarded as a search procedure that searches for an appropriate value in a continuous grayscale interval. Hence, ABC algorithm is introduced to search for the optimal threshold. In order to get an efficient fitness function for ABC algorithm, after the definition of grey number in Grey theory, the original image is decomposed by discrete wavelet transform. Then, a filtered image is produced by performing a noise reduction to the approximation image reconstructed with low-frequency coefficients. At the same time, a gradient image is reconstructed with some high-frequency coefficients. A co-occurrence matrix based on the filtered image and the gradient image is therefore constructed, and an improved two-dimensional grey entropy is defined to serve as the fitness function of ABC algorithm. Finally, by the swarm intelligence of employed bees, onlookers and scouts in honey bee colony, the optimal threshold is rapidly discovered. Experimental results indicate that the proposed method is superior to Genetic Algorithm (GA) based and Artificial Fish Swarm (AFS) based segmentation methods in terms of segmentation accuracy and segmentation time.

1. Introduction

Image segmentation plays a very important role in the interpretation and understanding of SAR images. It has received an increasing amount of attention and therefore hundreds of approaches have been proposed over the last few decades [1]. Different from optical images, SAR images are inherently contaminated by speckle noise, which inevitably deteriorates the performance of segmentation. Approaches with good performance are often involved in complex computation which may lead the whole process to be more expensive in terms of time. So it is still an urgent task to devise simple and efficient methods.

Generally, existing segmentation approaches dealing with SAR images can be divided into two categories: segmentation based on texture and segmentation based on grey levels. The former partitions an image into several homogeneous regions with respect to specific textures. However it is often difficult to determine an exact discrimination for a texture field as well as the number of segmentation areas, especially when the image contains similar texture fields. The latter divides an image into several regions by some thresholds. Hence, an issue of segmentation in this case is a threshold estimation problem [2,3]. Currently, there are five classes of widely used estimation methods, namely, image statistic methods, between class variance methods, entropy methods, moment preserving methods and quadtree methods [4]. This paper aims at the segmentation based on grey levels, and moreover proposes a new entropy method for SAR images.

Nature-inspired computation has received significant attention in recent decades, in which the two most popular algorithms are Evolutionary Algorithms (EAs) and Swarm Intelligence (SI). EAs, such as Genetic Algorithm (GA), are inspired from natural selection and survival of the fittest in the natural world. SI, like Artificial Fish Swarm (AFS) algorithm and Particle Swarm Optimization (PSO) algorithm, is enlightened by animal foraging behavior [5]. Owing to the simplicity and flexibility of EAs and SI, various methods are developed for image engineering, which almost cover all related fields, including image enhancement, image denoising, superresolution restoration, image registration, digital watermarking, edge detection, image fusion, image compression, texture classification, image retrieval, image recognition, image segmentation, etc. [6–19].

Similar to the existing nature-inspired algorithms, a few of researchers proposed some mimic algorithms on the basis of the behavior of honey bees in the last few years [20–25]. This paper focuses on the most popular one, i.e. the ABC algorithm presented by Karaboga in 2005 [24], which has been clearly proved to be better than PSO algorithm, GA, Evolutionary Algorithm (EA), Differential Evolution (DE) and Particle Swarm inspired Evolutionary

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doi:10.1016/j.asoc.2011.05.039

Algorithm (PS-EA) in the case of numerical function optimization [25,26]. As a powerful optimization tool, soon after its production, ABC algorithm is successfully applied to complex function optimization, robot path planning, parameter identification, job-shop scheduling, etc. However, its application in image segmentation is seldom studied. This paper employs ABC algorithm to estimate the global threshold for SAR image segmentation. In addition, to acquire a reasonable foraging guide for the bee colony, we combine discrete wavelet transform with Grey theory to obtain an improved two-dimensional grey entropy that is used as the fitness function of ABC algorithm [13].

The remaining of this paper is organized as follows. Section 2 makes a brief summary of the features of honey bees and describes the working mechanism of ABC algorithm. Section 3 gives the definition of grey number in Grey theory, and introduces an improved two-dimensional grey entropy for threshold estimation. Section 4 shows how to employ ABC algorithm to the segmentation of SAR images. Some typical experiments on noise-free images, noise images and real SAR images are carried out in Section 5, where both segmented images and segmenting time are compared among some nature-inspired methods. Finally, Section 6 summarizes our work and the future developments.

2. ABC algorithms

As a kind of social insects, honey bees live in colonies and exhibit many features. These features include bee foraging, bee dance, queen bee, task selection, collective decision making, nest site selection, mating, pheromone laying and navigation systems, which can be used as models for intelligent applications. Actually, a lot of researchers have been inspired to develop algorithms by the behaviors of bees [20–25]. A survey of the algorithms based on the intelligence in bee swarms and their applications has been presented in [20].

As mentioned in Section 1, the ABC algorithm proposed by Karaboga and Basturk is one of the most popular algorithms [24,25]. The following discusses its working mechanism.

In ABC algorithm, an artificial bee colony consists of employed bees, onlookers and scouts. A bee waiting on the dance area to obtain the information about food sources is called an onlooker, a bee going to the food source is named as an employed bee, and a bee carrying out random search is called a scout. The position of a food source denotes a possible solution to the optimization problem, and the nectar amount of a food source represents the quality of the associated solution. Initially, a randomly distributed population is generated. For every food source, there is only one employed bee. So the number of employed bees is equal to the number of food sources. Thereafter, the positions (solutions) will be updated repeatedly with the following cycles until the maximum iteration is reached or stop conditions are satisfied. Each employed bee always remembers its previous best position, and produces a new position within its neighborhood in its memory. According to the greedy criterion, the employed bee updates its food source. In other words, when the new food source is better, the old food source position is updated with the new one. After all employed bees finish their search process, they share the information about the direction and distance to food sources and the nectar amounts with onlookers via a so-called waggle dance in the dancing area. By the observation on the waggle dance, each onlooker chooses a food source depending on the probability value associated with the food source, and searches the area within its neighborhood to generate a new candidate solution. And then, the greedy criterion is applied again just as it works in the employed bees. If a position cannot be improved after a predetermined number of cycles, the position should be abandoned; meanwhile, the corresponding employed bee becomes a scout. The abandoned position will be replaced with a new randomly generated food source [24–26].

The main steps can be described as follows:

(1) Initialize the bee colony $X = \{x_i | i = 1, 2, \ldots, n\}$, where n denotes the population size, x_i is the ith bee.
(2) According to the fitness function, calculate the fitness f_i of each employed bee x_i, and record the maximum nectar amount as well as the corresponding food source.
(3) Each employed bee produces a new solution v_i in the neighborhood of the solution in its memory by $v_i = x_i + (x_i - x_k) \times \phi$, where k is an integer near to i, $k \neq i$, and ϕ is a random real number in $[-1, 1]$.
(4) Use the greedy criterion to update x_i. Compute the fitness of v_i. If v_i is superior to x_i, x_i is replaced with v_i; otherwise x_i is remained.
(5) According to the fitness f_i of x_i, get the probability value P_i via formulas (1) and (2).

$$P_i = \frac{fit_i}{\sum_{i=1}^{n} fit_i} \tag{1}$$

$$fit_i = \begin{cases} \dfrac{1}{1+f_i}, & \text{if } f_i \geq 0 \\ 1 + abs(f_i), & \text{if } f_i < 0 \end{cases} \tag{2}$$

(6) Depending on the probability P_i, onlookers choose food sources, search the neighborhood to generate candidate solutions, and calculate their fitness.
(7) Use the greedy criteria to update the food sources.
(8) Memorize the best food source and nectar amount achieved.
(9) Check whether there are some abandoned solutions or not. If true, replace them with some new randomly-generated solutions by $x_i = min + (max - min) \times \phi$, where ϕ is a random real number in [0, 1], min and max stand for lower and upper bounds of possible solutions respectively.
(10) Repeat steps (3)–(9), until the maximum number of iterations ($kmax$) is reached or stop conditions are satisfied.

As mentioned above, the fitness function is a key component of ABC algorithm, which evaluates the foraging quality of the colony, i.e. the accuracy of possible solutions. Besides, some control parameters, such as the number of employ bees or onlooker bees, the limit times for abandonment, the maximum number of iterations or stop conditions, need to be assigned. They would have a direct influence on the speed and stability of convergence.

3. Improved two-dimensional grey entropy

3.1. Grey number in Grey theory

Grey theory, developed by Deng in 1982, is an effective mathematical means of resolving problems containing uncertainty and indetermination [27]. This multidisciplinary and generic theory deals with systems containing poor information. Now, fields covered by Grey theory include society, economics, finance, agriculture, industry, mechanics, meteorology, ecology, hydrology, geology, medicine, etc.

In Grey theory, a random variable is regarded as a grey number, and a random process is treated as a grey process within a certain range. A grey system is defined as a system containing information presented as grey numbers. Here, we only give some simple conceptions used in our segmentation method.

Definition 1. Let x denote a closed and bounded set of real numbers. A grey number $\otimes x$ is defined as an unknown value in an interval with known lower and upper bounds for x:

$\otimes x \in [\underline{\otimes} x, \bar{\otimes} x]$