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Optimization and Parameters Estimation in Ultrasonic Echo Problems Using Modified Artificial Bee Colony Algorithm

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Abstract

The patterns of ultrasonic backscattered echoes represent valuable information pertaining to the geometric shape, size, and orientation of the reflectors as well as the microstructure of the propagation path. Accurate estimation of the ultrasonic echo pattern is essential in determining the object or propagation path properties. This paper proposes a parameter estimation method for ultrasonic echoes based on Artificial Bee Colony (ABC) algorithm which is one of the most recent swarm intelligence based algorithms. A modified ABC (MABC) algorithm is given by adding an adjusting factor to the neighborhood search formula of traditional ABC algorithm in order to enhance its performance. The algorithm could overcome the impact of different search range on estimation accuracy to solve the multi-dimensional parameter optimization problems. The performance of the MABC algorithm is demonstrated by numerical simulation and ultrasonic detection experiments. Results show that MABC not only can accurately estimate various parameters of the ultrasonic echoes, but also can achieve the optimal solution in the global scope. The proposed algorithm also has the advantages of fast convergence speed, short running time and real-time parameters estimation.

Keywords: artificial bee colony algorithm, swarm intelligence, global optimization, ultrasonic echoes, ultrasonic testing
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1 Introduction

Using ultrasonic pulse echoes to perform nondestructive detection is an important method in industrial nondestructive detection and biomedical engineering[1–6]. The purpose of this method is that, through the analysis of detected target echoes to determine the physical characteristics of the reflective targets, such as geometric shape, size and other information on the transmission path[7–10]. It is essential to estimate ultrasonic echo parameters accurately and quickly for ultrasonic nondestructive testing. So far, many methods have been used to estimate the parameters of ultrasonic echo. In 1998, Femmam and M'Sirdi applied the nonlinear method to the study of ultrasonic nondestructive testing and biological tissue characterization, and used the wavelet transform method to study the ultrasonic target echo[11]. In 2001, Demirli and Saniie systematically discussed the nonlinear methods and used Gauss-Newton algorithm to estimate ultrasonic echo parameters[12–14]. But the estimated results of Gauss-Newton algorithm may be a local optimum point rather than a global optimum point because that the results usually depend on the selection of the initial values. In order to solve the problem that the estimation results depend on the initial values, Zhou *et al*. applied the Ant Colony Optimization (ACO) algorithm to Gaussian echo model and successfully estimated the ultrasonic echo parameters[15]. This algorithm not only overcomes the disadvantage that parameter estimation results depend on the initial values, but also has high estimation accuracy. However, the algorithm is prone to stagnation in parameter estimation.

In order to solve complex real world optimization problems, some efficient and effective algorithms have been introduced such as particle swarm optimization, ACO, artificial fish school algorithm, shuffled frog leaping algorithm and artificial bee colony algorithm[15,26–29]. Swarm means the collective behavior of insect or animal groups in nature such as fish, birds, ants and bees. Swarm intelligence optimization algorithms

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are widely used to solve the optimization problems in many fields in view of their superiority. Compared with traditional methods, swarm intelligence algorithms have obvious advantages in solving global optimization problems, such as short computing time and high precision.

ABC algorithm is a new optimization algorithm of bionic intelligence which simulates the behavior of honey bees to solve practical optimization problems. ABC algorithm was introduced by Karaboga in 2005[16], and he did further researches on ABC algorithm in the following years[17–23]. Compared to genetic algorithm[24,25], particle swarm optimization[26,27], ACO algorithm[15,28,29] and other swarm intelligence, ABC algorithm has more superior optimal performance and has been successfully applied in various fields such as digital filtering, target recognition and cluster analysis[19,30,31]. However, similar to other swarm intelligence algorithms, ABC algorithm still has some challenges to overcome. When solving multidimensional parameters optimization problem, the range of different parameters will influence the search step length of the employed bees.

This paper presents a new algorithm which is called Modified Artificial Bee Colony (MABC) algorithm to estimate the parameters of ultrasonic echo based on a new search formula. The new search formula can control the search step length of each parameter of multivariable problems. The rest of this paper is organized as follows: in section **2**, the general aspects of ABC are discussed and the MABC algorithm is proposed. Section **3** describes the mathematical model of ultrasonic echo. In section **4**, the MABC algorithm is applied to the ultrasonic echoes estimation problems and finally, section **5** presents the conclusions of this work.

2 Modified ABC algorithm for multidimensional ultrasound parameters estimation

2.1 ABC algorithm

The theory of ABC algorithm has been clearly expressed by Akay and Karaboga[21]. In a real bee colony, some tasks are performed by specialized individuals; while in ABC algorithm, foraging artificial bees are classified into three groups, namely, employed bees, onlooker bees, and scout bees. The ABC algorithm begins with a population of randomly generated food sources. The responsibility of an employed bee is to collect the nectar information of a food source and pass the information to an onlooker via a special dance in the hive. Then depending on the nectar information, an onlooker determines whether to recognize a food source and make further search of this food source. When a food source is abandoned, a scout randomly searches for a new food source. In the ABC algorithm, each solution to the problem under consideration is called a food source and represented by an n dimensional real-valued vector where the fitness of the solution corresponds to the nectar amount of the associated food resource[21,32,33].

In ABC algorithm, each food source represented by the position is a possible solution for the problem under consideration. The scout bees generate a set of $\boldsymbol{x_i}$ in the initialization of the algorithm[16], let $\boldsymbol{x_i}$ =[$x_{i1}, x_{i2}, \ldots, x_{iD}$] represent the ith food source and solutions are generated by Eq. (1):

$$x_{ij} = lb_j + \mathrm{rand}(0,1)(ub_j - lb_j), \tag{1}$$

where $i = 1, \ldots, N/2, j = 1, \ldots, D$, D represents the vector dimension of the location of food source, lb_j and ub_j are the lower and upper bounds of the jth parameter of the solution i. After generated the initial food sources, evaluate[16] each food source by Eq. (2):

$$fit_i = \begin{cases} 1/(1+f_i) & f_i \ge 0 \\ 1+\mathrm{abs}(f_i) & f_i < 0 \end{cases}, \tag{2}$$

where f_i is the objective function value of the corresponded solution i. After the initialization evaluation, all bees begin to repeat the cycle of the search progress; each employed bee is associated with only one food source and searches a new food source[16] in the neighborhood by Eq. (3):

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}), \tag{3}$$

where ϕ_{ij} is a random number in [−1, 1], $k = 1\ldots N/2$, j=1, …, D, $\boldsymbol{v_i}$ is a new food source, $\boldsymbol{x_i}$ is the current food source, $\boldsymbol{x_k}$ is a neighbor food source and k is a randomly chose that has to be different from i. After all employed bees completed neighborhood search, onlooker bees get the nectar amount of food sources in the hive through a special dance of employed bees. Then onlooker bees choose food source depending on the nectar amount of food source, and the probability[16] of the solution i can be expressed as:

$$p_i = \frac{fit_i}{\sum_{i=1}^{N/2} fit_i}, \tag{4}$$

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