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Bees algorithm for interference suppression of linear antenna arrays by controlling the phase-only and both the amplitude and phase

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ABSTRACT

In this paper, bees algorithm (BA) has been used for null steering in the antenna radiation pattern by controlling the phase-only and the complex weights (both the amplitude and phase) of the array elements. The BA is an optimization algorithm inspired by the behavior of the honey bees to find the optimal way of harvesting food resources around the hive. Simulation results for Chebyshev patterns with the imposed single, multiple and broad nulls are given to show the effectiveness of the proposed method. The sensitivity of the nulling patterns due to small variations of the element phases is also investigated.

1. Introduction

Due to the increasing pollution of the electromagnetic environment, the antenna array, which allows placing nulls in the far field pattern at prescribed directions, is becoming important in communication systems, sonar, and radar applications for maximizing signal-to-interference ratio. The antenna array pattern null forming and steering methods available in the literature (Akdagli & Guney, 2004; Akdagli, Guney, & Karaboga, 2002; Babayigit, Akdagli, & Guney, 2006; Er, 1990; Guney & Akdagli, 2001; Guney & Babayigit, 2008; Guney, Babayigit, & Akdagli, 2007, 2008; Guney & Basbug, 2008a, 2008b; Guney & Onay, 2007a, 2007b, 2008; Haupt, 1997; Ismail & Dawoud, 1991; Khodier & Christodoulou, 2005; Karaboga, Guney, & Akdagli, 2002, 2004; Liao & Chu, 1997; Mailloux, 1994; Shore, 1984; Tennant, Dawoud, & Anderson, 1994; Yang, Gan, & Qing, 2004), varying in accuracy and computational effort, include controlling the amplitude-only, the phase-only, the position-only, and the complex weights of the array elements. These methods have been used with their own benefits and limitations. In spite of the large variety of nulling methods, it appears that none of them completely satisfies the requirement of a general and flexible solution for the pattern synthesis problem.

The problem of phase-only nulling is inherently nonlinear and it cannot be solved directly by an analytical method. By assuming that the phase perturbations are small, the nulling equations can be linearized. The phase-only control utilizes the phase shifters. The array pattern nulling with phase-only control has been attractive for the phased antenna arrays because it is less complicated and the required controls are available at no extra cost. Moreover, it is also easier to control main beam direction by controlling the phase weights instead of controlling the amplitude weights. Interference suppression with complex weights is the most effective since it has the larger solution alternatives. However, it is also the most expensive considering the cost of the controllers used for phase shifters and variable attenuators for each array element.

It is well known that the classical optimization techniques are likely to be stuck in local minima if the initial guesses are not reasonably close to the final solution. The most of the classical optimization techniques and analytical approaches also suffer from the lack of producing flexible solutions for a given antenna pattern nulling problem. In recent years, the methods (Akdagli & Guney, 2004; Akdagli et al., 2002; Babayigit et al., 2006; Guney & Akdagli, 2001; Guney & Babayigit, 2008; Guney & Basbug, 2008a, 2008b; Guney et al., 2007, 2008; Haupt, 1997; Karaboga et al., 2002, 2004; Khodier & Christodoulou, 2005; Liao & Chu, 1997; Tennant et al., 1994; Yang et al., 2004) based on the genetic algorithm, ant colony optimization, bacterial foraging, immune, particle swarm optimization, differential evolution, tabu search and clonal selection algorithms have become more popular, and they have been used in solving antenna array pattern nulling problems. The performances of these methods are found to be better than those of the classical optimization techniques and the conventional analytical techniques. Each of these methods has its specific advantages and disadvantages.

In this paper, an efficient method based on the BA (Pham, Koc, Ghanbarzadeh, & Otri, 2006; Pham, Otri, Ghanbarzadeh, Koc, 2006; Pham, Ghanbarzadeh, et al., 2006; Pham, Soroka et al., 2006) is presented to steer the single, multiple and broad nulls to the directions of interference by controlling the phase-only and both the amplitude and phase of each array element. The

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sensitivity of the phase-only nulling by using the BA is also investigated by rounding the element phase values of the nulling patterns to the second decimal position.

The BA (Pham, Ghanbarzadeh et al., 2006; Pham, Koc et al., 2006; Pham, Otri et al., 2006; Pham, Soroka et al., 2006) is a recently developed parameter optimization algorithm that is inspired by the natural foraging behavior of honey bees to find the best solution of a given optimization problem. The BA has been demonstrated to exhibit a more robust performance compared to the other intelligent optimization methods for a variety of complex problems. The results obtained by Pham, Ghanbarzadeh et al. (2006) for multi-modal functions in n-dimensions reveal that the BA offers remarkable robustness generating a 100% success rate. The BA achieved a successful convergence to the maximum or minimum without getting trapped at local optima. It was demonstrated by Pham, Ghanbarzadeh et al. (2006) that the BA generally yielded superior performance over other techniques including the deterministic simplex method, the stochastic simulated annealing optimization, the genetic algorithm and the ant colony system in terms of the speed of optimization and the accuracy of the results. The BA was successfully utilized to train the learning vector quantization (LVQ) and the multi-layered perceptron (MLP) neural networks for control chart pattern recognition (Pham, Koc et al., 2006; Pham, Otri et al., 2006). In spite of the high dimensionality of these problems, the classifiers obtained by using the BA are more accurate than those obtained by the standard LVQ training algorithm and the backpropagation algorithm. An application of the BA to the optimization of neural networks for the identification of defects in wood veneer sheets was also presented by Pham, Soroka et al. (2006). The BA was used to train multi-layer perceptron neural networks to model the inverse kinematics of an articulated robot manipulator arm (Pham, Castellani, & Fahmy, 2008). The results obtained using the BA were compared to the results obtained using the backpropagation algorithm and an evolutionary algorithm. The comparative study (Pham et al., 2008) highlights the superior performance of the BA over the other algorithms. It was emphasized by Pham, Soroka et al. (2006) and Pham, Ghanbarzadeh et al. (2006) that the swarm-based optimization algorithms (Bonabeau, Dorigo, & Theraulaz, 1999; Camazine et al., 2003; Frisch, 1976; Seeley, 1996) with names suggestive of possibly bee-inspired operations do not closely follow the behavior of the bees. In particular, they do not seem to imitate the techniques that bees perform when harvesting for food.

In our previous works (Guney & Onay, 2007a, 2007b), the BA has been applied to solve the pattern nulling problem of the linear antenna arrays by *amplitude-only control* and *position-only control*, and successful results were obtained. However, in this paper, the BA is used for the pattern nulling of linear arrays by controlling *the phase-only and both the amplitude and phase*. Furthermore, the BA used here employs an adaptive mechanism for producing neighborhoods. Therefore, the neighborhood production mechanism of the proposed BA is different from that of the BA proposed by Pham, Soroka et al. (2006), Pham, Ghanbarzadeh et al. (2006), Pham, Koc et al. (2006) and Pham, Otri et al. (2006). Guney and Onay (2008) also used the BA to design reconfigurable dual-beam linear antenna arrays with digital attenuators and digital phase shifters.

The next section briefly explains the formulation of the problem. The basic principles of the BA are presented in the following section. The numerical examples are then presented and conclusion is made.

2. Formulation

If the elements are symmetrically placed and conjugate-symmetrically excited about the center of a linear array, the far field array factor of this array with an even number ($2N$) of isotropic elements can be written as:

$$F(\theta) = 2\sum_{n=1}^{N} a_n \cos\left(\frac{2\pi}{\lambda} d_n \sin\theta + \delta_n\right) \tag{1}$$

where d_n is the distance between position of the nth element and the array center, θ is scanning angle from broadside, and a_n and δ_n are amplitude and phase weights of the nth element, respectively. Generally, the main beam of the array pattern is required to be directed to the desired signal and the undesired interference signals from other directions to be suppressed as much as possible. To find an appropriate set of required element excitations that achieve interference suppression, the BA is used to minimize the following cost function:

$$C = \sum_{\theta=-90^\circ}^{90^\circ} W(\theta)|F_o(\theta) - F_d(\theta)| \tag{2}$$

where $F_o(\theta)$ and $F_d(\theta)$ are, respectively, the pattern obtained by using BA and the desired pattern. $W(\theta)$ is included in the cost function to control the null depth level. The value of $W(\theta)$ should be selected by experience such that the cost function is capable of guiding potential solutions to obtain satisfactory array pattern performance with desired properties. The factor $W(\theta)$ gives the antenna designer greater flexibility and control over the actual pattern.

3. Bees algorithm

3.1. Bees foraging process in nature

A bee colony can be considered as a distributed creature that can extend itself in order to make use of a large number of food sources at long distances in multiple directions (Frisch, 1976; Seeley, 1996). The colony attempts to attain the most optimal use of colony members by recruiting more bees for visiting flower areas with more nectar and pollen that can be carried to the hive with less effort than the areas with less nectar and pollen (Bonabeau et al., 1999; Camazine et al., 2003).

The food search process is initiated by despatching the scout bees from the colony to look for and then evaluate potential flower patches around the hive. During a harvesting season, a certain proportion of the bees in the colony is kept as the scout bees and these bees continuously and randomly fly to the flower patches around the hive (Seeley, 1996).

If these scout bees happen to discover a flower patch that contains more food than a predetermined level, they fly back to the hive and inform the other bees in the colony about their finding by performing a special dance called the "waggle dance" (Frisch, 1976). The waggle dance is illustrated in Fig. 1. This dance is an essential form of communication between the members of the colony and actually performed to convey three important pieces of information regarding flower areas around the hive. These are the direction of the flower patch, the distance of the patch to the hive and the quality of the food in the patch (Camazine et al., 2003; Frisch, 1976). This information allows the other bees in the colony to accurately evaluate the relative quality of the food areas around the hive and the effort necessary to collect them (Camazine et al., 2003). After the waggle dance ends, the scout bee flies back to the flower patch together with a number of other bees from the colony. The number of bees accompanying the scout bee is determined by the colony depending on the relative quality of the flower patch. In this manner, the colony can collect food in a fast and efficient manner.

The bees collecting food from a flower patch also regularly check its food level. If the food level is still high after harvesting,