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COMPETITIVE ALGORITHM OF SIMULATING NATURAL TREE GROWTH AND ITS APPLICATION IN ANTENNA DESIGN

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Abstract—A novel Competitive Algorithm of Simulating Natural Tree Growth is presented in this paper. It searches from a simple status to complex ones and is characterized by quick convergence. The algorithm has been used to design a novel tree-shaped antenna which has an appreciably larger gain of 2 dBi more than traditional dipole antenna with a reflector of the same size. A prototype antenna has been fabricated and tested. A good agreement between the calculated and measured results verifies the feasibility of the algorithm.

1. INTRODUCTION

The genetic algorithm has been widely used in antenna design and produces lots of new antenna designs [1–10], such as the famous NASA's genetic antenna. However, the genetic algorithm starts with a large random population, takes a lot of time for each generation to be completed, even at the beginning of the algorithm may take a lot of time to converge. Here we propose a novel algorithm, namely, the Competitive Algorithm of Simulating Natural Tree Growth which simulates a natural tree growth to overcome the drawback of the genetic algorithm [11]. Only sunlight and nutrition are considered and used to control the growth process to obtain an optimized status in the growth of a tree. In order to gain enough sunlight, the branch would spread out to the sun as long as possible. However, the longer the branch is, the harder it is for the branch to get nutriments from the soil. So the final shape is an optimized status. Because a tree can be considered as an antenna that receives enough electromagnetic waves

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to perform photosynthesis, so the algorithm can be naturally extended to design antennas.

2. COMPETITIVE MODEL AND THE SIMULATING NATURAL TREE GROWTH

Usually, the growth of a tree is very complicated. Here, only the branch's growing and wilting is considered, while the roots, leaves, seeds and flowers are neglected. The process of the tree growth in our model can be described as: firstly, a seed germinates and becomes a trunk a_0 from the starting point, creates ramification a_1 subsequently. Then, the trunk and its branches create more ramifications a_i. The growth of a natural tree can be performed with an iterative process. In the process, it is assumed that new branches may start at a random point along the previous branch.

In order to gain sufficient sunlight to perform its photosynthesis, the branches have to grow toward sunlight. In this process, the direction of sunlight is set to be the direction of incident waves. For the incident waves from the $+z$ direction, we define the sunlight fitness of a tree as follows:

Definition 1 Sunlight fitness $\eta = w_1 s/100 + w_2(90-\theta)g/700$ (1)

where s stands for the impedance bandwidth of the tree-shaped antenna; θ is the elevation angle of the main lobe of the antenna in spherical coordinate; g is the directive gain of the antenna. w_1 and w_2 are the weights.

Meanwhile, the growth of the branches needs nutriment from soil. The further the position of the branch is from the root, the more difficult it gets the nutriment from the soil. So the nutrition factor of a branch can be defined as the value of the total length from the trunk to itself:

Definition 2 Nutrition factor $\alpha_i = \exp\left(-\sum_{r=0}^{m} |a_r|\right)$ (2)

where $i = 0, 1, 2, 3, \ldots$; m is the total amount of branches which connect the branch a_i to the trunk a_0; and $|a_r|$ is the current length of the branch a_r.

Generally, the outer branches may shade the inner branches. The shaded branches may fade away due to the lack of sunlight. The topmost branches occupy the competitive advantage, and have a priority of growth. So, after the transformation from the spherical coordinate to the cylindrical coordinate, the shading factor of a branch can be simply defined as follows:

Definition 3 Shading factor $$\beta_i = \left(1 - \frac{r_i}{r_{\max}}\right)\left(1 - \frac{z_i}{z_{\max}}\right) \quad (3)$$

where $r_{\max}$ and $z_{\max}$ are the maximum radius and height of the crown respectively. r_i and z_i are the locations of the middle point of the branch a_i.

The competitive growth equation of the branch a_i may be described as

$$a_i^{t+1} = a_i^t + D\alpha_i(1 - \beta_i)R(0, 1)\lambda/4 \quad (4)$$

where t is the generation of the tree; a_i^t is the length of branch a_i in the t-th year. D is a directive coefficient and equals 1 or -1. The branch a_i grows one by one. After the growth of the branch a_i, the new fitness η^{t+1} needs to be calculated. If $\eta^{t+1} > \eta^t$, the branch has an increment, at the time, $D = 1$. Otherwise, the branch has a decrement, and $D = -1$. $R(0, 1)$ is a uniform random number between 0 and 1.

A branch may fade due to the lack of sunlight or nutrition. The wilting of the branch occurs if the following condition is satisfied:

$$a_i = \begin{cases} 0 & \alpha_i < \varepsilon_1 \quad \text{or} \quad \beta_i > \varepsilon_2 \\ a_i & \text{others} \end{cases} \quad (5)$$

where $\varepsilon_1,\ \varepsilon_2 \in (0, 1)$ are constants which indicate the minimum threshold of the nutrition factor and the maximum threshold of the shading factor respectively. The wilting of branches may reduce the fitness. However, for the entire iterative process, it is favorable for the growth to jump out of a local maximum. As most of the optimization algorithms, if the generation t reaches the set value T or the fitness η arrivals the requested η_{req}, the calculation stops and outputs the result. The flow chart of the algorithm is shown in Fig. 1. Where, t is current generation, T is the maximum iteration times, η is the sunlight fitness, and η_{req} is assumed optimal sunlight fitness, and ρ is the branching probability.

3. THE TREE-SHAPED ANRENNA DESIGN

Figure 2 depicts the configuration of the tree-shaped antenna. It consists of a tree-shaped patch printed on a foursquare Teflon substrate with side of $\lambda/2$ and a reflector with radius of $\lambda/2$. The relative permittivity and thickness of the Teflon substrate are 2.65 and 1 mm, respectively.

In this work, the proposed tree-shaped antenna will work at 2.45 GHz. To achieve end-fire radiation pattern and a high end-fire gain which exceeds 8 dBi at the working frequency, the antenna will be designed by the Competitive Algorithm of Simulating Natural Tree

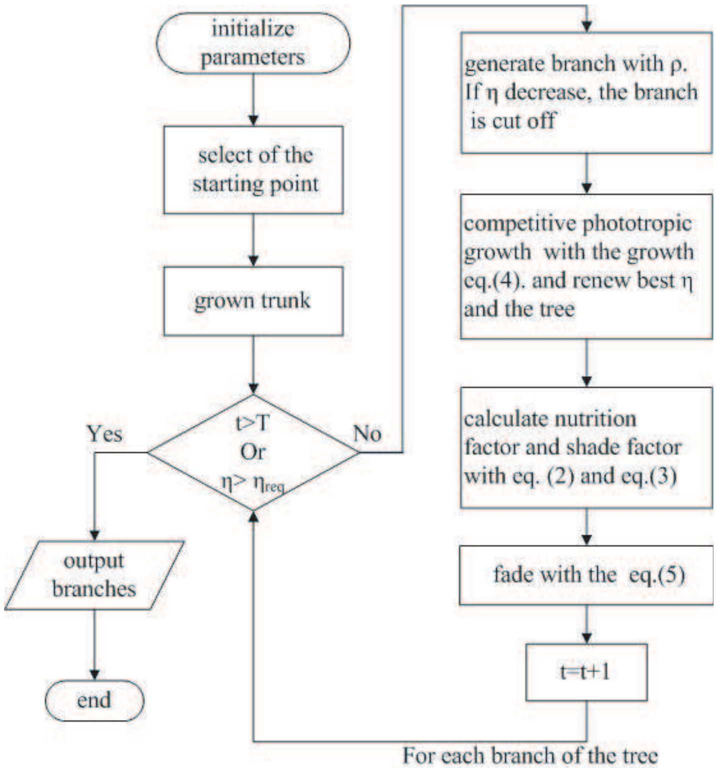


Figure 1. The flow chart of the algorithm.

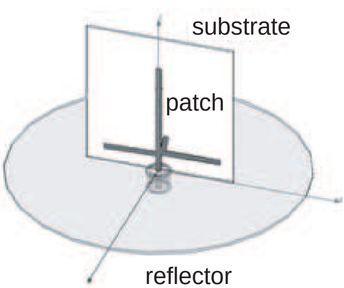


Figure 2. The configuration of the tree-shaped antenna.

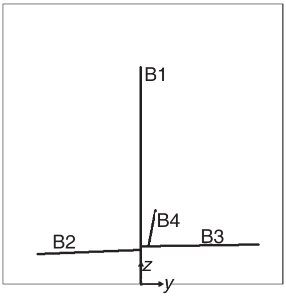


Figure 3. The optimized tree structure.

Growth in conjunction with the full-wave EM simulation based on the Finite-Difference Time-Domain (FDTD) method.

The branch coordinates of the tree-shaped antenna are the parameters needed to be optimized. According to the flow chart in Fig. 1, parameters in the calculation are listed in Table 1. After several iterations, the directive gain reaches 8.9 dBi. As shown in Fig. 3, the optimized tree has 4 branches whose coordinates are listed in Table 2. The width of the patches is 2.24 mm.

A prototype antenna has been fabricated as shown in Fig. 4. Fig. 5 presents the simulated and measured S_{11} of the antenna. There is a good agreement between simulated and measured S_{11} of the antenna.

Figure 6 shows the end-fire radiation pattern of the antenna at the frequency 2.45 GHz. The radiation patterns show a typical end-fire performance and the cross polarization level is much lower than the co-polarization level in E-plane. A good agreement between the calculated and measured results is observed which verifies the feasibility of the design.

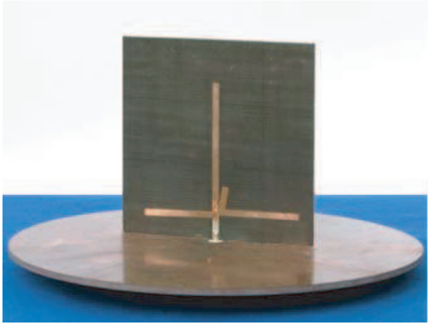


Figure 4. The optimized structure of the antenna.

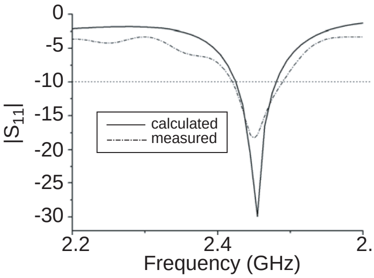


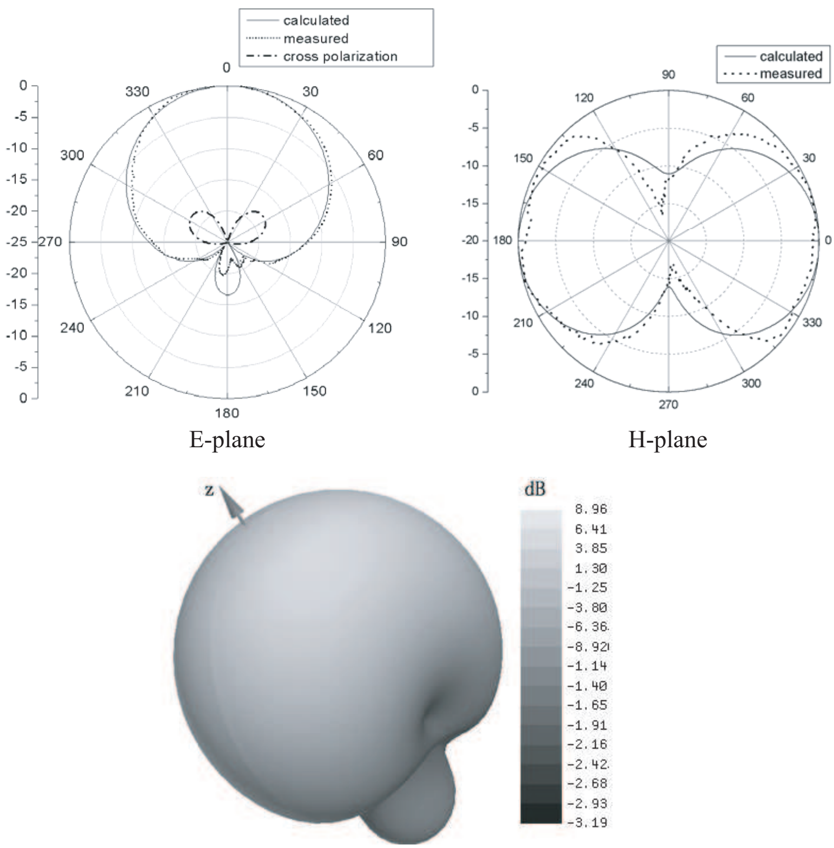
Figure 5. The measured and simulated S_{11} of the antenna.

Table 1. The values of the parameters.

No.	Parameter	Value
1	w_1	0.35
2	w_2	0.65
3	ε_1	0.05
4	ε_2	0.05
5	T	500
6	η_{req}	0.95

Table 2. The coordinates of the 4 branches of the tree.

No.	Start point (y, z)	End point (y, z)
1	(0.0, 0.0)	(0.0, 47.1)
2	(0.0, 7.4)	(−22.6, 6.6)
3	(0.0, 8.2)	(25.6, 8.6)
4	(0.0, 13.5)	(1.4, 14.1)



E-plane H-plane

calculated 3D radiation pattern

Figure 6. The calculated and measured radiation pattern at 2.45 GHz.

4. CONCLUSION

A novel Competitive Algorithm of Simulating Natural Tree Growth is presented, and it has been successfully used to design a new tree-shaped antenna. The optimized antenna gains greater directivity than traditional dipole antenna with a reflector of the same size [12] and obtains an almost perfect end-fire radiation pattern. The good agreement between the calculated and measured results verifies the feasibility of the algorithm and shows that this new approach has tremendous potential in antenna design.

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REFERENCES

1. Kadri, B. and F. T. Bendimered, "Linear antenna synthesis with a fuzzy genetic algorithm," *Proc. Eurocon 2007 — The International Conference on "Computer as a Tool", IEEE*, 942–947, Sep. 2007.
2. Santarelli, S. and T. L. Yu, "Military antenna design using simple and competent genetic algorithms," *Mathematical and Computer Modelling*, Vol. 43, No. 9–10, 990–1022, May 2006.
3. Sathi, V., C. Ghobadi, and J. Nourinia, "Optimization of circular ring microstrip antenna using genetic algorithm," *International Journal of Infrared and Millimeter Waves*, Vol. 29, No. 10, 897–905, Oct. 2008.
4. Abdelaziz, A. A. and H. A. Kamal, "Sector synthesis of antenna array using genetic algorithm," *Frequenz*, Vol. 62, No. 1, 12–15, 2008.
5. Weile, D. S. and E. Michielssen, "The control of adaptive antenna arrays with genetic algorithms using dominance and diploidy," *IEEE Trans. Antennas Propag.*, Vol. 49, No. 10, 1424–1433, Oct. 2001.
6. Mani, V. V. and R. bose, "Genetic algorithm based smart antenna design for UWB beamforming," *IEEE International Conference on Ultra-Wideband, ICUWB*, 442–446, 2008.

7. Boeringer, D. W. and D. H. Werner, "A simultaneous parameter adaptation scheme for genetic algorithms with application to phased array synthesis," *IEEE Trans. Antennas Propag.*, Vol. 53, No. 1, 356–371, 2005.
8. Xu, Z., H. Li, Q.-Z. Liu, and J.-Y. Li, "Pattern synthesis of conformal antenna array by the hybrid genetic algorithm," *Progress In Electromagnetics Research*, PIER 79, 75–90, 2008.
9. Mahanti, G. K., A. Chakrabarty, and S. Das, "Phase-only and amplitude-phase only synthesis of dual-beam pattern linear antenna arrays using floating-point genetic algorithms," *Progress In Electromagnetics Research*, PIER 68, 247–259, 2007.
10. Sijher, T. S. and A. A. Kishk, "Antenna modeling by infinitesimal dipoles using genetic algorithms," *Progress In Electromagnetics Research*, PIER 52, 225–254, 2005.
11. Guo, G. W. and K. M. Huang, "Competition algorithm of natural tree growth and its application in curve fitting," *J. Computational and Theoretical Nanoscience*, Vol. 4, No. 7–8, 1301–1304, 2007.
12. Kraus, J. D. and R. J. Marhefka, *Antennas*, 3rd edition, 277–281, McGraw-Hill, New York, 2003.