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Research Article

Optimization of Gain, Impedance, and Bandwidth of Yagi-Uda Array Using Particle Swarm Optimization

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Particle swarm optimization (PSO) is a new, high-performance evolutionary technique, which has recently been used for optimization problems in antennas and electromagnetics. It is a global optimization technique-like genetic algorithm (GA) but has less computational cost compared to GA. In this paper, PSO has been used to optimize the gain, impedance, and bandwidth of Yagi-Uda array. To evaluate the performance of designs, a method of moments code NEC2 has been used. The results are comparable to those obtained using GA.

1. INTRODUCTION

Yagi-Uda arrays are quite common in practice because they are light weight, simple to build, low cost, and provide moderately desirable characteristics for many applications. Yagi-Uda antenna was developed by Uda and Yagi during 1930s. Since then, it has received much attention in the literature. There are several gradient-based methods for optimization of Yagi antenna [1–3]. The shortcoming of gradient-based methods is that they are vulnerable to stuck in local optima. Also, these heavily depend on the choice of initial point, which depends on the experience of antenna designer. The solution to the problems of gradient-based methods can be overcome by using global optimization methods like genetic algorithm (GA) and particle swarm optimization (PSO). GA optimizers are particularly effective when the goal is to find an approximate global maximum in high dimension, multimodal function domain in near optimal manner. Haupt has compared GA and gradient-based methods for electromagnetic problems and found that the genetic algorithms are better than gradient-based methods [4]. Many reserachers have used GA for optimization of Yagi-Uda array for different design objectives [5–9]. In [7], the Yagi-Uda array has been optimized for gain, impedance, and bandwidth using GA. In this paper, we are also achieving the same design objective using PSO.

PSO has been found to work better than GA in certain kind of optimization problems. Compared to GA, it is easily implemented and has least complexity [10]. Recently, it has been used for the synthesis of linear arrays [10, 11]. It has also been used for the optimization of gain, impedance, and relative side lobe level of Yagi-Uda array and has shown better performance than GA [12]. Bandwidth is also an important design objective, which needs to be explored along with gain and impedance. In this paper, PSO has been used for optimizing the gain, impedance, and bandwidth using length and spacing between elements as variables. Section 2 describes the PSO algorithm and the Yagi-Uda design optimization using PSO with simulation example. The work has been concluded in Section 4.

2. PARTICLE SWARM OPTIMIZATION

PSO is an evolutionary algorithm based on the intelligence and cooperation of group of birds or fish schooling. It maintains a swarm of particles, where each particle represents a potential solution. In PSO, algorithm particles are flown through a multidimensional search space, where the position of each particle is adjusted according to its own experience and that of its neighbors. Table 1 shows some key terms used to describe PSO [13]. More details of algorithm can be found in [14, 15].

Table 1: Key PSO vocabulary.

Some key terms used to describe PSO	
Particle/agent	One single individual in the swarm
Location/position	An agent's N-dimensional coordinates which represents a solution to the problem
Swarm	The entire collection of agents
Fitness or cost	A single number representing the goodness of a given solution
Personal best (pbest)	The location in parameter space of the best fitness returned for a specific agent
Global best (gbest)	The location in parameter space of the best fitness returned for the entire swarm
V_{max}	The maximum allowed velocity in a given direction

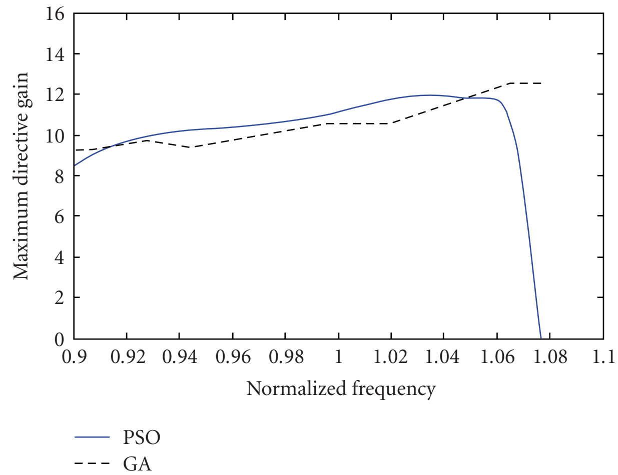

Figure 2: Maximum directive gain in dB versus normalized frequency for GA and PSO.

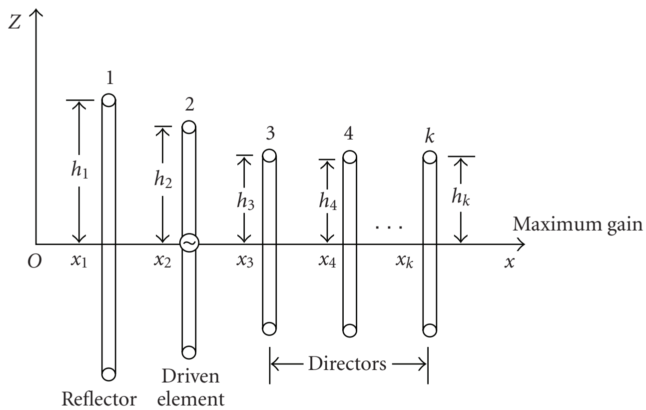

Figure 1: Geometry of a K element Yagi-Uda array.

3. THE DESIGN PROCESS

The goal of the design process is to develop an antenna that meets or exceeds some desired performance characteristics. A few of the characteristics that define the antenna performance are sidelobe level, beamwidth, bandwidth, front-to-back ratio, size, gain, and input impedance. The quality of a design is expressed mathematically by an objective function. This paper uses the function which tries to maximize gain and to obtain optimum impedance, that is, $Z = 50\,\Omega$ for the 10% bandwidth. The objective function used is given by

$$F = aG(x) - b\,|50 - \operatorname{Re} Z(x)| - c|\operatorname{Im} Z(x)|, \quad (1)$$

where G is the Gain of antenna x in the endfire direction; Z is the impedance; and $|\cdot|$ denotes the absolute value. The value of a was taken as 40 and b and c equal to 2. The values of a, b, and c have been taken by hit and trail. It is clear that if the real part of impedance is far from 50 or the imaginary part is large, the fitness will be worse. To optimize the pattern for bandwidth, fitness operation is done in three frequencies: up, central, and down as in [7]. For example, if it is desired 10% of bandwidth, the operation is made in three frequencies: f_{up}, f_c, and f_{down}, where, $f_{up} = 1.05 * f_c$ and $f_{down} = .95 * f_c$.

Here, f_c, is the central frequency. Figure 1 shows the geometry of a K element Yagi-Uda array. The six-element Yagi-Uda array has been optimized for gain, impedance, and bandwidth using PSO algorithm. The distances between consecutive elements (five different distances) and the lengths of each element are the parameters to be optimized. The problem with the antenna design is that if we increase gain, the impedance gets bad or bandwidth decreases. So, in order to have good antenna it should have high gain, low VSWR, and good bandwidth. The cross section radius is the same for all elements and is set equal to $0.003369\,\lambda$ wavelengths at 299.8 MHz. The NEC2 simulation program [6] has been used to evaluate all antenna designs. The source element for excitation was specified to be the middle segment of the driven element. The z location of the reflector element was always set to 0. The antenna was analyzed in free space. The spacing between elements was allowed to vary between $0.10\,\lambda$ and $0.45\,\lambda$, and the length of each element is allowed to vary between $0.15\,\lambda$ and $0.35\,\lambda$. Figure 2 shows the maximum directive gain versus frequency response for GA and PSO. As can be seen, PSO shows better gain characteristics compared to GA. Figure 3 shows the VSWR versus frequency for GA and PSO. It can be observed that GA has better impedance characteristics. But it has to be noted that in [7] the position of feedpoint has been varied for getting better impedance characteristics, whereas in this work the feedpoint position is fixed. Table 2 shows the relative performance comparisons. The convergence rate of the PSO has been shown in Figure 4. In general, PSO converges in a few iterations compared to GA since it has less complexity and can be easily implemented. In this very particular problem, PSO converges after 2500 iterations, whereas GA took 10 000 iterations. This results in considerable time saving. The memory complexity is also less in PSO as PSO is inherently less complex compared to GA.

Table 2: Length, spacing, and performance comparisons. The central frequency is 300 mHz. The radius of elements is 0.003369 λ. Length and spacing are also in terms of wavelength.

	GA optimized gain, impedance, and bandwidth [7]		PSO optimized for gain, impedance, and bandwidth	
Element	Length	Spacing	Length	Spacing
1	.52	—	.4939	—
2	.47	.182	.4665	.2269
3	.42	.152	.4213	.1662
4	.41	.229	.4149	.2883
5	.39	.435	.4120	.3213
6	.39	.272	.4199	.2731
Feedpoint	0.025		0	
Gain (dBi) (f_{down}/f_{up})	9.39	11.29	10.22	12.12
Z (Ω)	$52.4 - j6.6$	$47.1 + j2.6$	$49.08 - j20$	$49.99 + j0.50$

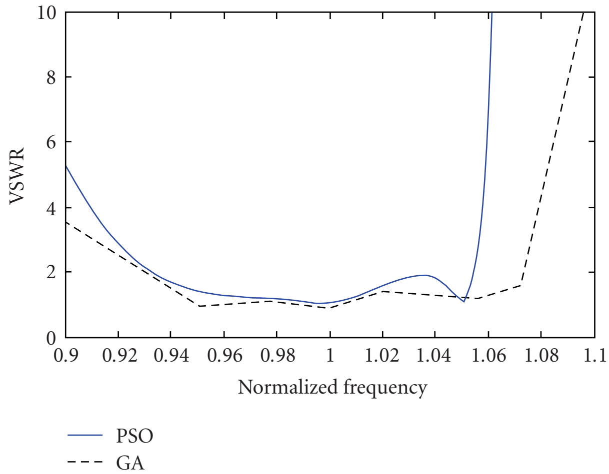

Figure 3: Voltage standing wave ratio versus normalized frequency for GA and PSO.

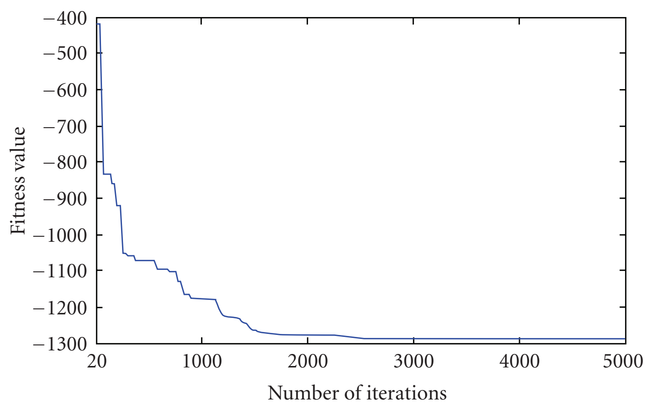

Figure 4: Convergence rate of the PSO algorithm, showing fitness value versus number of iterations.

4. CONCLUSION

Particle swarm optimization is currently being used for antenna optimization due to its low complexity and global nature. Earlier designs using PSO did not consider bandwidth as optimization variable. The bandwidth is an important parameter as antennas work in the specific frequency bands. In the present work, PSO has been successfully used for the optimization of gain, impedance, and bandwidth of Yagi-Uda array. Results show that PSO is well suited for these kinds of multimodal problems. The results are comparable to those obtained using GA taking length and spacing as variable. More control over the pattern can be obtained by taking length, spacing, and radii, that is, all three as variables. Also, other design objectives like sidelobe level and beamwidth can be included in the optimization process.

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