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Authors	Mohammed, Husham J.;Abdullah, Abdulkareem S.;Ali, R.S.;Abdulraheem, Yasir I.;Abd-Alhameed, Raed
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Performance Comparison of Particle Swarm Optimization, And Genetic Algorithm in The Design Of UWB Antenna

Husham J. Mohammed, Abdulkareem S. Abdullah, Ramzy S. Ali, Yasir I. Abdurraheem and Raed A. Abd-Alhameed

Abstract— An efficient multi-object evolutionary algorithms are proposed for optimizing frequency characteristics of antennas based on an interfacing created by Matlab environment. This interface makes a link with CST Microwave studio where the electromagnetic investigation of antenna is realized. Very small, compact printed monopole antenna is optimized for ultra- wideband (UWB) applications. Two objective functions are introduced; the first function intends to increase the impedance bandwidth, and second function to tune the antenna to resonate at a particular frequency. The two functions operate in the range of 3.2 to 10.6 GHz and depend on the level of return loss. The computed results provide a set of proper design for UWB system in which the bandwidth achieved is 7.5GHz at the resonance frequency 4.48GHz, including relatively stable gain and radiation patterns across the operating band.

Index Terms—UWB antenna, Bio-inspired algorithms, Genetic Algorithm (GA), Particle Swarm Optimization (PSO).

1 INTRODUCTION

One of the most critical issues in the design of a UWB system is the antenna component. Unlike typical narrowband antennas, in which the antenna is tuned to resonate at a specific frequency over a fractional bandwidth of less than a few percent, a UWB antenna must resonate well over the entire 3.2-10.6 GHz band, a fractional bandwidth of over 100 percent. Although broadband antennas have been in use for decades, even as early as the nineteenth century, current development has focused on smaller, planar antennas that can easily be integrated onto printed circuit boards [1].

One of the challenges for the design of UWB system applications is the development of an optimal or suitable antenna. In the designing of UWB antenna, the first important requirement is the extremely wide impedance bandwidth. The frequency spectrum for UWB applications assigned from 3.1GHz to 10.6GHz by The FCC as an unlicensed band [2]. So, a bandwidth up to 7.5GHz is required for a practical UWB antenna. Also the return loss for the entire ultra-wide band should less than 10dB. Next, omnidirectional property in radiation patterns is demanded for indoor wireless communication to allow convenience in communication between transmitters and receivers. Hence, low directivity is preferred and the gain should be as stable as possible over the band.

Several methods for improving the bandwidth have been informed, such as beveling [3], parasitic elements [4], shorting pins [5], semi-circular bases [6], and multiple feeds [7]. These designs have resulted in antennas that unsuitable for circuit board integration or too large.

A considerable attention paid to the algorithms that are

inspired from natural phenomena so as to solve an antenna optimization problems; examples Genetic algorithm [8-9], particle swarm optimization [10-11].

This paper presents a performance comparison of genetic algorithm (GA), and particle swarm optimization. Some of optimization tools are built-in the current electromagnetic simulators such as CST, IE3D and HFSS which can help the designers to optimize their antennas. But, in most of these simulators, designers cannot formulate the desired functions for their optimization purposes in details, which is necessary for every optimization problems. Accordingly, in case of complex settings of optimization problems objective function, it is desirable to define objective function in a programming environment. Hence, a simple, very small and compact antenna has been proposed and optimized using the particular algorithms to yield the required characteristics of UWB system.

2 ANTENNA STRUCTURE

Fig. 1 shows the geometry of the proposed monopole UWB antenna. The radiation component is a Circular patch with H slot of radius r printed on one side of a substrate characterized by relative dielectric constant of 4.4 and thickness $0.8mm$ of FR-4 material with overall dimensions of $25 \times 25mm^2$. The radiation element is fed by a microstrip line with width of w_f and length l_f . Dimensions of the vertical arm of the H-slot are $1 \times 4mm^2$ and the length of the horizontal arm of the H-slot is $1mm$. On the other side of the substrate, the conducting ground covering only the section of the micro-strip feed with a length of l_g . The radius r , length of the partial ground l_g , feeder line dimensions and width of the horizontal slot w_1 are important and sensitive

parameters inaccurately controlling the achievable objective functions. So, these parameters are optimized using genetic algorithm and Particle swarm.

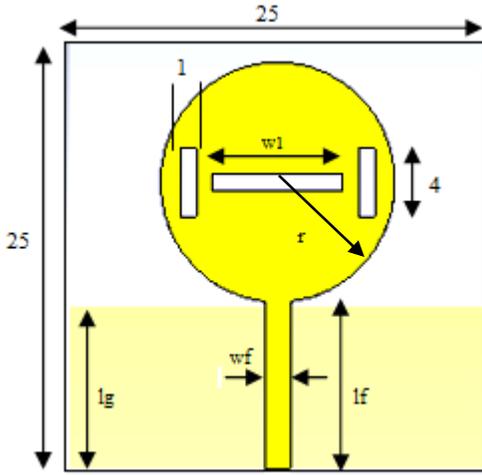


Fig. 1. The proposed antenna geometry.

3 OPTIMIZATION ALGORITHMS

3.1 Genetic algorithm (GA)

Genetic Algorithm (GA) is one of the most effective Bio-inspired algorithms established until now [12, 13], it is inspired from the natural evolution, in terms of survival of the fittest, biological operators are used such as crossover, mutation, selection and many other additional operators introduced to get a faster convergence rate.

In genetic algorithm, the set of agents that characterize a particular problem is called a chromosome and it is composed of a list of strings (genes). Each gene contains the parameter itself or a suitable encoding of it. Therefore, in the search space, each chromosome represents a point in that space, and thus a probable solution to the problem. The fitness function is evaluated for each chromosome of the population, resulting in a fitness level assigned to the chromosome. New population is generated iteratively based on this fitness levels.

Randomly population generated chromosomes at the starting represent an initial population. There are three basic GA operators; selection, crossover, and mutation, which are applied in so as to deploy the genetic routine. Selection is the process by which the fittest chromosomes in the current generation are chosen to be involved as parents in the creation of a new generation. The crossover operator produces two new chromosomes (offspring) which also represent candidate solutions by the recombination of the information from two parents.

After the selection and crossover process, the offspring are subjected to the mutation operator. Mutation in biology is a small change in DNA; similarly in genetic algorithm, mutation is implemented as a bit flip at a random position in a chromosome in order to avoid solutions converging to

a local extreme by maintain some amount of population diversity in which it represents the effect of mutation. However, mutation is considered as a background operator to the main operation of recombination [14]. The process of selection, recombination and mutation repeats until either a specific criterion is attained or set number of iterations is reached.

3.2 Particle Swarm Optimization (PSO)

Again Particle Swarm Optimization (PSO) is one of the Bio-inspired algorithms developed for several applications [9]. It is based on a suitable model of social interaction between independent agents and it uses social knowledge in order to find the global maximum or minimum of a generic function. Unlike GA, as discussed in section 3.1, the main PSO operator is the velocity update that takes into account the best position explored during the iterations, resulting in a migration of the swarm towards the global optimum instead of a biological operators, such as selection, crossover and mutation.

In the PSO the so called swarm intelligence (i.e. the experience accumulated during the evolution) is used to search the parameter space by controlling the trajectories of a set of particles according to a swarm-like set of rules [15, 16]. The computed value of the function to be optimized is based on the position of each particle. Therefore, every position represents a possible solution of the optimization problem. Particles traverse the problem space and are attracted by both their best past performance position and the position of the global best performance of the entire swarm. With variable speeds, Particles are moved into the space of the problem and every position they reach denote a particular values of the variables set which is then valued so as to get a fitness level.

Similarly to a GA, the population for PSO is started by definition of a random population. In the PSO technique each particle is defined by its position vectors in the domain of the parameters to be optimized but, unlike GA, such a particle also has a random velocity in the parameter domain. At each iteration, the particle moves with respect to its velocity and the fitness function to be optimized is evaluated for each particle in their current position. The value of the fitness function is then compared with the best value obtained during the previous iterations. Besides, the best value ever obtained for each particle is stored and the corresponding position is saved too. The velocity of the particle is then stochastically updated following the updating rules based on the attractions of the position of its personal optimum and the position which is the global optimum. Note that the global optimum value is the best fitness ever reached by the swarm, the well-known standard PSO updating rule for particles' velocities given by:

$$v_i^{k+1} = w^k v_i^k + \emptyset 1 \alpha_{1,i}^k (b_i^k - x_i^k) + \emptyset 2 \alpha_{2,i}^k (o_i^k - x_i^k) \quad (1)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \Delta t \quad (2)$$

Where k is the current iteration, i is the index of particles, w is a friction factor that tends to stop the particle, efficiently speeding up convergence, and avoids oscillations nearby the optimal value. ϕ_1 and ϕ_2 are the social and cognitive constants which are equal to 2 [17], whereas α_1 and α_2 are positive random numbers with a uniform distribution between 0 and 1, b refers to the best position seen by each particle, O is best position seen by whole Swarm, v is the current particle velocity, x is the current particle position, and Δt is the time step that is equal to 1.

4 SYSTEM DESIGN

4.1 Method of Design

An automated environment is introduced between Matlab [18] and CST Microwave Studio [19]. It is a type of interface that allows Matlab to control the design process as a client and CST will be the server. The whole process is shown in Fig. 2.

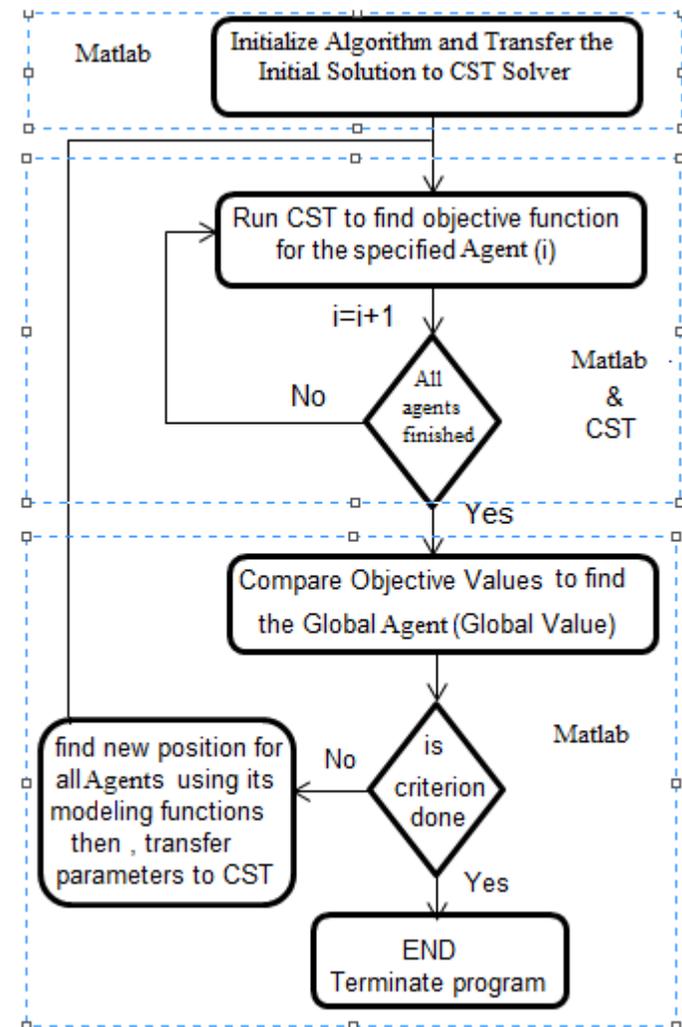


Fig. 2. Description of the automated system

4.2 Algorithms Settings

For optimization with a GA several parameters were chosen. These are, the population size was 20, the number of bits/variables was 8 and the number of variables was 8 with a 0.05 mutation rate. Tournament selection and single point cross over were used. The optimization was run for 20 iterations. The minimum and maximum values of the variables which are needed by the algorithm are given in Table 1.

As with the GA, the population size was 20, the number of variables was 8. For the PSO, the social parameter was set to 2, the cognitive parameter was 2, and the inertial weight was 0.65. Also, the variables boundaries are the same as in GA as shown in Table 1. The optimization was run for 20 iterations.

TABLE 1
PARAMETERS LIMITS

Parameters	Max_Value (mm)	Min_Value (mm)
lg	6	12
r	5	9
wf	1	3
lf	6	13
wl	4	12

4.2 Objective Function

The fitness function for the optimization routines was defined as,

$$OF2 = \sum_{f_1}^{f_2} p(f) + \sum_{f_{3+0.01}}^{f_4} p(f) \quad (3)$$

$$p(f) = \begin{cases} S_{11} & \text{for } S_{11} \geq -10 \\ 0 & \text{for } S_{11} < -10 \end{cases}$$

$$OF2 = \sum_{f_{2+0.01}}^{f_3} p(f) \quad (4)$$

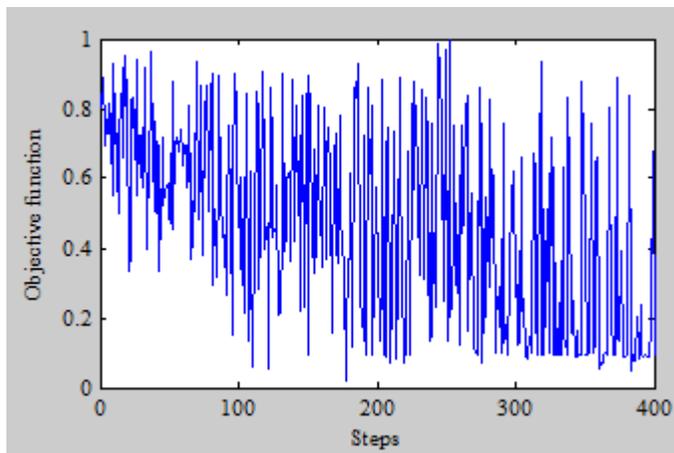
$$p(f) = \begin{cases} S_{11} & \text{for } S_{11} \geq -22 \\ 0 & \text{for } S_{11} < -22 \end{cases}$$

$$OF = -\frac{1}{N} (OF1 + OF2) \quad (5)$$

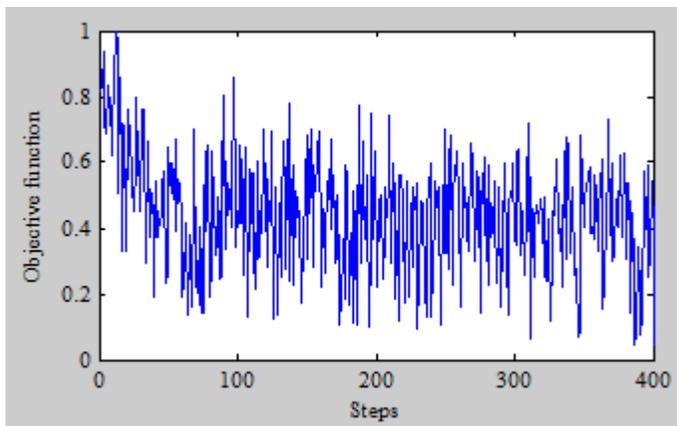
Where, S_{11} is the input reflection coefficient in dB, f_1 is the lower frequency of the operating band which is 3.2GHz, f_2 and f_3 are the lower and higher frequencies for a particular band covering 4.2 to 5.2 GHz respectively, f_4 is the higher frequency of the operating band which is 10.6GHz, N is the number of frequency samples taken from f_1 to f_4 , OF1 is the first objective function that concerned with bandwidth enhancement, OF2 is the second objective function which is concerned for making the antenna resonates at the particular band and OF is the overall objective function.

5 SIMULATION RESULTS

Simulation is done using HP Compaq 8200 Elite CMT PC with 3.4 GHz CPU and RAM of 16GB, a single run of fitness function evaluation took about (7 - 10) minutes and an entire optimization run took about (3-4) hours. The normalized objective functions of the GA, and PSO agents are shown in Fig. 3.



(a)



(b)

Fig. 3. Objective function versus steps of the (a) GA, and (b) PSO

From Fig. 3, it can be seen that PSO agents unlike the GA which improved their fitness levels with a relative stable behavior. However, GA achieve a best fitness of 0.0212 at step 177 whereas PSO achieve a best fitness of 0.0432 at step 387, two important issues in the optimization algorithms were considered; the best fitness and who is the faster. It should be noted in this study the GA has a better performance than PSO.

Fig. 4 displays the simulated S_{11} results of the proposed antenna that is designed based on the optimal parameters shown in Table 2 from the GA result. It can be observed that the designed antenna achieved a wideband performance from (3.75 - 11) GHz for $S_{11} < -10$ dB with a resonance frequency of 4.48GHz.

The simulated normalized radiation patterns in the xz and yz planes at (4.48, 9.3) GHz are shown in Fig. 5 respectively. E_{ϕ} represents the co-polarization properties; E_{θ} represents the cross-polarization properties. The yz coordinates taken into as the H-plane and xz coordinates as the E-plane. The cross-polarization is smaller than the co-polarization on the E-plane at the resonances 4.48GHz and 9.3GHz respectively whereas the co-polarization level is smaller than the cross-polarization level on the H-plane at the same resonances. The proposed antenna has nearly omni-directional radiation patterns.

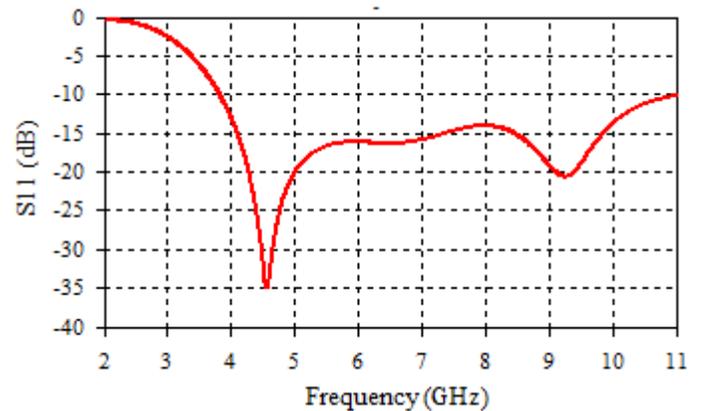


Fig. 4. The response of the input reflection coefficient.

TABLE 2
OPTIMAL PARAMETERS

Parameters	Optimal Value (mm)
lg	9.1316
r	7.0585
wf	1.4719
lf	9.533
wl	8.1170

The simulated peak gain over the spectrum from 2 to 11 GHz is shown in Fig. 6. As illustrated in the Figure, antenna gain with variation of less than 4dB is achieved, indicating stable

gain performance over the operating band.

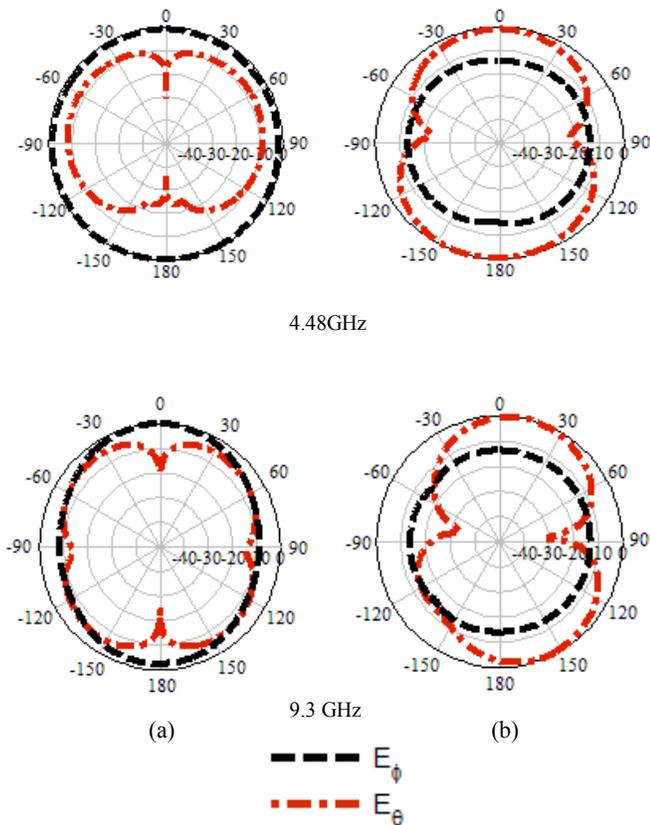


Fig. 5. Simulated radiation patterns in (a) xz-plane, and (b) yz-plane.

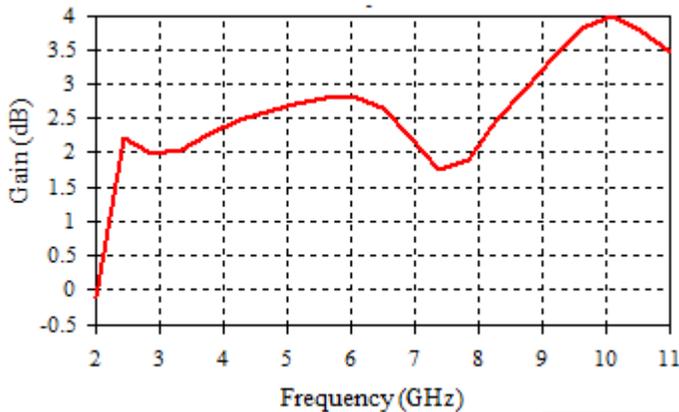


Fig. 6. Peak gain versus frequency

6 CONCLUSIONS

The optimization process of using bio-inspired algorithms for the development of UWB antennas, in particular GA and PSO have been presented. A new UWB antenna design procedure was demonstrated through the optimization of several antenna geometry parameters. The computational performances of the GA was found quite reasonable than the PSO for such design mechanism. Simulated results showed that the antenna has a good radiation pattern and gain with a wider performance bandwidth of 7.25GHz over the operating band.

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