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Compact Dual Band RFID Reader Antenna Designed using Ramped Convergence Particle Swarm Optimization

***Abstract**. A simple Particle Swarm Optimization (PSO) variant for micro-strip antennae is presented in this paper. A dual-band RFID reader broadband antenna, designed through traditional means, is optimized using this Ramped Convergence PSO (RCPSO). It is a Multi-Start algorithm that works on a specific set of optimization parameters. The algorithm is implemented using Matlab for the RCPSO computations. It uses Zeland IE3D 10.3 for simulation and fitness evaluation. The gain improves a significant 2 dBi over SHF band while keeping the effective antenna size same.*

***Streszczenie.** W artykule przedstawiono zastosowanie wariantu algorytmu PSO (RCPSO - PSO z konwergencją zmienną wg. rampy) w optymalizacji anteny mikro-paskowej typu RFID (dwupasmowa). Algorytm, ze względu na swoją specyfikację, wymaga dopasowania parametrów optymalizacji. Całość zaimplementowana została w Matlabie. W symulacjach oraz ocenie sprawności wykorzystywane jest środowisko Zeland IE3D 10.3. (**Projektowanie kompaktowego, dwuzakresowego odbiornika antenowego RFID z wykorzystaniem algorytmu PSO z konwergencją zmienną wg. rampy**).*

Keywords: PSO, microstrip antenna, RFID, optimization
Słowa kluczowe: PSO, antenna mikro-paskowa, RFID, optymalizacja.

Introduction

Advances in wireless communications have introduced tremendous demands on antenna technology. It also paved the way for widespread usage of mobile phones in modern society, resulting in mounting concerns surrounding its harmful radiation [1-5]. However, in the form of RFID technology, its use is quite handy for analysing high voltage devices and elements from a distance. Particle Swarm Optimization, or PSO, was first presented in [6]. Various practical applications have been found since the algorithm's inception, including but not limited to antenna design [7]. In [7], an extensive study of PSO is carried out various benchmark functions and problems. It illustrates the handling of particles flying out of the search space. It shows the 'invisible wall technique' to be the best of the lot but fails to explain why. In this study, some underlying assumptions were inferred from [7] about the 'walls' and a hybrid implementation was perceived. Wireless communication is considered one of the booming industries across the globe [8]. Thus it faces many challenges like meeting demands for added robustness, and in case of RFID antennae, higher gain. This results in a higher read range usually. Micro-strip antennae have a low profile and are compact enough to be placed on mobile communication units [8]. They are easier to combine with microwave circuits and are simple to fabricate and mass produce. Micro-strip antennae suffer drawbacks of low gain and narrow bandwidth. It may thus be inferred as an optimization problem. It practically makes no assumptions about the antenna or its properties [9]. While the underlying phenomena of patch antennae are understood, it is hard to extend them to complex geometric shapes and parametric analyses. Thus, a multi-start PSO algorithm is used as premature convergence is the key issue with PSO. It has been named Ramped Convergence PSO, or RCPSO. It breaks down the search-space to a two or three dimensional space and applies a rapid convergence PSO to it. The process is repeated for the next set of dimensions in the optimization problem.

Analogy and PSO terminology

PSO was pioneered by Kennedy and Eberhart in 1995 [6]. It was developed from the foraging behavior of bees in a garden looking for nectar. PSO uses particles, bees in our analogy, to represent candidate solutions. As the particles fly though the solution space, i.e. 'the garden', PSO stochastically updates the flight path. The updates depend on three factors which are termed inertia, cognitive and social. The equations used to describe PSO are shown below.

Eq. 1 shows how the momentary velocity of each bee is modified and eq. II shows how velocity is used to update the position of the bees. Now, the variables w, c1 and c2 are constants that determine the nature of the search. Choice of values for them is hotly debated and considered by most to be application specific.

$$(1)\qquad v_{i+1} = wv_i + c_1 r_1 \left(d_{localbest} - d_i\right) + c_2 r_2 \left(d_{globalbest} - d_i\right)$$

$$(2)\qquad d_{i+1} = d_i + v_{i+1}$$

where: v_i, d_i – velocity,dimensions of a particle at i^{th} iteration, w – inertia coefficient, c_1,c_2 – cognitive and social coefficients, r_1,r_2.- uniformly distributed random values between zero and one.

RCPSO

In this paper, the PSO was tweaked for the problem at hand. Industry requirements push for more multifunctional and miniature sized antennae. This was accounted for by considering any solution that resulted in an antenna that is larger than the original to be a non-feasible solution. Their performances were not evaluated and fitness was considered negative infinity. This work deals with a maximization problem (maximum gain achievable). Hence it is an elegant workaround to the particular problem. This is the invisible wall strategy.

On the other extreme, if a dimension becomes negative as allowed by equations (1) & (2), it results in a non-feasible shape and actually cannot be simulated properly or meaningfully. Hence another novel tactic is devised for this problem. The violating dimension is set to zero, making the design feasible. This is the absorbing wall strategy as shown in Figure 1. These violation handling techniques ensure reduced computation and a more thorough search for 'better' antennae which are definitely smaller than the original design.

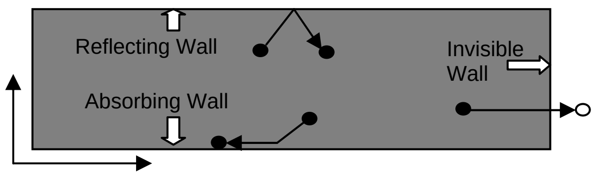

Fig.1. Illustration of different types of 'Walls' in a 2 dimensional search space. Valid region is shaded. Particles outside it (hollow particle to the right) are not evaluated.

In RCPSO, the acceleration coefficients are chosen for quick convergence. Finally, PSO is applied for about 7 to 10 generations on a set of sequential dimensions. The process is repeated for the next bunch of dimensions in sequence. The process lasts until a predetermined termination criterion. Pseudocode is as follows:

PSEUDOCODE FOR RCPSO

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Initialize no_of_dims, population:=18, g_best:=-∞, gen_max:=9,
fitness_function, n_shift:=2, active:=3,w=0.7,c1=1.2,c2=1.2
loop for i:=1 to no_of_dims
 initialize g_best_dims(i):=null , dmax(i), dmin(i)
 loop for j:=1 to population
  initialize v(j,i):=0, d(j,i):=rand(0,1), l_best_dims(j,i):=null,
l_best(j):=-∞
 end loop
end loop
n:=[1,2,….,active]                ;i.e. n:=[1,2,3]
loop
 loop for k:=1 to gen_max
  loop for j:=1 to population
   d_conv(j,n):=(d_max(j,n)-d_min(j,n))*d(j,n)+d_min(j,n)
   create antenna according to d_conv and simulate it
   get fitness for each member of population using simulation results
and          fitness function and store in fitness
   if l_best(j)<fitness(j)
    l_best(j):=fitness(j)
    l_best_dims(j,n):=d(j,n)
    if g_best<fitness(j)
     g_best_dims:=d(j)
     g_best:=fitness(j)
    end if
   end if
   v(j,n):=w* v(j,n)+c1*rand(0,1)*(g_best_dims-d(j)) +
               c2*rand(0,1)*(l_best_dims(j,n)-d(j))
   d(j):=d(j)+v(j,n)
   loop for i:=1 to no_of_dims
    if d(j,i)>1
     Do not evaluate, fitness(j)=-∞
     else if d(j,i)<0
      d(j,i):=0
     end if
    end if
   end loop
  end loop
 end loop
 n:=n+n_shift
 n:=(n-1)%no_of_dims +1
 loop for j:=1 to population
  v(j,all):=0, d(j,all):=g_best_dims, l_best_dims(j,all):=null,
l_best(j):=-∞
  d(j,n):=rand(0,1)
 end loop
while termination criteria not met
```

Antenna Design Considerations

The initial design was inspired from [10] and is shown in Figure 2. RFID bands from 840-920 MHz (UHF) and about 2.4-2.6GHz (SHF) are the target bands that require gain maximization, as higher gain usually translates to higher read range [10]. The fitness was hence considered the mean gain over the said frequencies. The initial design itself is simple. It is designed on a FR4 substrate with relative permittivity of 4.55, thickness of 1.6 mm, and loss tangent of 0.002. On one side a square ground plane of side 108 mm with a concentric circular slot is etched. One passive and one active strip are etched on the other side as shown in Figure 2. Antenna on the right is the optimized one. The dimensions of the strips were put up for optimization and the results are discussed in the next section.

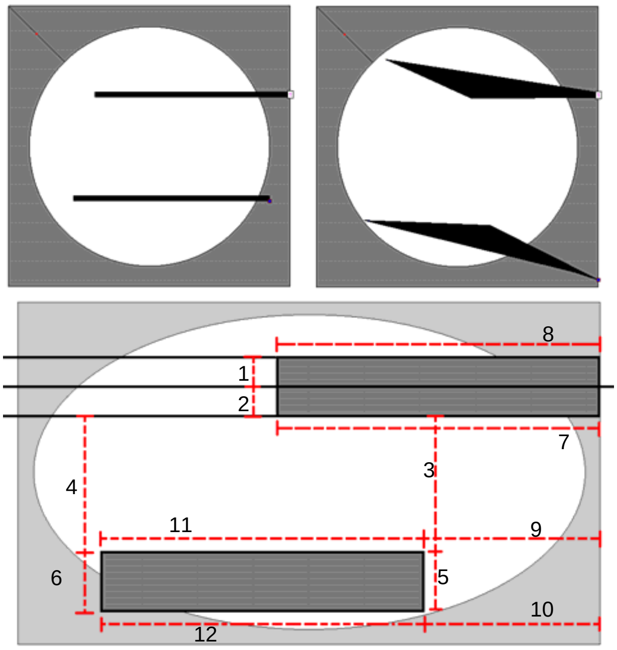

Fig.2. (Top left) Initial Design. (Top Right) Optimized design. (Bottom) Dimensions considered for optimization are marked with dashed lines with dimension number adjacent.

Table 1. Dimensions before and after optimization. All measurements are in millimeters

Dimension	Initial value	Optimized value
1	1	13
2	1	1.24
3	38	66.77
4	38	47.16
5	2	3.36
6	2	1.98
7	75	48.75
8	75	81.58
9	8	10.45
10	8	0
11	75	41.43
12	75	79.40

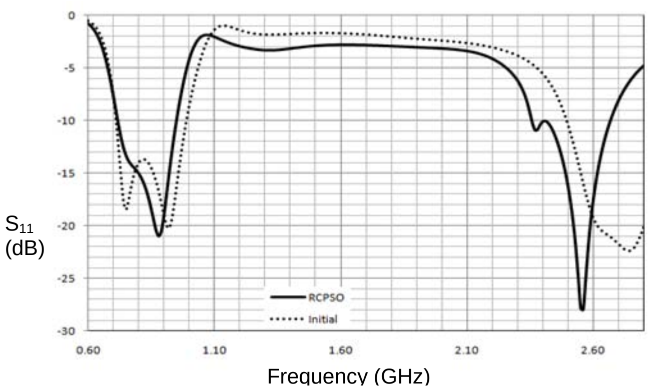

Fig.3. Return loss profile of antenna before and after optimization.

Discussions and Results

The dimensions and their values are shown in Table I. It can be seen that practically all dimensions have been significantly altered. Return loss profile in Figure 3 shows that S_{11} at both bands of interest are beneath -10 dB after optimization. Note that before optimization, the SHF band was misaligned and the resonance occurred at about 2.75 GHz, which is beyond the target range. In [10] it was claimed that the target SHF frequencies were covered, however, that design was evaluated in CST Microwave Studio and this study used Zeland IE3D. The discrepancy between results in [10] and the initial antenna results may be attributed to the fact that the two software use different evaluation techniques. Results show that the optimized design has return loss below -10 dB at 717-950 Mhz and 2.36-2.66 GHz, which covers our target bands. Though S_{11} was not explicitly present in the fitness function, it is accounted for by optimizing the antenna gain, which intrinsically considers return loss.

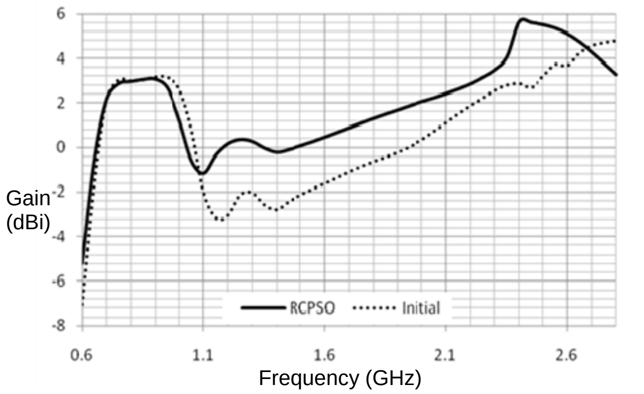

Fig.4. Simulated peak gain of antenna before and after optimization.

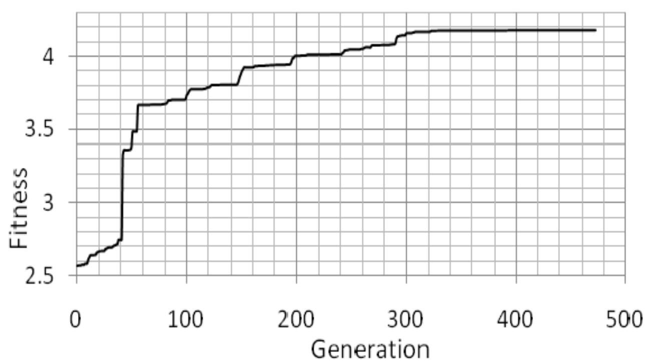

Fig.5. Global best fitness against generations of RCPSO.

Figure 4 compares gain of the initial to optimized antenna. It can be seen that the gain over the UHF band is practically same, whereas SHF band has seen marked improvement. Although it would have been preferred that both bands had gain improvement, the lower band was properly optimized in the initial design and further improvement requires increase in overall size, which was not allowed in this study. The SHF band shows an average of 2 dBi improvement, which once fabricated, should translate to higher read range. For the optimized design, average gain in UHF and SHF bands are 2.9 dBi and 5.5 dBi respectively, compared to 2.94 dBi and 3.2 dBi of the initial design. Finally, Figure 5 shows how the fitness of the antenna improved over the generations of RCPSO. The optimization stagnates about 340th generation. Considering the fact that this is a 12 dimensional antenna and that the RCPSO algorithm is designed for exhaustiveness of search, rather than speed of convergence, this is an acceptable value.

Conclusion

RCPSO is quite a light and handy tool for antenna design and optimization. This study illustrates how conceptual considerations can be incorporated into a RCPSO algorithm. The use of different walls yields an interesting avenue of study. Their combinations may be used to create countless possibilities and a study needs to be conducted to form guidelines in picking the correct combination for a particular problem. This algorithm shows great robustness in dealing with antenna design problems. It can be used with surgical precision to improve any desired antenna parameter from scratch or an initial design.

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