Optimal Antenna Design with QPSO-QN Optimization Strategy

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***Abstract*— A new optimization strategy with the ability of global search and rapid convergence is proposed for optimal antenna design with multi-parameters. The strategy combines the Quantum-behaved Particle Swarm Optimization (QPSO) algorithm with the Quasi Newton (QN) technique. The QN is employed after QPSO, in order to overcome the premature and to achieve higher accuracy. The method is demonstrated in optimizing a circularly polarized microstrip antenna design with five parameters. Heavy computation caused by sweeping on the parameters can be considerably reduced.**

***Index Terms*—Design optimization, particle swarm optimization, Newton method, microstrip antennas.**

I. INTRODUCTION

Particle Swarm Optimization (PSO) algorithm [1] has been widely used in optimization of complex engineering designs, due to its simplicity and rapid convergence speed. However, it has been shown that PSO does not satisfy the requirement for global research and cannot guarantee to converge upon the global optimum [2]. Considering the fact that the optimum attracts particles and in light of the concept of quantum potential well, the QPSO algorithm [3] was proposed to overcome the above mentioned shortage of PSO.

In recent years, PSO has also been applied to various microwave device and antenna design optimization [4]-[6]. QPSO is useful for solving electromagnetic optimization problems, and it is also necessary to pay enough attention to the inherent problem of possible premature. The Quasi Newton (QN) technique [7] with fast convergent ability near the optimum has relatively more strict demands on the original point and can complement QPSO.

Therefore, a new optimization strategy combining QPSO with QN is proposed for antenna optimization, namely QPSO-QN strategy. The basic idea of the strategy is using QPSO to produce the original point for QN.

II. DESCRIPTION OF THE STRATEGY

A. The QPSO Algorithm

Considering the QPSO algorithm searched by M particles in the D-dimension space, where D means also the number of parameters, the main formulas to be used in the iteration procedure [2] can be summarized by (1)-(3),

$$p_{id}(t) = \varphi_{id} \cdot P_{id}(t) + (1-\varphi_{id}) \cdot P_{gd}(t) \tag{1}$$

$$mbest_d = \frac{1}{M}\sum_{i=1}^{M} P_{id}(t) \tag{2}$$

$$x_{id}(t+1) = p_{id}(t) \pm \beta \left| mbest_d - x_{id}(t) \right| \cdot \ln(1/u_{id}) \tag{3}$$

where $x_{id}(t)$ is the d-th coordinate of the i-th particle at the t-th iteration, $\varphi_{id}(t)$ and $u_{id}(t)$ random number in the interval (0,1), $P_{id}(t)$ and $P_{gd}(t)$ the d-th coordinate of the best current position of both the i-th particle and the whole group respectively, $mbest_d$ the current mean best d-th coordinate, β (less than 1/ln2) usually set to decline linearly with the increase of the iteration order, and ± randomly set as + or −.

B. The QPSO-QN Strategy

The QPSO-QN strategy can be illustrated by the flow chart in Fig. 1, where $\mathbf{x}_i(t)$, $\mathbf{P}_i(t)$ and $\mathbf{P}_g(t)$ are all D-dimension vectors with the coordinate of $x_{id}(t)$, $P_{id}(t)$, and $P_{gd}(t)$, respectively. The flow chart of the standard QPSO will appear if the bold and italic text is ignored.

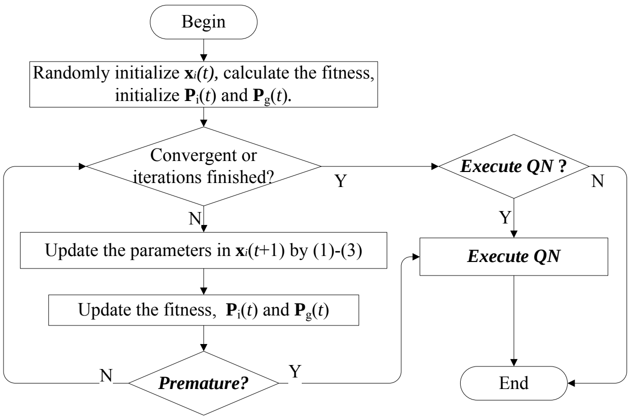

Fig. 1. Flow chart of the proposed QPSO-QN strategy.

III. ANTENNA OPTIMIZATION EXAMPLE

A. Structure and Optimization Strategy

A single feed chamfered and slipped microstrip patch antenna is chosen for example. The parameters of the FR-4 substrate are width W_s=80mm, thickness h=4mm, relative permittivity ε_r=4.4 and dielectric loss tangent δ=0.02. The top view of the patch and the sectional outline of the antenna are shown as Fig. 2, together with characteristics demands and the intervals of the variable parameters. The antenna may serve for the multi-mode receivers of GPS and COMPASS.

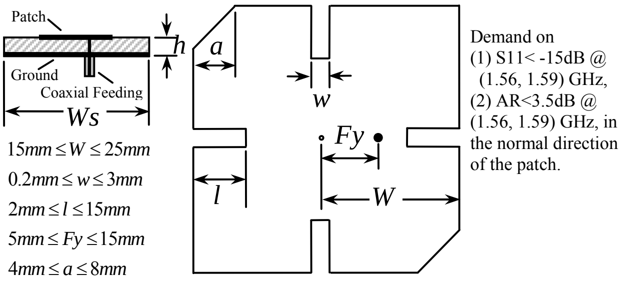

Fig. 2. Structure of the microstrip patch antenna.

The optimization is implemented by both MATLAB and Ansoft HFSS. HFSS implements electromagnetic computation and QN, while MATLAB is used to control HFSS by VBScripting and to implement QPSO. The parameters are organized as the vector $\mathbf{x}_i(t)=[W_i(t) \quad l_i(t) \quad w_i(t) \quad Fy_i(t) \quad a_i(t)]$.

The fitness value is calculated as (4),

$$Fit_i(t)=\left\{\max_{f\in[1.56,1.59]}\left[S11_i(t,f)+15\right]\right\}+\left\{\max_{f\in[1.56,1.59]}\left[AR_i(t,f)-3.5\right]\right\} \tag{4}$$

where $S11$ and axial ratio (AR) are both in dB, and the operator $\{value\}$ is defined as 0 if $value$ < 0, otherwise $value$. Therefore, $Fit_i(t)=0$ means that all the demands are satisfied.

As to accelerate the antenna optimizations, the size of the main radiation structure can be simply updated due to the principle of electromagnetic proportion. Hereby the parameter W of the i-th particle is updated as (5),

$$W_i(t+1)=W_i(t)\cdot f_{0i}(t)/1.575 \tag{5}$$

where $f_{0i}(t)$ is the frequency in GHz with the minimum axial ratio after the t-th iteration.

B. Optimization results and analysis

TABLE I. PERFORMANCE OF THE QPSO-QN.

Particle Number	Result of QPSO			Result after QN		
	[W, l, w, Fy, a]	*Fit*	*N*1	*[W, l, w, Fy, a]*	*Fit*	*N*2
3	[21.17, 5.20, 1.22, 11.32, 6.37]	0.49	39	[21.17, 5.20, 1.65, 11.32, 6.87]	0	13
	[20.54, 5.99, 2.20, 8.18, 4.28]	4.91	60	Acceptable cost limit not satisfied by HFSS	--	--
	[18.81, 9.91, 2.09, 7.51, 5.27]	3.18	36	[18.81, 9.91, 2.09, 7.54, 5.47]	1.99	23
7	[20.94, 6.76, 0.85, 10.50, 6.36]	3.23	56	[20.94, 6.76, 0.85, 10.82, 6.42]	0.46	9
	[21.23, 4.30, 2.56, 12.62, 6.77]	1.13	49	[21.24, 4.30, 3.00, 12.62, 6.90]	0	19
19	[20.59, 8.32, 0.57, 11.64, 6.58]	0.65	190	Acceptable cost limit not satisfied by HFSS.	--	--
	[21.63, 2.00, 0.31, 11.16, 6.76]	1.00	152			
29	[20.38, 7.94, 1.35, 10.96, 6.40]	2.27	319			

The performance of the QPSO-QN is illustrated by Table I. Since the electromagnetic computation spends almost all the time, the number of electromagnetic computations, denoted as $N1$ and $N2$ respectively for QPSO and QN, is given for indicating the efficiency of the strategy. Compared with the geometrically increasing computation number of parameter sweeping method, such that will mount to 3^5=243 if each interval of the 5 parameters is divided into only 3 subintervals, $N1$ and $N2$ are small and quite acceptable.

It seems that several solutions are found out by QPSO-QN. Among these solutions, the best one is [21.24, 4.30, 3.00, 12.62, 6.90]. Fig. 3 and Fig. 4 show the frequency responses of the Return Loss and the Axial Ratio.

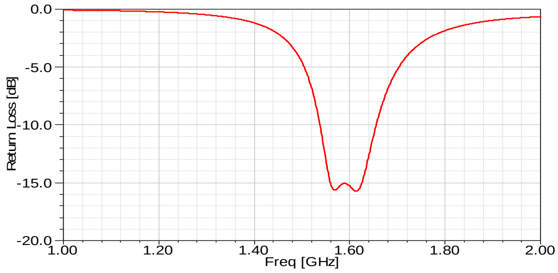

Fig. 3. $S11$ response with [21.24, 4.30, 3.00, 12.62, 6.90].

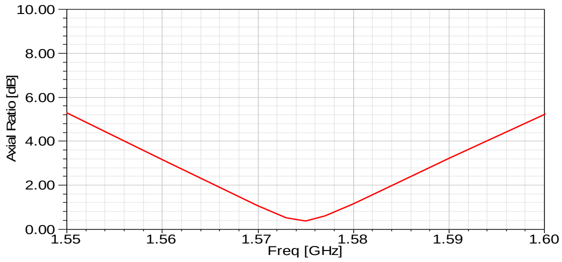

Fig. 4. AR response with [21.24, 4.30, 3.00, 12.62, 6.90].

According Table I, it seems unnecessary to use large particle population number M, because the result falls into premature so deeply that QN cannot achieve a result with acceptable cost, furthermore, the corresponding $N1$ is much larger than the case of small particle numbers.

IV. CONCLUSION

The proposed QPSO-QN strategy can be used for multi-parameter antenna optimization. The example shows that the QPSO-QN can find the solutions with no more than 7 particles. The proposed QPSO-QN strategy may be applied to other optimization problems with multi parameters.

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