Robust Optimization of IC Tag Antennas

Hidetoshi Makimura, Yasuhisa Ito, Yuta Watanabe and Hajime Igarashi
Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, 060-0814, Japan
igarashi@ssi.ist.hokudai.ac.jp

Abstract — This paper presents the optimal design for IC tag antennas considering uncertainties. In the optimization processes, fluctuations are added to design parameters and material constants to express the uncertainties. It is shown that the antenna shapes which have robustness are obtained with the robust genetic algorithm.

I. INTRODUCTION

Radio frequency identification has been widely used for wireless recognition and tracking, and been developing for other applications. It is uneasy to design the antennas which have desired properties, thus antenna shapes have been designed through optimization techniques. The authors have reported an evolutional design optimization of the antennas [1]. However, in the optimization, it has not been taken into consideration that the properties of the obtained antennas can be sensitive to the change of shape, materials, environment, and so on.

In this paper, we introduce a robust optimization for meander line antennas for parameter-tolerant design with the Genetic Algorithm (GA) [2]-[3]. This paper shows effectiveness of the approach and discusses the robustness of the solutions.

II. OPTIMIZATION APPROACH

A. Algorithm

We apply the robust GA [2]-[3] to antenna design problem to consider uncertainties. This approach searches the robust solutions by adding the fluctuations to the parameters such as material constants which have uncertainties. The expected value of the objective function is effectively evaluated with this method without time-consuming explicit sampling.

B. Objective Function

We optimize the shape of meander line antennas with the present techniques described above. The aim of this optimization is to maximize the read range of passive IC tags. For the passive RFID, the read range represents the maximum distance to receive the enough power to drive the IC chip from RFID reader/writer. To achieve the aim, it is important to realize impedance matching between the IC chip and tag antenna, and to maximize antenna gain. And from a practical aspect, decrease in the antenna size is desirable.

We assume that there is uncertainty in the relative permittivity ε_r of the dielectric substrate on which the antenna is formed. The fluctuations δ obeying the normal distribution N(μ, σ^2)=(0.0, $\varepsilon_r\times0.1$) are added to the ε_r to consider production error or effects of the ages. In our study, the mean value of ε_r is assumed to be 4.1 at 956MHz which corresponds to the legal frequency in Japan for RFID operation. Thus, fitness $f(C,\delta)$ of each antenna whose shape is defined by the chromosome C are obtained from,

$$f(C,\delta) = \tau(C,\delta)\cdot G(C,\delta) + k\left(1-\frac{S(C)}{S_{\max}}\right), \tag{1}$$

where the factor τ is the power transmission coefficients, G the antenna gain, S the antenna size, $S_{\max}$ the maximum size, and k is a weighting constant, respectively. The optimized antenna shapes would depend on the weight k. Increasing in k tends to decrease the antenna size, and reduces variety of the antenna shapes. Note that the change in ε_r of the substrate influences only the first term in the objective function. The transmission coefficients τ which represents the fraction of the power transmitted from the tag antenna to the IC chip is evaluated by,

$$\tau = \frac{4R_a R_c}{|Z_a + Z_c|}, \tag{2}$$

where, $Z_a=R_a+jX_a$ is the antenna input impedance and $Z_c=R_c+jX_c$=30-j350 the chip impedance which connected to the antenna as load, respectively. In this study, the Z_a and G are computed with the moment method.

III. RESULTS

The GA parameters are set as follows: the number of individuals N=200, crossover probability P_c=100% and mutation probability P_m=5%. To avoid convergence to local optima, 25% individuals are randomly generated every generation. We execute the optimized design with 10 random seeds. After the optimization, we compute the expected values of the objective function for the nine best individuals by Monte Carlo method with 2000 trials.

Figs. 1-3 show the average of τ, G and S for 10 random seeds depending on k, respectively. It can be found that the values of τ obtained with the present method are larger than those by the conventional GA without robustness consideration. From this result, it is concluded that the present method increases robustness in τ. On the other hand, there are little differences between G resulted from the two methods. Moreover the antenna sizes S without robustness consideration are smaller than those with the present method in all cases. It is suggested from these results that S tends to increase to ensure robustness. It is finally found that the values of f, which decreases with the antenna size, of the robust solutions are smaller than those of non-robust solutions when k is large, despite the optimized antennas obtained by the present method have robustness for ε_r which have uncertainties. Table I shows the values of τ and f with k=4, where it can be seen that the values of τ obtained by the robust optimization are greater than those by conventional optimization, whereas the values of f obtained by the robust optimization are smaller than those by the conventional optimization.

Figure 4 illustrates the profiles of f depending on ε_r where k=4. In Fig. 4 (a), the red zone, which shows the value of the first term of f, is wider in comparison with that in Fig. 4 (b). This suggests that the solution obtained by the present method is robust with respect to the first term in f. However the second term of f, which is not affected by the fluctuation δ, dominates the value of f. If robustness in τ is more important than the size, the present solution would be preferable. The present method has been extended to multi-objective problem, which will be discussed in the full paper.

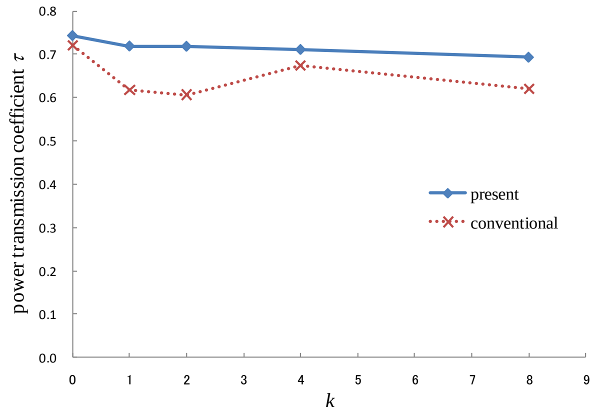

Fig. 1. Expected value of the power transmission coefficient τ.

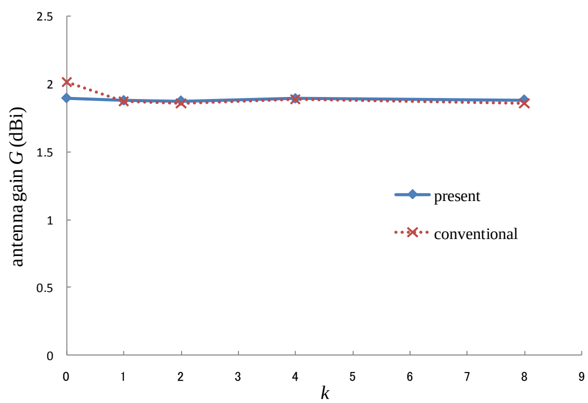

Fig. 2. Expected value of the antenna gain G.

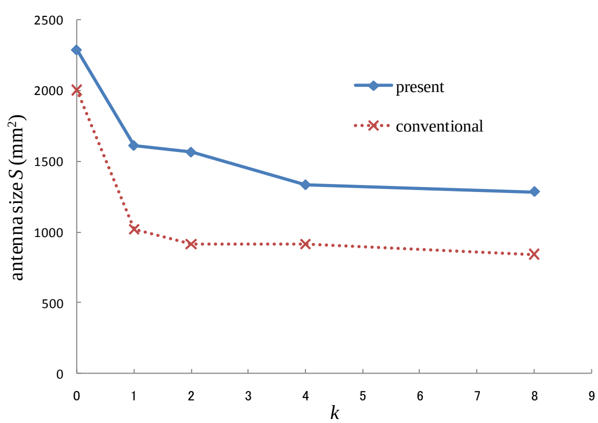

Fig. 3. Antenna size S.

IV. REFERENCES

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TABLE I

THE POWER TRANSMISSION COEFFICIENT τ AND FITNESS f (k=4).

	τ		f	
	present	conventional	present	conventional
max	0.736	0.726	4.338	4.556
min	0.641	0.521	4.044	4.192
average	0.711	0.674	4.219	4.437

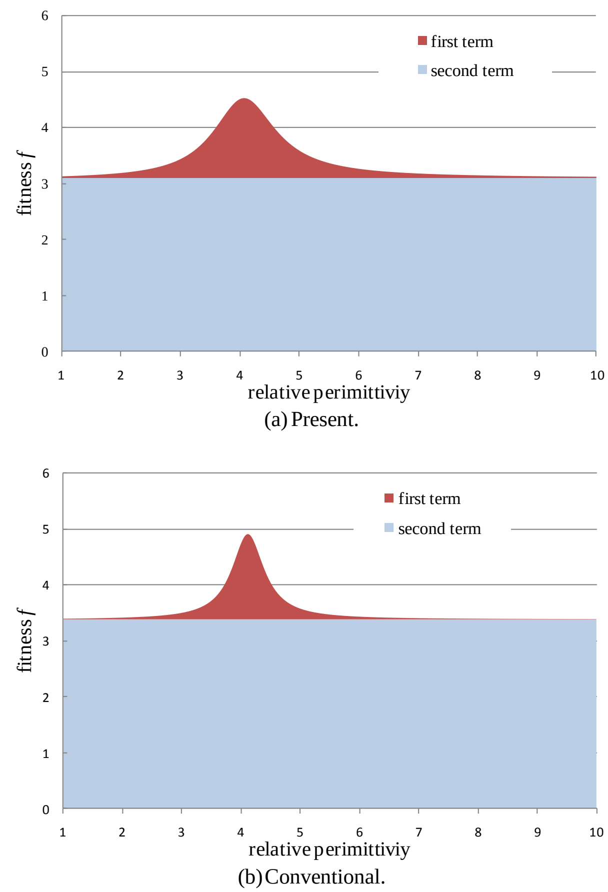

Fig. 4. Profiles of fitness f with k=4. (a) Present method. (b) Conventional method.