Design of the High-sensitivity RFID Sensor Tag with MOEA/D-DE

Xiaotian Song1, Gang Wang1, 2, and Yuxing He1
1Department of Electronic Engineering and Information Science, University of Science and Technology of China, Hefei 230027, China
2Key Laboratory of Electromagnetic Space Information, Chinese Academy of Sciences, Hefei 230027, China

Abstract **– The MOEA/D-DE (multi-objective evolutionary algorithm based on decomposition combined with differential evolution) is firstly applied to design a high-sensitivity RFID sensor tag with the consideration of its communication performance. For demonstration, an RFID temperature sensor tag is designed and tested. Both simulated and measured results show the designed sensor tag achieves a three times higher sensing sensitivity and a better communication performance than the one in the literature.**

Index Terms **— RFID sensor tag, sensitivity, temperature sensing, multi-objective evolutionary algorithm.**

1. Introduction

In recent years, passive RFID sensor tags (i.e., standard passive RFID tags combined with sensors) have found distinctive applications in several promising fields such as safety and security, industry process control, and habitat monitoring [1]-[3].

When a sensor is combined into an RFID tag antenna, the input impedance and gain of the tag antenna will be affected by the impedance of sensor, which usually changes with its environment. Thus, the change of environment will reflect on performance of tag, and can be remotely detected by reader.

The antenna of sensor tag is designed to perfectly match the RFID chip at a reference state of environment. Mismatch between chip and antenna occurs during sensing process. A wide dynamic range of mismatch indicates a high sensing sensitivity, and however greatly damages the communication performance (viz., read range) of the sensor tag at a fixed transmitted power of RFID reader.

For conventional designs of sensor tags [1]-[3], sensing sensitivity is treated as a nature outcome of a specific tag rather than a design objective. At meanwhile, the trade-off between sensing response and communication performance of tag should be carefully considered, which can be defined as a multi-objective optimization problem.

In this work, a multi-objective evolutionary algorithm based on decomposition combined with differential evolution (MOEA/D-DE) [4] is firstly applied to design a high-sensitivity passive RFID temperature sensor tag with the consideration of good communication performance.

2. MOEA/D-DE for High-sensitivity RFID Sensor Tag Design

For design of a high-sensitivity RFID sensor tag, the geometry parameters of tag antenna are determined by optimization searching with MOEA/D-DE. The formation of objective functions for the MOEA/D-DE is significant.

(1) MOEA/D-DE Framework

In the MOEA/D-DE, differential evolution (DE), one of the most powerful real parameter optimizers, is introduced into the MOEA/D [4] as the search method. The DE operator and a polynomial mutation operator are utilized to generate a new solution from the selected solutions. A flowchart of the MOEA/D-DE is shown in Fig. 1. The MOEA/D-DE is implemented by using Visual C++ 6.0 and HFSS 13.0.

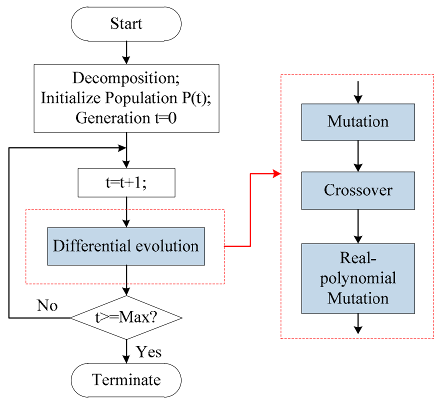

Fig. 1. Flow Chart of MOEA/D-DE.

(2) Multi-Objective Optimization Problem

In passive RFID sensors, high sensing sensitivity requires a sensor tag to have a wide dynamic range of realized gain (the product of gain G and power transmission coefficient τ). However, small values of realized gain in that range greatly damage the tag's communication performance or read range. The trade-off as discussed in Section 1 may be satisfyingly solved by multi-objective optimization.

In this work, the optimization is for minimization. By denoting the start and end states of monitored environment as Ψ_{max} and Ψ_{min}, the objective functions can be given as

$$\begin{aligned} f_1 &= \frac{1}{1+\max[G(\psi_{\max})\cdot\tau(\psi_{\max})-G(\psi_{\min})\cdot\tau(\psi_{\min}),0]} \\ f_2 &= \frac{1}{G(\psi_{\max})\cdot\tau(\psi_{\max})} \end{aligned} \quad . \quad (1)$$

In (1), f_1 is set to obtain as high as possible sensing sensitivity, while f_2 is for good communication during sensing. It should be noted that f_1 cannot be acquired through one time simulation, which reveals the difficulty of mastering sensitivity in conventional sensor tag design [1]-[3]. The G and τ in (1) is obtained at the center frequency of RFID system, e.g., 915MHz.

3. Design of A High-sensitivity Passive RFID Temperature Sensor Tag

In this section, an RFID temperature sensor tag is designed with MOEA/D-DE. Temperature sensing is performed by a thermistor NTC-MF52 used in [1]. RF impedance of the thermistor is viewed as a parallel connection of a resistance and a capacitance $Z_S(T) = R_S(T) \parallel C_S(T)$, both dependent on temperature T [1]. It is found that R_S decreases from 2.2$K\Omega$ to 200Ω while C_S increases from 0.3pF to 0.7pF, as the temperature moves from 25°C to 160°C. The impedance of RFID chip used here is 27-j200 Ω at 915MHz.

The structure of the sensor tag is shown in Fig. 2. The geometry parameters and their decision spaces are also defined in Fig. 2. The tag is optimized on an RF substrate with relative permittivity of 6.15 and a thickness of 1 mm.

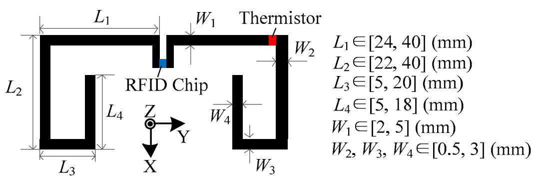

Fig. 2. The structure and geometry parameters of sensor tag.

By taking Ψ_{max} = 25°C and Ψ_{min} = 160°C into objective functions in (1), one good solution is given as L_1 = 36.3mm, W_1 = 2.1mm, L_2 = 22.3mm, W_2 = 1mm, L_3 = 20mm, W_3 = 2.6mm, L_4 = 18mm, W_4 = 2mm. For comparison, the simulated realized gain of the designed sensor tag, as well as that of the sensor tag in [1], changed versus temperature are depicted in Fig. 3. In the calculation of realized gain, the gain is along Z direction.

From Fig. 3, we can see the dynamic range of realized gain of the designed sensor tag is 0.6, almost 3 times larger than that of the sensor tag in [1]. The realized gain of the designed sensor tag is also much higher during the temperature variation process. Therefore, the sensor tag designed with MOEA/D-DE achieves not only much higher sensing sensitivity but also better communication performance than the sensor tag in [1].

The prototype of the designed RFID temperature sensor tag is shown as inset in Fig. 4. The maximum read ranges of the sensor tag at different temperatures are measured by an ALIEN-9900 RFID reader with a 4W EIRP transmitting power. The measured maximum read ranges, as well as theoretical ones, versus temperature are shown in Fig. 4.

From Fig. 4, we find that the difference between the theoretical and experimental results is within 10%. The measured maximum read range is decreased from 10.1 m to 4.3 m as temperature increases from 25 °C to 160 °C. Therefore, both simulated and measured results show that MOEA/D-DE can be used to design a high-sensitivity sensor tag with a good communication performance.

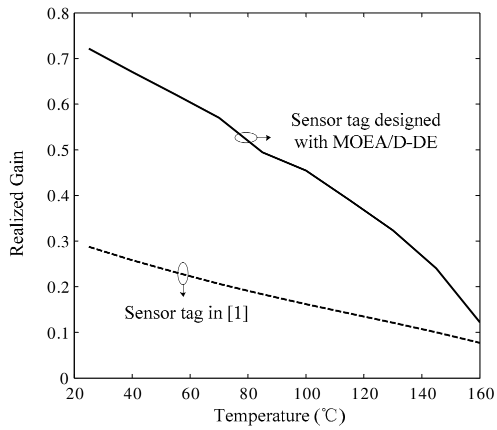

Fig. 3. The simulated realized gains of the designed sensor tag and sensor tag in [1] changed versus temperature.

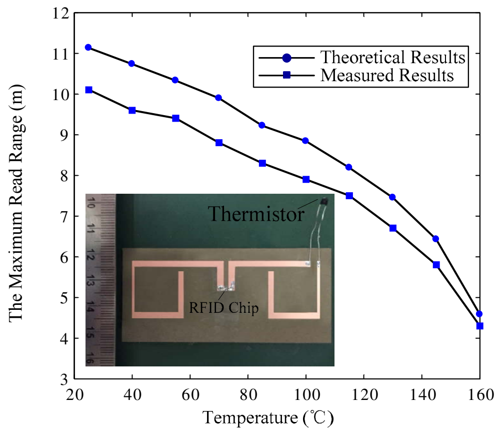

Fig. 4. Theoretical and measured maximum read ranges of the sensor tag in inset changed versus temperature.

4. Conclusion

In passive RFID sensor tag design, sensing and communication have opposite requirements. The trade-off between them can be greatly solved by a multi-objective optimization technique MOEA/D-DE, which is introduced to design an RFID temperature sensor tag in this paper. Both simulated and measured results show the designed sensor tag achieves a three times higher sensing sensitivity and a better communication performance than the one in the literature.

References

[1] S. Manzari, S. Caizzone, C. Rubini, and G. Marrocco, "Feasibility of Wireless Temperature Sensing by Passive UHF-RFID Tags in Ground Satellite Test beds," in *Proc. IEEE Int. Conf. WiSEE*, Noordwijk, The Netherlands, pp. 1–6, Oct. 2014.

[2] J. Gao, J. Sidén, H-E Nilsson, and M. Gulliksson, "Printed humidity sensor with memory functionality for passive RFID tags," *IEEE Sensors J.*, vol. 13, no. 5, pp. 1824–1834, May. 2013.

[3] R. Bhattacharyya, C. Floerkemeier, and S. Sarma, "Towards tag antenna based sensing—An RFID displacement sensor," in *Proc.IEEE Int. Conf. RFID*, pp. 95–102, 2009.

[4] H. Li and Q. Zhang, "Multiobjective optimization problems with complicated Pareto sets, MOEA/D and NSGA-II," *IEEE Trans. Evol. Comput.*, vol. 13, no. 2, pp. 284–302, Apr. 2009.