A Prior-Knowledge-Based Optimization Method for Microwave Sensor Design in Heavy Metals Detection

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***Abstract*—This paper describes a microwave sensor design optimization method based on prior knowledge for detecting heavy metals. combines prior-knowledge to optimize the structure and size of the microwave sensor simultaneously. In order to verify the detection performance of the microwave sensor optimized by the proposed method for heavy metal ions in liquid, the detection effect of the microwave sensor is verified using liquids containing copper. The results show that the microwave sensor optimized by the proposed method can efficiently identify the heavy metal ions content in the liquid.**

Keywords—design optimization, heavy metal ion detection, microwave sensor.

I. INTRODUCTION

Due to various heavy metal ions in water are highly toxic and difficult to degrade, they can accumulate in the animals, plants, and human body through the ecological chain [1]. Therefore, the industry has proposed various methods for heavy metal ion detection in liquid, such as the atomic fluorescence brightness method and the atomic absorption spectroscopy method. However, these methods still have problems, including cumbersome operation and long detection time. This work intends to optimize the microwave sensor of the heavy metal ion detection system to use microwave technology's heavy metal ion detection system for rapid detection of heavy metal ions.

As an essential part of the wireless detection system, the performance of microwave sensors [2] directly affects the effectiveness of the entire detection system. Therefore, the design of microwave sensors has become increasingly challenging due to the high-performance requirements. Fortunately, various optimization methods are used to address the challenges posed by design, including differential evolution [3] and particle swarm optimization [4]. However, most of the current optimization methods focus on the size of the microwave sensor, so a novel microwave sensor optimization method that can simultaneously optimize structure and size is urgently needed.

In this paper, a novel design optimization method based on prior knowledge that takes into account both the structure and size of microwave sensors is proposed. The sensor optimized by the proposed method was used for heavy metal ion detection to test its effectiveness.

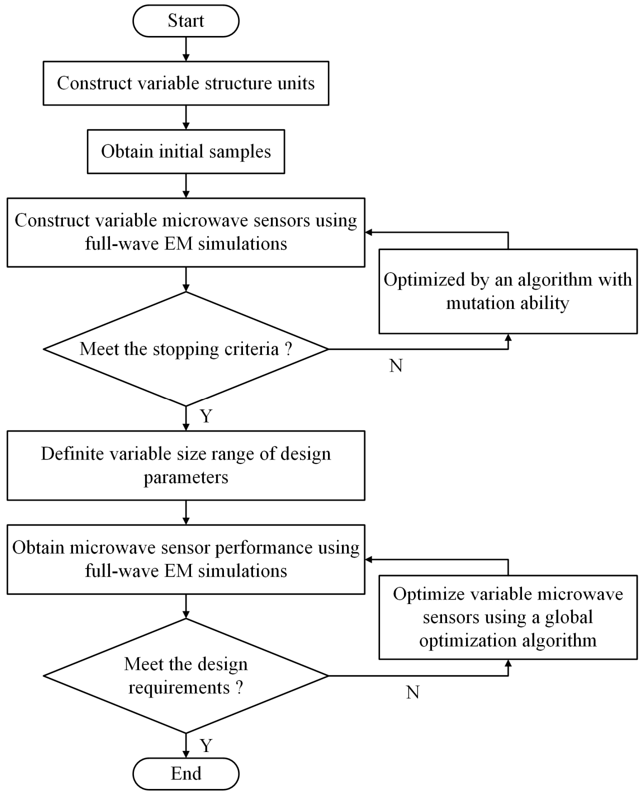

Fig. 1. The flowchart of the proposed method.

II. MICROWAVE SENSOR DESIGN OPTIMIZATION

The flowchart of the prior-knowledge-based microwave sensor design optimization method is shown in Fig.1. In the proposed method, the structure that can effectively affect the sensor's performance is used as variable structure units. The binary code is used to express the state of the variable structure units in the initial sample. Then, according to prior-knowledge, the number and location of the variable structure units on the microwave sensor are optimized by the algorithm with mutation ability. The variable range size of the microwave sensor's design parameters is further determined based on its

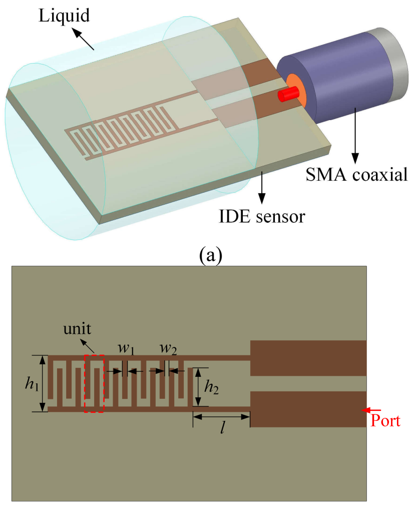

Fig. 2. Structure of IDE sensor. (a) 3D view. (b) Top view.

structure after structure optimization. Finally, based on the microwave sensor optimized in *Step 3*, the global algorithm is used to further optimize its performance in the defined definite variable size range of design parameters.

III. Applications and Results

A interdigitated electrode (IDE) sensor is optimized by the proposed method and used to detect the heavy metal ions. The variable structure unit of the IDE sensor is selected based on prior-knowledge, as illustrated in Fig. 2. The variable design parameter vector is $\boldsymbol{v} = [l, w_1, w_2, h_1, h_2]^T$. The vector's upper bound is $[8, 0.6, 0.6, 7, 4]^T$ mm and the vector's lower bound is $[3, 0.2, 0.2, 4, 1]^T$ mm. The working frequency of the IDE sensor is 0.3 GHz to 0.6 GHz.

Due to the heavy metal iron detection based on the microwave sensor's resonance peak responding to the dielectric constant's change of liquid, the objective function is defined as

$$O(\varepsilon, p) = \min \ln\left(\left|\frac{\sum_{i=1}^{N}\left(\varepsilon_i-\bar{\varepsilon}\right)\left(p_i-\bar{p}\right)}{\sqrt{\sum_{i=1}^{N}\left(\varepsilon_i-\bar{\varepsilon}\right)^2\sum_{i=1}^{N}\left(p_i-\bar{p}\right)^2}}-1\right|\right) \quad (1)$$

where N is the number of dielectric constants. ε_i and $\bar{\varepsilon}$ are the i_{th} value and the mean value of liquid's dielectric constant, respectively. p_i and $\bar{p}$ are the i_{th} resonance peak in the i_{th} dielectric constant of liquid and the mean of the resonance peaks. A lower $O(\cdot)$ value means that the liquid's dielectric constants and resonance peaks have a better linear relationship, and it also means that the page can more accurately reflect the detection results. In this work, the population size of the proposed method is 10, and the stopping criteria is exceeding 30 iterations.

In order to verify the performance of the IDE sensor after optimization by the proposed method, a heavy metal ion detection system is built, as shown in Fig. 3. The detection system mainly consists of a microwave sensor and a vector network analyzer for S-matrix measurements. As shown in Fig. 4, it can be known that the optimized IDE sensor's S_{11} by the proposed method shows a linear increasing change in

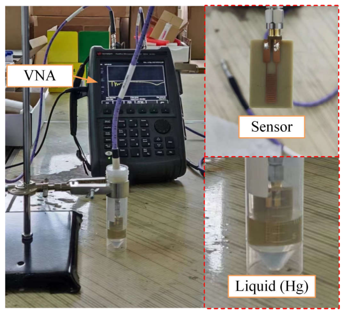

Fig. 3. Photograph of the heavy metal ion detection system.

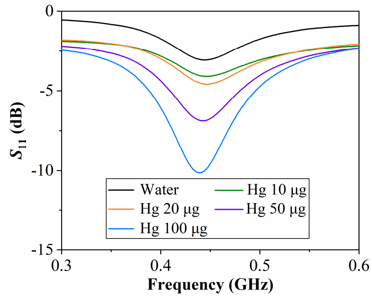

Fig. 4. Measured S_{11} of IDE sensor with different Hg ion content in 10 ml of liquid.

response to the content change of the Hg ion in the liquid, which proves the effectiveness of the proposed method for microwave sensor design optimization.

IV. Conclusions

This paper describes a new microwave sensor design optimization method that allows take into account both the structural and size optimization of the microwave sensor. The optimized microwave sensor is applied to a heavy metal ion detection system for Hg ion detection. The results show that the microwave sensor optimized by the proposed method has strong detection performance for liquids with different Hg ion contents, which verifies the effectiveness of the proposed method.

Acknowledgment

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