Electromagnetic Characterization of Biological Tissues with Particle Swarm Optimization

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6. OPTIMIZATION

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***Abstract* — The objective of this research is the electromagnetic characterization of biological tissues in radiofrequency domain. In this aim, a measurement bench including a vector network analyzer and an open-end coaxial probe was introduced. The complex permittivity identification of the middle under testing is performed by solving an inverse problem. A quadratic fitness function that represents the difference between reflection coefficient measurement and reflection coefficient acquired with the normalized aperture admittance is minimized. The optimization is based on a heuristic algorithm: particle swarm. The approach is validated on well known dielectric middle and then tested on biological tissues.**

I. INTRODUCTION

Numerical simulations of electric field distribution in the human body exposed to radiofrequencies waves require the knowledge of dielectric tissues properties [1]. In the radiofrequency domain, several experimental techniques can be used for measuring permittivity ($\varepsilon^*=\varepsilon_r-i\varepsilon_i=\varepsilon_r+i\sigma/\varepsilon_0\omega$): free space, resonant technique, transmission/reflection line and open-ended coaxial [2]. In our study, the open-ended coaxial probe has been selected for its suitability for liquid or soft materials such as biological materials without specific preparation. Temperature can be easily controlled and after the bench calibration several samples can be rapidly treated. This point is crucial since biological samples can be easily altered or desiccated. The bench measurement provides an electric Scattering (S) parameter or reflection. The permittivity is identified on the base of an inverse method that using Particle Swarm Optimization (PSO) procedure for minimizing the quadratic difference between the measured and the calculated reflection from a direct model. In the first part, the global procedure measurement is described and the method to identify the permittivity of the Middle Under Testing (MUT) is exposed. In the second section, the proposed approach is validated on MUT known and then tested on biological tissues.

II. PROCEDURE

The characterization contents two parts, the reflection coefficient measurement from probe aperture/MUT interface and the identification of permittivity from the reflection coefficient measured. A sensitivity analysis has been performing so as to optimize the experiments. Calibration, sensitivity and identification procedure are in C-language.

A. *Measurement bench and calibration*

The experimental radiofrequency bench is composed of a Vector Network Analyzer (VNA), an open-ended coaxial probe and an optical fiber thermometer. The probe is a semi-rigid coaxial line (UT85) mounted on a N connector. The probe is 200 mm long, inner and outer radius are respectively a=0.255mm and b=0.84mm. The reflection coefficient (S_{11} parameter) of the MUT is obtained with VNA in the frequency range fixed (0.5 to 4 GHz) and for each frequency imposed by the linear step.

To determine the correct reflection coefficient of MUT, it is necessary to apply to the measured parameter $S^*_{11,m}$ some correction coefficients [3]. These coefficients are obtained from three additional measurements, on well known middles, respectively j=short circuit ($S^*_{11,m}=-1$), air (ε_r=1, ε_i=0) and de-ionized water (ε_s=25, ε_∞=4.3, τ=170ps) (1). The corrected $S_{11,c,MUT}$ is then calculated for each frequency (1).

$$S^*_{11,m,j} = E_D + \frac{E_R S^*_{11,c,j}}{1-E_S S^*_{11,c,j}} \tag{1}$$

B. *Inverse problem*

The identification of the MUT permittivity is based on the normalized aperture admittance [4]:

$$Y^* \approx \frac{-i2\omega\varepsilon_0\varepsilon^*}{\ln b/a} \int_a^b\int_a^b\int_0^\pi \frac{\cos\varphi}{r} + ik\cos\varphi - \frac{k^2 r}{2}\cos\varphi - i\frac{k^3 r^2}{6}\cos\varphi . d\varphi . d\rho . d\rho' \tag{2}$$

with $k=\omega\sqrt{\mu_0\varepsilon_0\varepsilon^*}$, the propagation constant for the MUT, $r=\sqrt{\rho^2+\rho'^2-2\rho\rho'\cos\varphi}$, the distance between the source point and the field point, ρ' and ρ are respectively the radial coordinates of these points at the aperture of coaxial probe. The reflection coefficient is related to the normalized probe admittance (3) with Y_0=1/50.

$$S^*_{11,adm} = \frac{Y_0 - Y^*}{Y_0 + Y^*} \tag{3}$$

The Fitness Function (FF) to minimize is given by (4).

$$FF = \left(\frac{\mathrm{Re}\left\{S^*_{11,adm} - S^*_{11,c,MUT}\right\}}{\mathrm{Re}\left\{S^*_{11,c,MUT}\right\}}\right)^2 + \left(\frac{\mathrm{Im}\left\{S^*_{11,adm} - S^*_{11,c,MUT}\right\}}{\mathrm{Im}\left\{S^*_{11,c,MUT}\right\}}\right)^2 \tag{4}$$

This minimization problem is solving with PSO technique. PSO involves simulating social behavior among individuals (particles) “flying” through a multidimensional search space, each particle representing a single intersection of all search dimensions [5]. Particles in a swarm move in discrete steps based on their current velocity, memory of where they found their best fitness value, and a desire to move toward where the best fitness value was found so far by all of particle during a previous iteration (Fig. 1). Each particle has a position and a velocity: their values are randomized initially. The position with highest fitness score in each iteration is set to be the entire swarm's global best (gbest) position, towards which other particles move. In addition, each particle keeps its best position that it has visited, known as the particle's personal best (pbest). Each particle n of the swarm is defined as a potential solution to the problem.

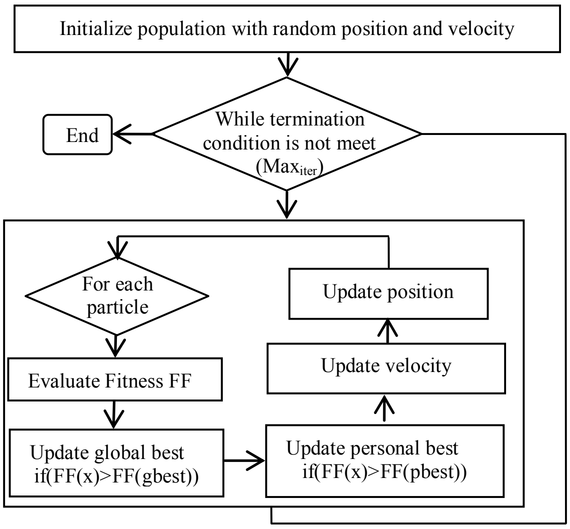

Fig.1. The Particle Swarm Optimization algorithm.

The particle dynamics are governed by the following rules which update particle positions x_n and velocities:

$$v_n = wv_n + c_1 rand1 \frac{pbest_n - x_n}{\Delta t} + c_2 rand2 \frac{gbest - x_n}{\Delta t} \quad (5)$$

After a new velocity for each particle, the position is calculated according to $x_{n+1} = x_n + v_n \Delta t$. Where x_n is the current position of particle n, Δt the time step equal to 1, x_{pbest} is the best position attained by particle n, x_{gbest} is the swarm's global best position, v_n is the velocity of particle n, w is a random inertia weight, c_1 and c_2 are two positive constants, called the social and cognitive parameter, rand1 and rand2 are random numbers between 0 and 1.

III. VALIDATION AND RESULTS

All the measurements presented in the following are realized on MUTs at 23°C for 1 000 frequencies linearly spaced. The swarm size is fixed to 10 particles. In a purpose of comparison an ethanol MUT has been tested and our proposed approach has been compared to Debye model (6) with these parameters ε_∞=4.3, ε_s=25 and τ=170ps (Fig. 2).

$$\varepsilon(\omega)^* = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} \quad (6)$$

Validation results are presented, a good agreement is found between the Debye model and our model approach results, the impact of calibration is also studied (Fig. 2). Then our approach is used on pork skin tissues (Fig. 3), since a sensibility analysis with reduced sensitivity functions has shown the ability to easily identify both imaginary and real of the permittivity in the range of frequencies by using the imaginary part or the phase of the reflection coefficient.

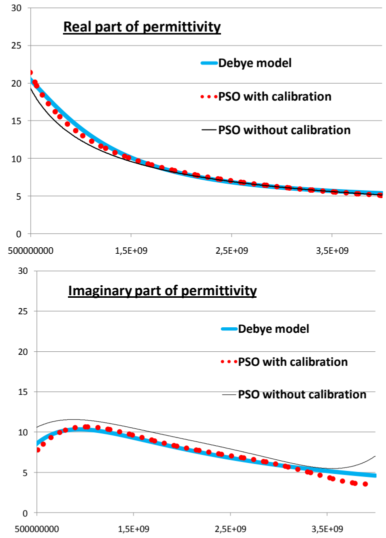

Fig.2. Validation on ethanol sample with and without calibration.

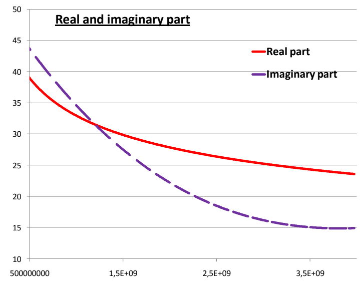

Fig.3. Complex permittivity of pork skin tissues.

IV. CONCLUSIONS AND PERSPECTIVES

Several perspectives of this work are considering. Firstly, a comparison in term of efficiency between the Levenberg Marquardt and the genetic algorithm will be done with application of the sensitivity conclusions. Secondly, the mono-layer approach presented in this paper will be enhanced for applications on bi-layered or multi-layered MUT and thirdly a micro coaxial probe will be developed.

V. ACKNOWLEDGMENT

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