HIGH FREQUENCY CHARACTERIZATION OF PRINTED AND ETCHED FABRIC BASED CONDUCTIVE MATERIALS FOR THE DEVELOPMENT OF WEARABLE ANTENNAS

Toumaj KOHANDEL GARGARI

***Abstract*— Wearable textile system and its revolutionary emphasis on the world of electronics, telecommunication and textile has undisputable role in our daily life. The use of flexible electronics and wearable antenna are growing each day. Industrial and space related applications along with the medical, rescue affairs, cell phone and GPS are outstanding usage of these technologies [1],[2].**

This article is dedicated on the characterization methods of wearable antennas and microstrip lines at resonance frequency of 2.45GHz, ISM band. Primarily, the characterization approach is presented in order to determine the complex permittivity of the textile antenna substrate as well as the effective conductivity of the electrotextile. In this inverse technique, material parameters are extracted by comparing measured and simulated antenna results. Additionally, the inverse problem is solved using a surrogate-based optimization method as implemented in the SUrrogate MOdeling (SUMO) Toolbox, resulting in the quicker and more accurate determination of the electromagnetic properties in comparison of solving inverse problem of manually.

Consequently, usage of electrotextile as conductor material affects the effective permittivity of the substrate. So, textile substrate characterization for wearable antennas and microstrip lines demands same conductive materials used for them in order to test them. This research concentrates on development of wearable antennas and microstrip lines.

***Index Terms*— Textile antennas, SUMO, Microstrip line**

I. INTRODUCTION

In this article, the characterization methods of wearable antennas and microstrip lines at resonance frequency of 2.45GHz is being researched. Primarily, the characterization approach is presented in order to determine the complex permittivity of the textile antenna substrate as well as the effective conductivity of the electrotextile. In this inverse technique, material parameters are extracted by comparing measured and simulated antenna results. Additionally, the inverse problem is solved using a surrogate-based optimization method as implemented in the SUrrogate MOdeling (SUMO) Toolbox, resulting in the quicker and more accurate determination of the electromagnetic properties in comparison of solving inverse problem manually.

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II. CHARACTERIZATION

For the fixed antenna geometry, resonance frequency f_r is only affected by relative permittivity ε_r. For the remaining unknown parameters, loss tangent $tan\delta$ and conductivity σ, there are no simple relations showing the dependency of them on antenna efficiency e_{cd} and bandwidth BW. Also, antenna efficiency e_{cd} and BW are affected by $\varepsilon_r$of the substrate. Therefore, the inverse characterization problem presented here uses an integral equation technique solved by the Method of Moments as implemented in Momentum from Agilent Technologies.

By using this method the complex permittivity of the substrate and conductivity of the electrotextile are extracted by fitting simulated data onto measured textile antenna performances. The outputs of the simulation model are the reflection coefficient and antenna efficiency at the resonance frequency, which are then compared to the measured data in order to calculate the error functions [3]. Then, inverse problem is converted into a forward optimization problem by minimizing an error function. Proceeding, Surrogate-based optimization technique is used in order to increase the accuracy of the method by minimizing the error function and extracting the unknown electromagnetic properties. As it is unfeasible to make a distinction between conductor losses and dielectric losses in antenna, a two-step characterization process is presented. First, the optimization process is applied to copper based textile antennas, yielding permittivity and loss tangent of the substrate. Second the optimization process is applied to electrotextile based textile antennas, resulting in the corrected permittivity of the textile substrate and the extracted effective conductivity of the electrotextile [4].

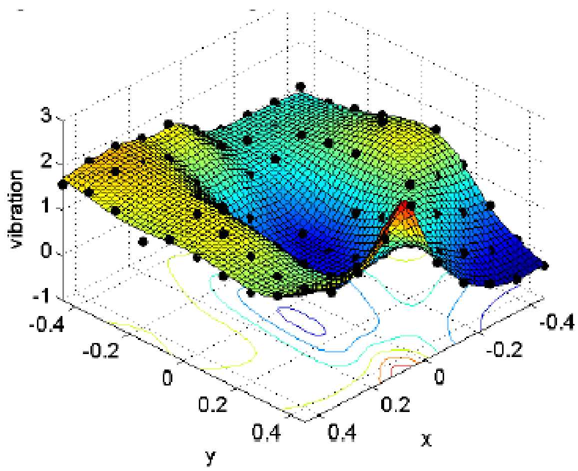

Fig. 1. Example of SUMO Toolbox Kriging Model

SUMO toolbox is a MATLAB toolbox which is used to solve inverse problem. It constructs a surrogate based model on the given data samples as depicted in Figure 1.The samples are well chosen points as they are chosen by optimization algorithm. This is done by building 24 initial samples which 4 are corners and the model stops building when 70 samples has been reached [26]. In Figure 2, you can see a clear description of SUMO toolbox function:

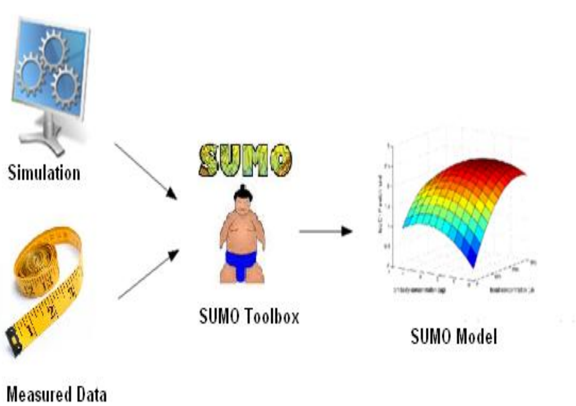

Fig. 2. SUMO Toolbox functioning

As the first step for SUMO toolbox before running, we have to set the permittivity, loss tangent limitation values for the Copper based antennas and in the second step where the loss tangent is extracted from step one, we set the loss tangent constant for the Flectron based antennas and we arrange the limitations for permittivity and conductivity to get the optimum point of conductivity.

MEAN ERROR FUNCTION APPLIED TO THE ANTENNAS

SUMO toolbox `s result of Kriging model is three dimensional model where the z-axis is always defined as MSE standing for mean error function and according to the name, it is the mean value of the calculated error between the simulation results and measurement results , so defined as:

$$\mathrm{MSE} = a_1 \frac{1}{n}\sum_{i=1}^{n} w_i \left(\left|S_{11,i}\right|^{dB} - \left|\widetilde{S_{11,i}}\right|^{dB}\right)^2 + a_2\left|e_{cd,fr,s} - \widetilde{e_{cd,fr,m}}\right| \quad (1)$$

Where ~ denotes the measured data; a_1, a_2 are weighting factors and initially are one but for changing the contribution of any part, they may vary.

III. Parametric Study and Experimental Results

Obtained results using above method is shown in this part.These results are yielded from two kinds of antennas; cotton based antennas and Azurri based antennas.

i. .COTTON BASED ANTENNA

By optimization process here, optimum points are obtained. They are representing the best agreement between simulated and measured results and showing the perfect performance of the surrogate based optimization process to optimize the error function in a relatively few numbers of evaluations. The first experiment is copper cotton antenna where we obtain MSE for given range of permittivity for [1.5 2.6] interval and loss tangent in the range [0.005 0.15].

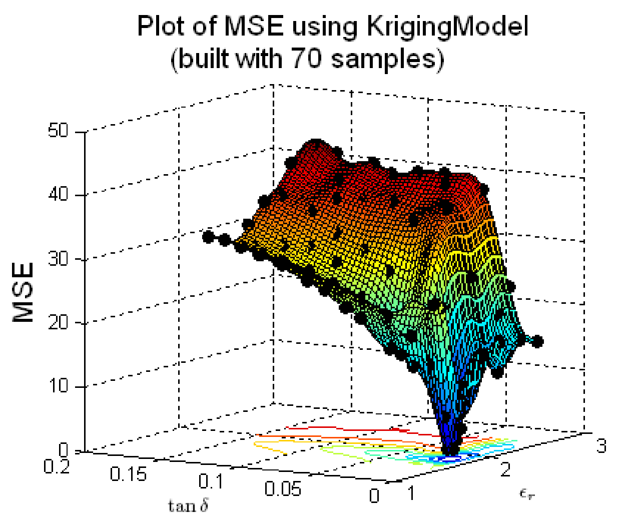

Fig. 3. Final Kriging surrogate model based on error function MSE in step 1 of the characterization process. Material: cotton, copper.

Table 5.1: Cotton Based Antenna Results

Antenna Type	Permittivity	Loss tangent	MSE
cotton_Copper	1.6041	0.0089	7.2248

Antenna Type	Permittivity	Conductivity(S/m)	MSE
cotton_Flectron 1	1.7028	659990	0.4976
cotton _Flectron 2	1.6842	616780	2.1777
cotton _Flectron 3	1.7164	682950	2.8348
cotton _Flectron 4	1.7204	692920	2.3614
cotton _Flectron 5	1.6678	572980	0.6569

Initially, target is obtaining the value of loss tangent.Then, we use the yielded value of loss tangent in second step of optimization of Flectron cotton antennas. In this step, we repeat the optimization process for five similar antennas where the given inputs are permittivity in the range of [1.5 2.6] and conductivity in the range of [5000 5000000]. Next is working on optimizing the conductivity for the Flectron.

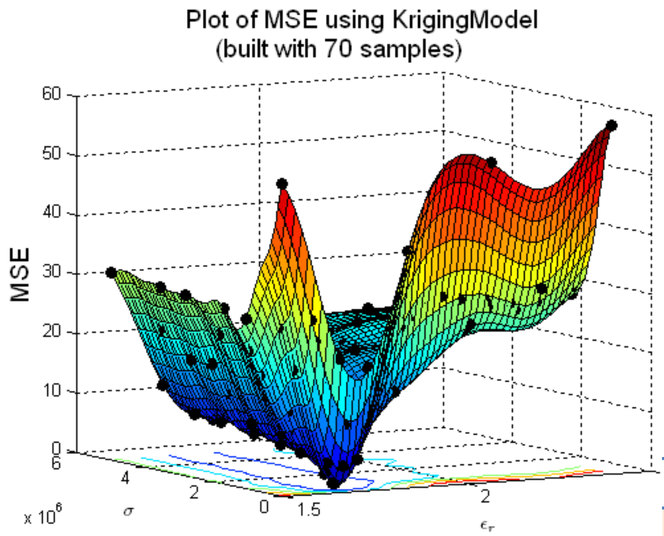

Fig. 4. Final Kriging surrogate model based on error function MSE in step 2 of the characterization process. Material: cotton, Flectron

Figure 3 represents the final Kriging model of cotton copper antenna where the minimum MSE can be seen clearly. This point is the optimum point which is is depicted in Table 5.1 shows the best fit between the simulated and measured results. The obtained loss tangent of this optimum point will be used as the constant input in the second step for cotton Flectron antennas. Final surrogate Kriging model of cotton Flectron is shown in Figure 4.

In second step, in addition of loss tangent, other two inputs are relative permittivity and conductivity. As Figure 4 one can see the minimum point of MSE where demonstrates the optimum point of fitted simulated and measured results. The goal of this step is to optimize the conductivity of the Flectron based antennas. Optimum values for Flectron based antennas are also depicted in Table 5.1.

ii. AZURRI BASED ANTENNA

We repeat the latter operation to Azurri based antenna where the optimization initial range of permittivity is [1 1.5] and loss tangent is [0.0001 0.05], respectively. Repeatedly, loss tangent is obtained from copper Azurri antenna optimization and then this value is applied as a constant input in optimization of five Flectron based antennas. In addition, the permittivity in this step is in the range of [1 1.5] and conductivity is in the range of [5000 5000000].So, for Azurri based antennas we follow the same steps which we used in cotton based antennas. In other word, extracted loss tangent value from copper based microstripline is used in the next step to optimize the the conductivity of the electrotextile.

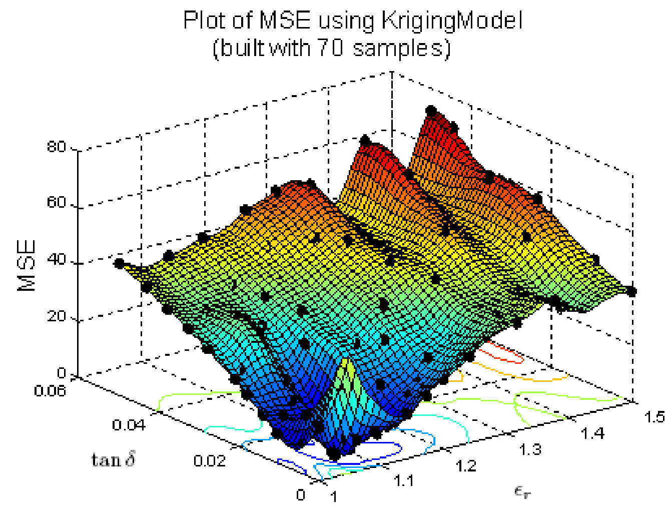

Fig. 5. Final Kriging surrogate model based on error function MSE in step 1 of the characterization process. Material: Azurri, copper

Table 5.2: Azurri Based Antenna Results

AntennaType	Permittivity	Loss tangent	MSE
Azurri_Copper	1.0738	0.0076	0.5904

Antenna Type and Number	Permittivity	Conductivity(S/m)	MSE
Azurri_Flectron1	1.0571	872380	6.4013
Azurri_Flectron2	1.1580	481740	3.6380
Azurri_Flectron3	1.1053	310530	7.2987
Azurri_Flectron4	1.1369	518900	5.6703
Azurri_Flectron5	1.1177	370250	3.1484

Figure 5 represents the final Kriging model of Azurri copper antenna where the minimum MSE can be seen. This point is the optimum point which is depicted in Table 5.2, shows the best fit between the simulated and measured results. The obtained loss tangent of this optimum point will be used as the constant input in the second step for Azurri Flectron antennas. Final surrogate Kriging model of cotton Flectron is shown in Figure 6.

In second step, in addition of loss tangent, other two inputs are relative permittivity and conductivity. Minimum point of MSE can be seen in Figure 6 where this point demonstrates the optimum point of fitted simulated and measured results. The goal of this step is to optimize the conductivity of the Flectron based antennas. Optimum values for Flectron based antennas are also depicted in Table 5.2.

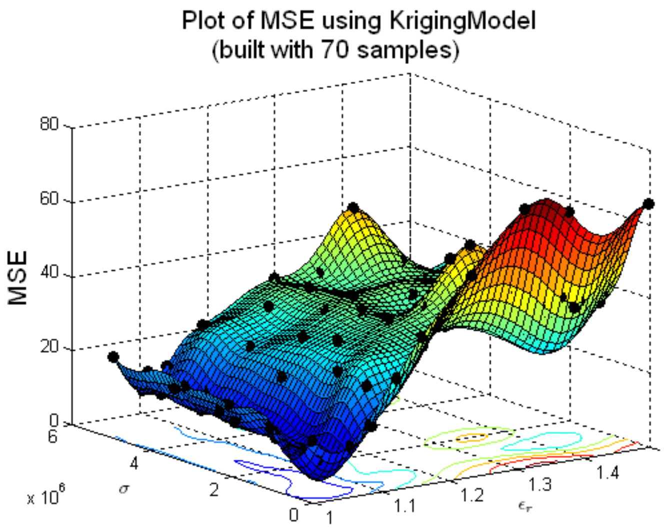

Fig. 6. Final Kriging surrogate model based on error function MSE in step 2 of the characterization process. Material: Azurri, Flectron

IV.CONCLUSION

According to the results of Tables 5.1 and 5.2 yielded from characterization process and comparing the conductivity colum of both Tables, it can be mentioned that the stability of conductivity in the cotton based antennas is more outstanding than Azurri based antennas. Furthermore, by performing these experiments on five samples each, we could conclude in the repeatability of the results.

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