USEFUL MATLAB TOOL FOR RADIO FREQUENCY DESIGNER

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Abstract

This article deals with the design and construction of the microwave applicator with transversal electro-magnetic (TEM) wave, which is filled by distilled water. We have constructed an applicator that works on the frequency *f = 434MHz* with aperture size of *100mm x 75mm*. The applicator is made of the copper. Design of dimensions of the applicator and simulation of the specific absorption rate (SAR) distribution were created in program SEMCAD X LIGHT 13. We have designed an image segmentation algorithm based on histogram fuzzification and k-means algorithms and a simple graphical user interface for computing of SAR distribution area, both in the MATLAB environment.

Introduction

Design of the microwave applicators for thermo – therapeutic applications is useful in hyperthermia oncology, which is a promising method of oncology treatment [1]. There is a need for simulation of the thermal effect of the applicator on the applied tissue. In design, there is an often spelled question: how does the applicator radiate into the tissue and what is the shape and size of the effective aperture area?

In nowadays market, there is a variety of simulators of electromagnetic field which offers us a great variety of running the simulations as well as really advanced visualization of the computed results. There are often very attractive output images in visualizing the results and showing the proportional radiated power from the antenna or the attenuation of a certain material according to its permittivity and conductivity but there is a need for the scalar interpretation. Thus, the MATLAB with the image processing toolbox can be useful in summarizing the whole area of radiated field from the aperture.

The algorithm from statistical and machine learning theory such as histogram fuzzification and K-means clustering are available candidates for performing the automatical results. Subsequently, we design the graphical user interface (GUI) to easily pick up the correspondent colours from the chart with the intended range of the radiated power. Subsequently, the total size of the radiated power area of the chosen range will be instantly shown, and the relative percentage of the aperture will be computed. The same principle can be applied on the cross sectional view of the antenna or applicator, and it can be simply separated from the sections of the chosen energy dissipation. This knowledge will help the radio frequency designers to effectively compare the antennas. Moreover, the applicator can be listed in the statistical database with a known scalar of an effective size of the aperture.

1 Microwave Thermotherapy

As for utilization of microwave technique in thermotherapy, especially in local hyperthermia, applicators suitable for heating of tissue are being constructed. Microwave thermotherapy is useful in tumors treating. It may be used in cancer treatment to kill or weaken tumor cells with limited effects on healthy cells. Tumor cells have problem with dissipating of the heat because of a disorganized vascular structure. Therefore, hyperthermia may cause cancerous cells to undergo apoptosis in direct response to applied heat while the healthy cells can easily maintain a normal temperature. Moreover, when the cancerous cells do not die outright, they may become more sensible to ionizing radiation treatment or to certain chemotherapies. Thus, the therapy can be applied in smaller doses. There are

number of thermotherapy methods, including focused ultrasound, infrared sauna, radio or microwave-frequency radiation, and magnetic nanoparticle therapy.

2 Design of the Applicator

From the analytical point of view, we can consider the analogy of the applicator as a transmission line where the one end represents the shorted circuit and the other end represents the connection between the applicator and the biological tissue [2] (see figure 2.1.).
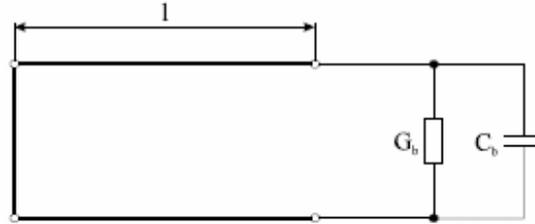

Figure 2.1: Electric circuit analogy of the applicator

The biological tissue can be modeled electrically [2], as a parallel connection of the resistor and capacitor. Using the equation (2.1) we will obtain a

$$Z_b = \frac{\omega\mu}{k} = \sqrt{\frac{j\omega\mu}{j\omega\varepsilon + \sigma}} \,, \tag{2.1}$$

impedance of the biological tissue. Conversion of this relation into admittance (2.2) and addition of the phase constant (2.3) lead to equation (2.4).

$$Y_b = 1/Z_b \,, \tag{2.2}$$

$$\beta = k = \omega\sqrt{\mu\varepsilon} \,, \tag{2.3}$$

$$l = \frac{arctg\,\mathrm{Im}(Y_b) + n\pi}{\beta} \quad . \tag{2.4}$$

Solving the equation (2.4), we will obtain all possible lengths that are suitable for creation of the applicator. From all the possible lengths, $l = 117mm$ has been chosen.

3 Simulations

All the simulations of this applicator have been performed using the simulator of electromagnetic field SEMCAD X LIGHT 13. It uses a finite diferention time domain (FDTD) method to solve the electromagnetic field problems.

The main objective of the simulations was to find the impedance matching of the thermo therapeutic applicator to the biological tissue with the required parameter $S_{11} < -10dB$. As can be seen in figure 3.1, the applicator is a simple open cavity resonator filled with the dielectric with the variety means of tuning. The most reasonable tuning can be performed by changing the position of N – connector (the high-frequency connector for coaxial line) which also works as the feed of this structure. The best performance of impedance matching of the applicator has been found using the feeding antenna $\lambda/5$ far from the shorted circuit end. In this case, the impedance matching was $S_{11} < -25dB$.
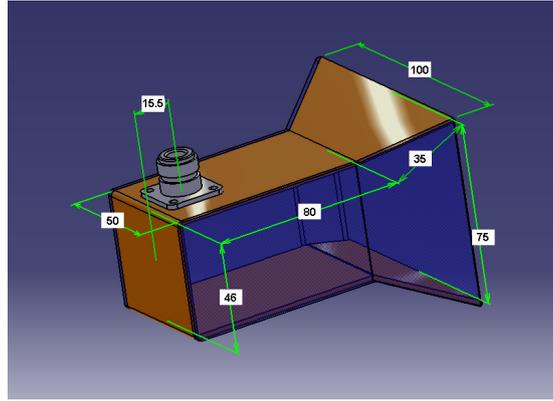
Figure 3.1: Brief sketch of the applicator.

After the modeling of the applicator's body shape, and setting the parameters of transient and harmonic analysis, we have gained the first results. Setting the cells mesh must be done with care and add the sufficient discretization density of cells when it is needed. Otherwise, the results will not gain the demanded performance. As the lowest discretization with the sufficient outcome, we can assume the density of 16 discretization lines per wavelength. The only disadvantage of the mentioned simulation program can be the absence of parameter sweep function which can make a work much faster. In other cases, it is necessary to change the parameters of the simulations manually. "*Light*" modification of the program can be the advantageous low cost solution for any radio frequency designer. Figure 3.2 shows depth of the effective penetration $d_{1/2} = 17$ that was obtained from the simulation.
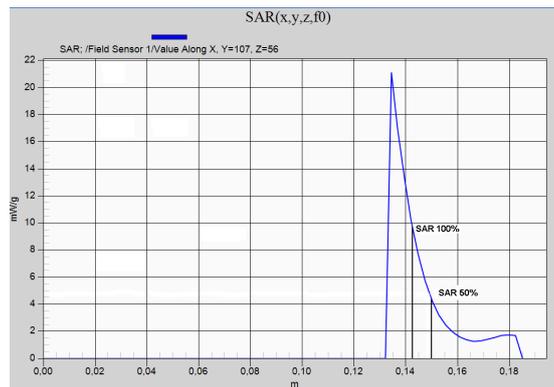

Figure 3.2: The depth of the effective penetration.

4   Construction

Construction of the applicator which is filled with water, the problems with the leaking of the water can occur [3]. Because lateral sides of the applicator cannot be constructed from conductive material, the whole applicator needs to be assembled from two major parts including copper coating and lateral sides made of plaster. The front of the aperture is covered with thin plaster foil.

Figure 4.1: Thermo therapeutic applicator with the TEM wave.

5 Image Segmentation Using Histogram Fuzzification and K-means

Another significant parameter in the thermo therapeutic applicator is the effective size of the aperture determined by SAR module of the simulator. Determination of the percentage of the area of the aperture where the power attenuation is not higher than the 3dB is called the effective area of aperture. To obtain this area automatically, an appropriate algorithm must be designed.

Thus, the MATLAB environment with self-build image signal processing toolbox algorithms is available candidate for use.

Figure 5.1 shows an example of the power radiated from the antenna. The whole radiated area is composed from the different "circle" regions. Each region is represented by various colors, which denotes the radiated power in dB. The dashdot line represents the area of half radiated power from the aperture.

For algorithmic implementation, the input color image is coarsely represented using 25 bins. In the first step, histogram fuzzification is used [4,5]. It is a simple image segmentation methodology using an adaptive fuzzification over a gray level histogram. This method does not use a criterion function to be minimized either for histogram thresholding or fuzzification. Instead, the image histogram is thresholded based on intersection of two linguistic variables (Object, Background) modeled by two fuzzy subsets calculated adaptively on the gray level histogram. Finally, the histogram threshold is determined for the gray level at which two fuzzy sets for object and background intersects. Method is not based on the minimization; the problem of detecting local minima is avoided. The gray levels are grouped according to their contribution for the adaptive calculation of fuzzification parameters toward the point of intersection.
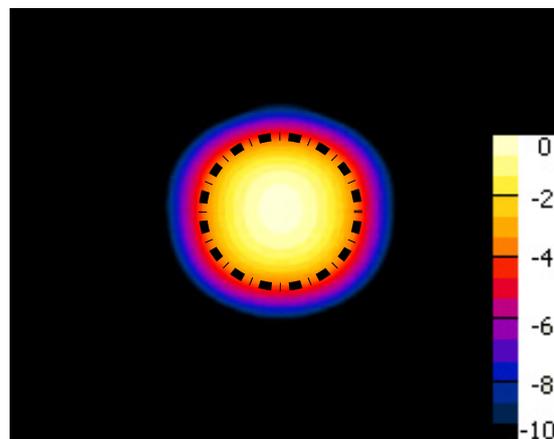

Figure 5.1: Power radiated from the antenna aperture with the chart in dB. The dashdot line represents the area of half radiated power from the aperture determined when using the MATLAB image processing toolbox.

In the second step after histogram fuzzification, K-means is used to cluster the coarse data [6]. K-means is clustering method from statistical and machine learning theory which aims to partition n observation into k clusters in which each observation belongs to the cluster with the nearest mean. Given a set of observations $(x_1, x_2, \ldots, x_n)$, where each observation is d-dimensional real vector, then k-means clustering aims to partition the n observations into k sets $(k < n)$ $S = \{S_1, S_2, \ldots, S_n\}$ so as to minimize the within-cluster sum of squares

$$\arg\min_{S} \sum_{i=1}^{k} \sum_{x_j \in S_i} \left\| x_j - \mu_i \right\|^2, \tag{5.1}$$

where μ_i is the mean of S_i. We used 40 starting clusters (it approximately matches the maximum of various circle region areas) with "drop" modification which removes any cluster that becomes empty. Thus, k-means choose an optimal amount of the clusters that could represent the radiated circle regions.

Finally, we need to align the circle regions in descending brightness order that will allow us to map each radiated circle region into appropriate radiated power in dB. This part is based on simple gradient of transit from the middle of the image (circle power region with the lowest radiated power) to one of the corners, where the increased gradient of transit signifies the change of the circle region. The algorithm expects that the radiated area is centralized in the middle of the image. In other cases, there is a possibility to use Hough transform as circle detector and centralize the circle of radiated power area to the middle of the image. Figure 5.2 shows the detailed results obtained using whole image segmentation algorithm.

The origin "radiated power" image

Segmented image using histogram fuzzification

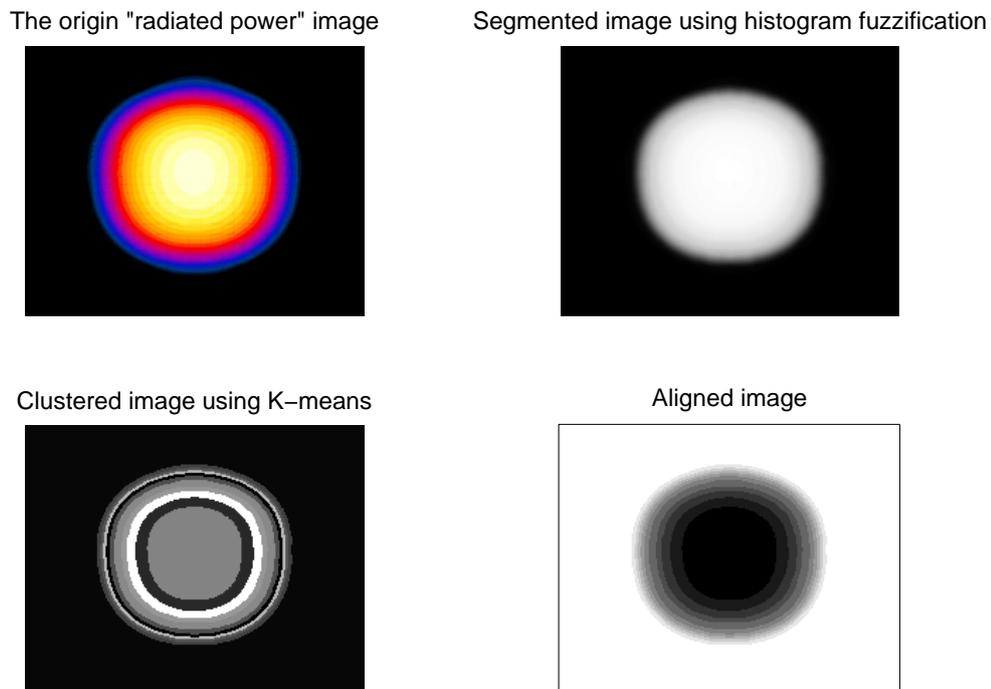Clustered image using K–means

Aligned image

Figure 5.2: Detailed results obtained using whole image segmentation algorithm on some selected image.

6   GUI

We have designed and created an easy manageable GUI in MATLAB environment for computing power radiated from the antenna aperture (see figure 6.1). The simulation outputs are scaled as images with a bar chart. The scale of the radiated power ranges from 0 to -10 dB which is the main point of interest in hyperthermia. In practice, we only need the scale from 0 to – 3 dB for treatment. Thus, we can separate only the important radiated power from the antennas and compute relative percentage of the aperture. It allows to list the applicator in the statistical database with the known scalar of the effective size of the aperture.
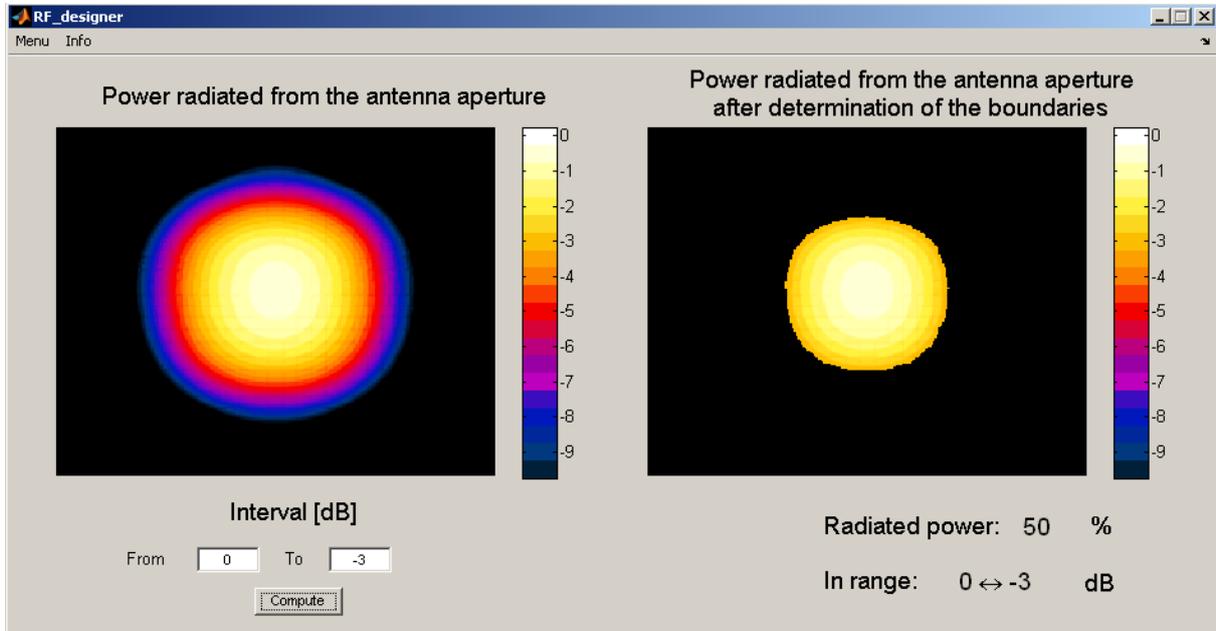

Figure 6.1: Example of radiated power percentage computation in the designed GUI

7   Results

The microwave applicator filled by distilled water with TEM wave was constructed. Subsequently, the algorithm based on histogram fuzzification and K-means clustering were design to compute the power percentage of radiated area from this applicator. Finally, the GUI for its computation has been created. As shown in previously presented results, the applicator is suitable for clinical practice where can be used as part of local superficial hyperthermia treatment. For a brief revision, the basic parameters of this applicator are effective area of the aperture *42%*, depth of effective penetration $d_{1/2} = 17.5mm$ and of course the value of reflection coefficient $S_{11} < -10dB$. We can assume that the constructed applicator is capable of heating superficial located tissues.

Acknowledgement

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