Genetic Algorithm Optimization of SAR Distribution in Hyperthermia Treatment of Human Head

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Abstract—Optimization is performed of the specific absorption rate (SAR) distribution inside a human head phantom for hyperthermia treatment of brain tumor. Two implementations of phased array are presented, using four and eight antenna, respectively. SEMCAD-X simulation along with genetic algorithm (GA) optimization under Matlab environment are conducted. Operation is performed at relatively low frequency values of 550-900 MHz to achieve good energy penetration. Results of SAR distribution illustrates the possibility of delivering microwave energy into relatively deep tumor positions with reduced heating side effects on the surrounding healthy tissue.

Keywords—Hyperthermia treatment; Genetic algorithm (GA), Optimization, specific energy absorption rate (SAR).

I. INTRODUCTION

Cancer is a challenging disease that accounts for around 13% of all deaths [1]. Various treatment plans are clinically used. Hyperthermia is an arising plan that is used to improve the capabilities of cancer treatment using temperature increase in the tissue in range 40–44 °C [2]. Three types of hyperthermia: whole-body, regional, and local hyperthermia [3]. Depending on the tumor location, there various methods are used to apply local hyperthermia, including external, intra-luminal and interstitial methods [4].

Non-invasive delivery of electromagnetic energy into deep tumors while reducing the side effects on healthy tissues is a challenge that hampers the development of hyperthermia treatment [5] and [6]. Recent technology advances, particularly the maturity of ultra-wideband (UWB) systems, and the progress in phased-array tools help to enhance the use of external applicators in hyperthermia treatment [7]. UWB Vivaldi antenna presents an attractive configuration for hyperthermia and microwave imaging [9-11]. Fig. 1 shows an illustration of the antenna array surrounding a human head phantom. The distance between the phantom and the antenna is set to one mm. Water background is used to allow reduction in antenna size, enhance the matching with the human tissue and achieve cooling of the elements.

II. SPECIFIC ABSORPTION RATE (SAR)

SAR is a quantity that describes the amount of absorbed radiated effect for a specific material at a certain frequency [12]. The specific absorption rate (SAR) is calculated as

\[
SAR = \frac{P}{\rho} = \frac{\sigma|E|^2}{\rho}
\]

(1)

Where \( P \) is the power absorbed in the tissue in W; \( \rho \) is the mass density in kg/m\(^3\), \( \sigma \) is the electrical conductivity in S/m, and \( |E| \) is the rms magnitude of the electric field strength vector in V/m [13]. SAR distribution induced by the external heating device should be determined by Pennes’ mathematical model [14, 15].

III. PHASED ARRAYS TECHNIQUES

The phased array concept is based on the use of individual elements that can be driven independently to control the relative phases of the feeding signals. The use of phased array elements, corresponding to each frequency of excitation sub-channels. A module in SEMCAD-X for optimizing electromagnetic field and SAR distribution is used in this research [8]. Excitation is implemented using an array of Vivaldi antenna elements. UWB Vivaldi antenna presents an attractive configuration for hyperthermia and microwave imaging [9-11]. Fig. 1 shows an illustration of the antenna array surrounding a human head phantom. The distance between the phantom and the antenna is set to one mm. Water background is used to allow reduction in antenna size, enhance the matching with the human tissue and achieve cooling of the elements.

Figure 1. Illustration of the proposed Configuration.
a phase array offers the opportunity to achieve constructive interference of the electromagnetic energy at the desired locations, while minimizing the energy in healthy and crucial tissues, based on destructive interference [16]. Circular phased array antennas are appealing in many applications since they show uniform beam coverage over 360 degrees in, and they can generate radiation patterns with a main beam [17].

The brain phantom model is taken to be a cylinder with a radius of 84 mm with a dielectric of electrical parameters equal to those of the brain tissue, such that the relative permittivity is 40, the electrical conductivity is 1 S/m and the mass density of the phantom material is 1000 kg/m$^3$. A small sphere is used to represent the tumor with a radius of 10 mm. The relative permittivity is taken to be 38, and the electrical conductivity is 0.5 S/m. Two circular array configurations are used with four and eight elements, respectively. The elements surround the phantom, while they are immersed in water background. The antennas are set at 1 mm from the phantom as shown in Fig.2.

![Figure 2. Eight-element phased array.](image)

IV. SIMULATION RESULTS

The simulation setup is based on SEMCAD-X environment that implements three-dimension finite difference time-domain (FDTD) modeling. SEMCAD-X environment provides fast simulation capabilities, computing up to 400-1500 Mcells/s with the use of the hardware acceleration. In this analysis, we investigate the effect of phase and amplitude on the specific absorption rate distribution in tumor location. Genetic algorithm based optimization is used due to their capability in finding the global optima in complex optimization problems, such as electromagnetic field problems [18, 19].

The optimization module in SEMCAD-X allows the user to perform the optimization with arbitrary number of parameters using combinations of goal functions with adjustable weights. The general GA flow-chart is shown in Fig. 3. A specific percentage of the best chromosomes is preserved from population to population, to avoid the loss of good solutions along the optimization.

SAR distribution corresponding to four and eight antenna array before optimization is shown in Fig. 4 to Fig. 11. The figures are shown for a cut-plane at vertical distance z=0. The horizontal axis in the figures points in the x-direction, while the other normal direction is the y-axis.

The considered frequency values are 250, 500, 750 and 900 MHz, respectively. All magnitude values are set to one and the phases are set to zero. SAR values are calculated corresponding to input power of 500 W. Average is performed per 1-g of tissue. The figures reveal the effect of frequency value on energy penetration in the tissue.

![Figure 3. Genetic algorithm flow chart in SEMCAD-X tool.](image)

![Figure 4. SAR distribution of four antenna array without optimization at frequency of 250 MHz. Scale is in dB.](image)
Performing GA based optimization, the optimum amplitude and phase values of each antenna element from the array are identified. The objective is set to maximize the SAR values at the tumor location, while minimizing the values in other brain tissues.

Fig. 12 and Fig. 13 present the results of SAR at frequency of 500 MHz for both four and eight element phased array implementation, respectively. Fig. 14 and Fig. 15 show the spatial peak SAR of both four and eight element array, respectively.
Fig. 12. SAR distribution with optimization using four antenna array at 500 MHz.

Fig. 13. SAR distribution with optimization using eight antenna array at 500 MHz.

Fig. 14. Spatial peak SAR using four antenna array at 750 MHz.

Fig. 15. Spatial peak SAR using eight antenna array at 750 MHz.

Fig. 16 and Fig. 17 present SAR distribution inside the phantom, after optimization as a function of y-distance, for $x = 20$ mm and $z = 0$ mm. The two figures correspond to four-element and eight-element arrays, respectively.

Fig. 16. SAR distribution profile as a function of y, using four element array. $x = 20$ mm and $z = 0$.

Fig. 17. SAR distribution profile as a function of y, using eight element array. $x = 20$ mm and $z = 0$. 
A genetic algorithm based optimization tool is also developed under MATLAB optimization environment [20]. A flow-chart of the tool is shown in Fig. 18. Simulation is performed considering a phantom model with one positioned antenna. The tumor is rotated by 45 degree, starting from the original position zero to 315 degrees. The simulated electrical field maps are exported to the tool to combine the electrical field of all experiments. The tool is used to identify the optimum amplitude and phase values. The following parameters are used: population size of 100, and the number of iterations of 100.

Fig. 19 and Fig. 20 show SAR distribution before conducting optimization for frequency values of 500MHz and 750MHz, respectively. The magnitudes values are set to one for each antenna and the phase values are set to zero. The result of optimum SAR distribution is show in Fig. 21 and Fig. 22 for frequency values of 500MHz and 750MHz, respectively. The figures show that the SAR distribution is directed towards the tumor location.
Figure 22. SAR distribution after performing GA optimization at 750 MHz.

V. CONCLUSIONS

In this paper, optimization of excitation of external applicators for hyperthermia treatment of brain is considered. The specific energy absorption rate (SAR) distribution is investigated inside phantom model. Two tools are developed. The first depend on using SEMCAD-X optimization module. The second tool is developed using MATLAB genetic algorithm environment. The objective is set to find the optimum amplitude and phase of each array elements to maximize SAR value and enhance the localization of the microwave energy inside the tumor location. Simulation has been conducted at various sub-channels of relatively low frequency values of 550MHz, 700MHz and 900MHz.

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REFERENCES


