HYPERTHERMIA TREATMENT OF DEEP SEATED TUMOURS USING TIME REVERSAL CAVITIES

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Introduction

Treatment of deep seated tumours has received a lot of attention in hyperthermia. However, so far no generally suitable method has been available. Presently, the most widely used method is the annular phased array (APA), [4]-[7]. It is based on using an array of radiators placed in a array around the patient, relying on constructive wave interference to selectively heat the tumour. This interference is driven by changing the amplitude and phase at the feeds-points of the antennas.

In this paper, we investigate a new beam forming method, which opens up new possibilities in the area of deep heating hyperthermia. It uses a large number of antennas with carefully controlled amplitude and phase of the individual antenna elements. The method is based on the time-reversal characteristics of the Maxwell equations. The basic principle of our new method is the electromagnetic modelling of the system. The wave front of the source is propagated through the patient from a virtual antenna placed in the tumour of the patient.

The simulated radiated field is then measured using the computer models of the surrounding antenna system. The real antenna system is then transmitting the field in a time reversed order, Fig. 1. It is the invariance of the wave equation under time-reversal in lossless media enables optimal refocusing of time-reversed signal at the original source. We have performed extensive simulations to determine the lower bound of the number of antennas needed for to-be experimental device.

Fig. 1. Time reversal cavity. (a) Recording step: A point-like source located at the origin generates a spherical wave front that is distorted after propagation through the inhomogeneities of the medium. The distorted EM field is recorded on the cavity elements located on the surface of the cavity. (b) Reconstruction step: The initial source is removed. The recorded signals are time-reversed and reemitted by the cavity elements. The time-reversed EM field back-propagates and refocuses on the initial source.
TRC in Hyperthermia Treatment

The SAR distribution is calculated using a model of a neck obtained from the Visible Human Project [9]. A point source with a sinusoidal signal in the frequency range 0.5 - 1 GHz is excited using a grid size of 300 Δ x 300 Δ, where Δ = 1mm. The area is initially filled with water (σ = 0.05, ε = 56). The 2-D neck model with a 1 mm resolution (Fig. 2) is included in this grid as a box of sizes 220Δx220Δ.

Fig. 2. Neck slice and its numerical model.

A tumour of radius \( r = 5\Delta \) and conductivity \( \sigma = 1.5 \) is included in the model. A system of 30 radiators situated in a circumferential array around the neck of the model. The time duration of forward simulation is \( N\Delta t \), where \( N \) is the number of iterations and \( \Delta t \) is time step. Recorded waveforms are then time reversed and reemitted back through medium. The following results are presented in terms of the distribution of absorbed energy (SAR) in the treated area.

\[
SAR = \frac{\sigma |E(x, y, z)|^2}{\rho} \tag{1}
\]

In Figure 3 the SAR distributions for two different cases are shown. Figure 3a), shows an ill placed tumour with sufficient values for a successful treatment in the tumour region but with relative high levels of energy also in the small region of healthy tissue in the vicinity of the tumour. The main reasons of this is the relatively high conductivity of the region. It is also worth noting that the cooling produced by varying blood perfusion rates within the heated volumes is not included in this study.

Figures 3 c) and d) represent cases with more favourable tumour positions. The amount of energy absorbed in the tumour is high compared with the healthy tissues. In all cases the absorbed energy on the surface of the neck (hot spots) situated in the vicinity of the radiators are present. This problem could be handeled by placement of a water bolus with circulated cold water between body and antennas. A coupling bolus is a flexible bag attached to the applicator that circulates temperature-controlled de-ionized de-gassed water. Using of water bolus is in praxis common method to reduce hot spots and improve the impedance matching between body and applicator.
Fig. 3. Focusing of EM energy in a neck slice containing tumour ($r = 5\Delta$) with $\sigma = 1.5$ in the different positions. (a) Tumour is situated in the centre of neck. (b) Conductivity of treated area. (c) Tumour is situated in position: 60x110. (d) Tumour is situated in position: 60x60.

Conclusion

The main goal of the paper has been to describe a system using TRC beam forming method obtained by carefully controlling amplitude and phase of the individual antennas of the regional applicator. The obtained results focusing the energy in the tumour achieves sufficient results for successful treatment. However, high level of energy is also absorbed in the vicinity of tumour. It can be expected, that achieved temperature will be considerably smaller due to the cooling produced by significantly varying blood perfusion rates within the heated volumes.

The obtained hot spots on the surface of the body represent limited difficulties and can be handguned by using water bolus with circulated cold water. The presented method represents a first initial step which encourages us in the construction of a real antenna system to make more realistic tests of the method.

References


