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Experimental Verification of Time-Reversal Microwave Hyperthermia System

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Abstract

In this contribution, we illustrate the performance of the developed UWB microwave hyperthermia system in combination with the treatment planning tool based on time-reversal algorithm. The experiment comparing the temperature distribution in muscle-equivalent phantom with the predicted SAR pattern was carried out at the ISM radio frequency 434 MHz. The obtained results have shown an excellent agreement between planned and measured data in terms of the correct focusing and iso-SAR countours.

Introduction

Hyperthermia is presently used as an adjuvant to the radiation therapy in the treatment of certain types of cancers. Recently, many randomised trials have shown a significant advantage of addition of hyperthermia combined with radiotherapy and/or chemotherapy in the treatment of solid tumours [1]-[3]. The objective of hyperthermia treatment is to raise the temperature in the tumour to a therapeutic level 41°C-45°C for a sufficient period of time to achieve cell death or render the cells more sensitive to ionizing radiation and chemical toxins. The present challenge is adequately heating of deep seated tumours while preventing surrounding healthy tissue from undesired overheating and damage.

Presently, the most widely used method of treatment of deep seated tumours is the annular phased array. It is based on an array of radiators placed in a circumferential array around a patient, relying on a constructive wave interference to selectively heat the tumour. The desired wave interference is driven by means of changing the amplitude and phase at the feed-points of the antennas. The right values of these quantities are calculated from a computer simulation where we exploit the time-reversal principle [4].

A TR-Hyperthermia System Prototype

The prototype has been designed to allow for applications of both continuous and pulsed waves at frequency range of 300 MHz to 1 GHz to enable tumour volume specific treatment. It consist of 12 separate channels with capability to extend it to 24 channels. All of the 12 channels of the system are driven by a common reference excitation signal and the power and the phase of each channel is adjustable, channel-wise, by independent digital phase shifter and voltage controlled power amplifier. In order to ensure accuracy, power level fluctuations and non-linearities associated with signal amplification need to be compensated. A calibration procedure devised in [5] is based on complex S21 parameter measurements using a vector network analyser (VNA).

The present applicator is based on a circular antenna array consisting of 12 elements. We consider two main array configurations: one configuration with 12 antennas placed in the single ring array and one configuration of two antenna rings with 6 antennas in each ring, while one of the rings is turned 30°. The distance between the rings is 55 mm. In order to keep distance in terms of wavelength between radiating elemets and phantom at different frequencies, the diameter of the applicator is adjustable and varies between 110 and 210 mm.

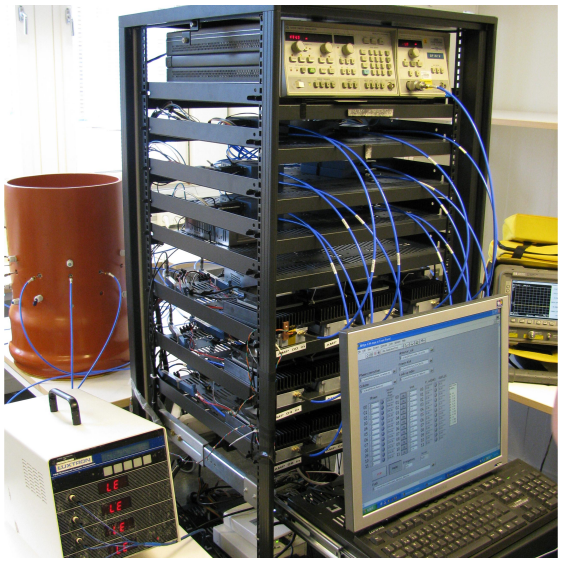


Figure 1: A photo of the proposed hyperthermia system.

Results

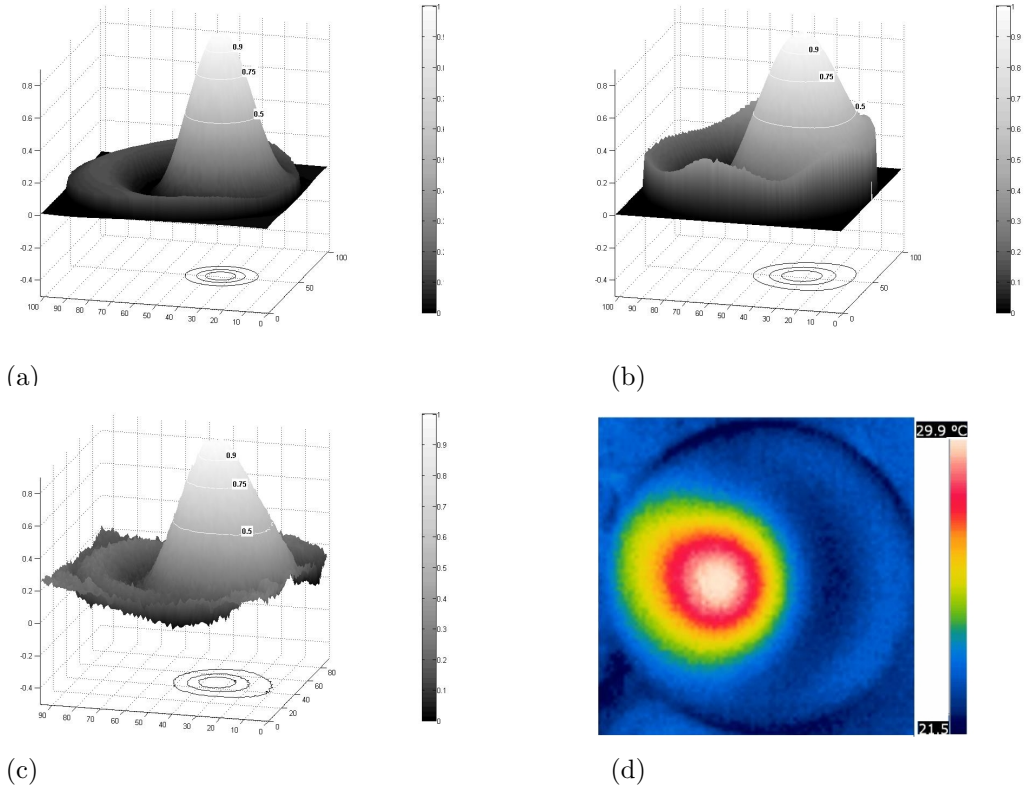
In this experiment, the antenna applicator with 12 elements placed in a single ring array with diameter 22 cm, was used to heat a homogeneous muscle phantom ($\epsilon_r = 64$, $\sigma = 0.41$ S/m). The phantom had a diameter of 10 cm and a length of 36 cm. Both the antenna array and the phantom were immersed in distilled water ($\epsilon_r = 78$, $\sigma = 0.05$ S/m) with the temperature of 20°C. The experiment was carried out at the ISM radio frequency 434 MHz.

The 2D-TR-FDTD treatment planning procedure was applied to determine the amplitude and phase settings for focusing at thr position 35x50 mm, which is located 15 mm from the centre of the phantom. The coordinate 50x50 mm is thus considered as phantom center in Figure 2. The application phase was first modelled using 2-D FDTD as well as in 3-D simulation package CST Microwave Studio including a detailed model of the experimental setup. Finally, the planned amplitude and phase settings were applied experimentally to expose the agar phantom using the developed system. Figure 2(d) shows the obtained temperature distribution in cross-section of the phantom after 9 minutes of exposure. A clear temperature rise of about 9°C in the designated location is observed.

The evaluation of the SAR distributions for the 2-D and 3-D simulations and the experiment was carried out by comparing the areas enclosed by 50%, 75% and 90% iso-SAR contours in cross-section through the phantom at z = 21 cm. The SAR distribution for experimental case was calculated from temperature distribution captured by IR camera after 9 minutes of heating. An excellent agreement between planned and measured data in terms of the correct focusing and iso-SAR countours was achived, see Figures 2(a)-(c). This can also be seen by comparing of the calculated aPA ratio and RTMi for the foci-spot of radius 10.6 mm (the 75% iso-SAR in 2-D) [4]. Although the 2-D modeling overestimates the quality of focusing, the results presented in Table 1 are still surprisingly coherent.

	2-D simulation	3-D simulation	IR camera
aPA	5.40	3.31	3.28
RTMi	0.80	0.89	0.87

Table 1: The aPA ratio and RTMi calculated for different stages of treatmnet planning.



(a) (b)

(c) (d)

Figure 2: Normalized SAR distributions obtained from (a) 2-D FDTD planning. (b) full 3-D model in CST. (c) calculated from temperature distribution obtained by IR camera.(d) Temperature distribution obtained by IR camera.

Conclusion

The obtained results have shown an excellent agreement between planned and measured data in terms of the correct focusing and iso-SAR countours. These promising results encourage the next step; the clinical study.

References

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