MSc project (Care & Cure):
Time-varying optimization and control for hyperthermia treatments

1 Introduction

Hyperthermia is shown to be a successful technique to enhance the effectiveness of radiotherapy and chemotherapy in cancer treatment for deep tumors, without increasing side-effects. During a hyperthermia treatment, a tumor is locally heated to 40–44°C for a defined period of time, by using an interference pattern of electromagnetic (EM) waves created by an antenna array in the hyperthermia applicator. The heating is determined by using pre-treatment simulations based on electromagnetic (EM) and thermal simulation models.

Two examples of systems for deep hyperthermia available at the Erasmus MC Daniel den Hoed Cancer Center are depicted in Fig. 1: the commercial BSD2000 system (BSD Medical, USA) for treatments in the pelvic region; and the in-house developed HYPERcollar for treatments in the head and neck region [1, 2]. Both systems consist of a number of antenna elements (4 to 12) that radiate electromagnetic waves at a frequency of 70–120 MHz (BSD-2000) or 433 MHz (HYPERcollar).

2 Current procedure

The current procedure for deep hyperthermia consists of the following steps. Firstly, a detailed 3D patient model is generated using computerized tomography (CT) or magnetic resonance imaging (MRI). This results in a large (typically more than 10 Mcells) voxelized model of the patient. Based on biomedical databases, EM material properties are assigned to the different organs/tissues. Secondly, using this patient model and a model of the hyperthermia applicator, EM simulations are performed to determine the EM fields inside the body and the distribution of SAR (specific absorption rate, W/kg). The SAR quantifies the focused energy at the target area. It is correlated with local temperature [3], or it can serve as an input for temperature simulations using Pennes’ bio-heat equation (PBHE) [4]. Hyperthermia treatment planning (HTP) is the procedure of determining amplitude and phase for each of the antennas in the...
applicator, such that the tumor is heated optimally. Finally, once a satisfactory SAR or temperature distribution has been obtained, the patient undergoes the hyperthermia treatment with the calculated antenna settings. An overview of the state of the art in HTP is given in [5].

3 Brief project description

The general idea behind the optimization in HTP can graphically be depicted in Fig. 2. The complex (i.e. magnitude and phase) amplitudes $a_i, i = 1, \ldots, 6$ need to be optimized to deposit heat in the target (tumor) region $D_1$. In region $D_2$, heat should be avoided. This can be a so-called hot spot (a local overheated zone, which could be very uncomfortable for a patient), or a region containing vital tissue (e.g. nerves).

![Figure 2: Schematic configuration for deep hyperthermia using six antennas.](image)

A major drawback of the HTP procedure, described in Sec. 2, is that it is computationally intensive. Furthermore, the approach is not flexible with respect to model and/or parameter uncertainties and patient movement. In addition, the current approach may heat large (larger than the heating focus) targets insufficiently, because treatment parameters are not (often) adjusted during a treatment. Finally, HTP is applied mainly in an open-loop sense (steering), because monitoring and control tools are not available yet. In recent work [6], we started tackling the computational drawback by developing a fast and more efficient optimization approach compared to what is currently used in the clinic.

The purpose of this research project is to build on [6] and to extend the method to include the required flexibility mentioned above, for instance, by using sensitivity analyses with respect to parameter variations and patient position. In addition, the heating of larger tumors (or the spreading hot spots over time), requires extension of the framework to (slowly) time-varying antenna amplitudes $a_i(t)$ instead of constant ones.

From the monitoring side, reflected signals at the antennas may provide information on the realized antenna settings and on the achieved excitation. As an example, consider Fig. 3, in which antenna 2 is excited with a time-varying signal $a_2(t)$, while reflections $b_i(t), i = 1, \ldots, 6$ are measured at all antennas. The purpose of the reflected signals can be two-fold. Firstly, they may be used to update the model and parameter values and/or may be used for corrections in the model for patient position and movement (model-based monitoring). Secondly, the information from both simulations and reflection measurements can be used for adjusting the antenna amplitudes $a_i(t)$ to achieve model-based control.
Prior work:
A first student project on the topic of this project proposal has been done in 2015/16 [7]. That work focused on (1D) model reduction for the thermal domain (PBHE) as well as on control solutions for time-varying steering. This will serve as a starting point for the current project.

4 Project organization

The MSc project is part of a long-term cooperation with the EM group and the Erasmus MC Cancer Institute in Rotterdam, who will provide the relevant clinical input (dr.ir. M. M. Paulides) This challenging problem is multiphysics of nature, due to the interaction between EM waves, thermal effects and model-based control. Depending on the student’s preference visits to the Erasmus MC Cancer Institute can be arranged.

Preference will be given to candidates who have affinity with both electromagnetics and control. Clinical relevance of the developed solutions and/or tools is an additional aspect that has to be taken into account in the project.

Intended starting date: to be defined
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Erasmus MC contact: dr.ir. M.M. Paulides

References
