MSc project (Care & Cure): Model-based temperature estimation for control during 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,

Figure 1: BSD-2000/3D Hyperthermia system (left) and HYPERcollar (right).
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.

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). Once the antenna parameters $a_i$ have been calculated, the settings are applied mainly in an open-loop sense (steering), because monitoring and control tools have only recently become available.

Although SAR is correlated with local temperature and although thermal simulations can be performed, two major limitations for accurate temperature dosimetry are present. Firstly, invasive temperature measurements (using probes or catheters) are, at best, only available from a few probes near the tumor region. Alternatively, temperature measurements inside an MR scanner require the hyperthermia applicator to be fully MR compatible. Secondly, EM and thermal tissue properties vary substantially with temperature during treatment.

Recent work towards overcoming these limitations has focussed on developing an MR-compatible hyperthermia applicator solutions [5,6]. However, a hyperthermia treatment combined with MR temperature measurements is very costly. Secondly, invasive measurements can also be used to achieve temperature dosimetry [7]. Although the approach looks promising, other techniques might be available that are less computationally intensive.

The purpose of this research project is to develop model-based techniques to incorporate temperature measurements (either from probes or from MR thermometry) into (real-time) control during hyperthermia treatments. Smart/dedicated model reduction techniques for the PBHE could pave the way for parameter estimation techniques, e.g. Kalman filter or observer, that ultimately allow to close the control loop in hyperthermia treatments. At the Mechanical Engineering Department (CST group) some recent work has been carried out on a related approach [8]. Also an example of a Kalman-filter approach for thermal therapies can be found in [9].

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1Dosimetry: assessment of clinically applied dose.
Prior work: A first student project on topic of this project proposal has been done in 2015/16 [10]. That work focused on a 1D case for the thermal model. Based on this model, temperature distributions were estimated using a Kalman filter and specific tissue properties were estimated with an extended Kalman filter. 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


