AN ELECTROMAGNETIC SIMULATION ENVIRONMENT, TO CONSTRUCT MICROWAVE IMAGING ALGORITHMS

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Abstract: This paper is about the construction of an ultra-wideband microwave (UWB) simulation environment and about the construction of a model of the human head including regions of stroke. It calculates the propagation of microwaves within a wide frequency range through biological tissues. The simulations will be used to guide the development of a new system for early detection of stroke with UWB. The simulation has to be as close as possible to the real physiological properties of human tissues including the dispersive effects.

Keywords: UWB, stroke, microwave, brain

Introduction

Stroke is still one of the main reasons for disability and death in developed nations [1]. For patients with stroke it is extremely important to receive the right treatment as fast as possible because the tissue surrounding the stroke core immediately starts to become necrotic. Unfortunately, a treatment can only begin if the cause of a stroke is verified, as there are two different types of stroke with the exactly the same symptoms. For each cause completely different medication is needed. Ischemic strokes caused by an occlusion of a vessel e.g. by a clot occurs most often. In this case a medication with haemodilution is needed. On the contrary the hemorrhagic stroke is induced by a rupture of a vessel and a medication promoting coagulation is needed. For the diagnosis two different procedures are applied today: the one is the computed tomography (CT), the other is the magnetic resonance imaging (MRI). Unfortunately, both procedures often lead to a long time span until therapy can be initiated. These systems are very expensive so that not every hospital can operate a CT or MRI, and these systems require professional personnel not always available for 24h per day and 7 days per week. The aim of this project is to develop a new diagnostic device based on ultra wideband techniques (UWB). Such a device will not need big and expensive hardware and thus could even be used in ambulances. A finite-difference time-domain method (FDTD) simulation environment with a model of a human head was created to develop the necessary algorithms. The software SEMCAD X 14.8 distributed by Schmid & Partner Engineering AG is used for the simulation environment.

Methods

Model of the head: To identify the characteristics of stroke in UWB signals, in a first step a simple spherical model of the human head is to be used. All in all it is made of five layers of tissues. They have the same electromagnetic properties in the selected frequency range such as the human tissue they represent, namely skin, skull, cerebrospinal fluid, gray matter and white matter. The properties of the human tissue are taken from the scientific publications of Gabriel et al.[2, 3, 4]. In particular for UWB simulations it is recommended to take the dispersive electric properties of tissue in account. SEMCAD offers the option to use up to five different dispersive poles in order to integrate the frequency dependency of the electromagnetic properties of the tissue. For each pole another physical model can be selected: the model of Drude, Debye and Lorentz. These three models are combined to one generic model in SEMCAD:

\[
\tilde{\epsilon}(\omega) = \epsilon_{\infty} - j \cdot \frac{\sigma}{\omega \cdot \epsilon_0} + \sum_{p=1}^{P} \frac{A_p}{B_p \cdot \omega^2 + C_p \cdot j \cdot \omega + D_p}
\]

With

- \(\tilde{\epsilon}\) is the approximation of the complex relative permittivity,
- \(\epsilon_0\) is the vacuum permittivity,
- \(\sigma\) is the conductivity,
- \(\omega = 2\pi f\) denotes the angular frequency,
- \(P\) is the number of poles,
- \(\epsilon_{\infty}\) is the permittivity for \(\omega \rightarrow \infty\)

Table 1: model specific params of generic model.

<table>
<thead>
<tr>
<th>Model</th>
<th>(A_p)</th>
<th>(B_p)</th>
<th>(C_p)</th>
<th>(D_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debye</td>
<td>(a_p \cdot (\epsilon_{s,p} - \epsilon_{\infty}))</td>
<td>0</td>
<td>(\tau_p)</td>
<td>1</td>
</tr>
<tr>
<td>Drude</td>
<td>(a_p \cdot \omega_p^2)</td>
<td>-1</td>
<td>(\delta_p)</td>
<td>0</td>
</tr>
<tr>
<td>Lorentz</td>
<td>(a_p \cdot \omega_p^2 \cdot (\epsilon_{s,p} - \epsilon_{\infty}))</td>
<td>-1</td>
<td>2 \cdot \delta_p</td>
<td>(\omega_p^2)</td>
</tr>
</tbody>
</table>

The parameters \(A_p, B_p, C_p\) and \(D_p\) are specific concerning the selected model and they can be seen in table 1. SEMCAD contains a dispersive material tool for the parameter-fitting. An average decrease of the permittivity of 4% and an average decrease of the conductivity of 12% (in respect to healthy brain tissue) is anticipated to conduct the simulation of the region representing the stroke.
With the FDTD method two criteria have to be fulfilled to gain a correct solution. The first criterion limits the maximum time step [6]:

\[ \Delta t \leq \frac{1}{c \sqrt{1/\Delta x^2 + 1/\Delta y^2 + 1/\Delta z^2}} \] (2)

With \( \Delta x, \Delta y \) and \( \Delta z \) the dimension of the smallest voxel and \( c \) the speed of light. For the spatial resolution there is the following inequation to be fulfilled:

\[ \Delta d \leq \frac{\lambda_{\text{min}}}{10}, \] (3)

To avoid numerical dispersion the largest step in \( x, y \) or \( z \) direction \( \Delta d \) has to be smaller than \( 1/10 \) of the smallest wavelength \( \lambda_{\text{min}} \).

Results

The frequency range of this simulation environment is mainly influenced by the criterion of equation 3. For example one calculation of the simulation set-up with a frequency range of \( 0.4 - 3.4 \, \text{GHz} \) (corresponding to a \( \Delta d \) of \( 8.817 \, \text{mm} \)) lasted ca. \( 20 \, \text{h} \) on a computer with an Intel Core-i7 3820 and 32GB of RAM. Originally the frequency range was planned to be \( 0.5 - 9.5 \, \text{GHz} \). This frequency range would have lasted 99 days (prognosticated by SEMCAD) due to a \( \Delta d \) of \( 3.156 \, \text{mm} \). To get a first impression of the order of magnitude of the change in the signal caused by the stroke region the simulation (figure 1) was calculated with and without the stroke region and the results were compared. Figure 2 shows as an example the difference of the reflected signals. To represent the region of the stroke a sphere with a \( 3 \, \text{cm} \) diameter was used. The UWB-signal was a gaussian pulse with a center frequency of \( 1.5 \, \text{GHz} \) and a variance \( \sigma_v \) of \( 0.375 \, \text{GHz} \). The so called edge-source (source-object in SEMCAD) integrated into the dipole-antenna had an impedance of \( 50 \, \Omega \) and used an amplitude of \( 70 \, \text{V} \) to produce the wave.

Discussion

The created simulation environment can be used to gain initial conclusions concerning requirements of signal processing. Improvements are still necessary to reach the intended frequency range. One possibility of solving the problem could be to remove the antenna from the simulation set-up and to replace it with a plane wave source which would reduce the amount of the necessary voxels. Within the region of tiny objects like the parts of the antenna the spatial resolution has to be increased extremely to reveal the behavior of electromagnetic waves in a correct way.

Bibliography