A Comparative Evaluation of Electrical Field Visualization from EEG/tDCS

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Authors:

Sebastian Eichelbaum[1], Moritz Dannhauer[2], Mario Hlawitschka[3], Dana Brooks[4], Thomas Knösche[5], Gerik Scheuermann[6]

Institutions:

[1]Leipzig University, Image and Signal Processing Group, Leipzig, Germany, [2]SCI, Salt Lake City, United States, [3]Leipzig University, Scientific Visualization, Leipzig, Germany, [4]Center for Integrative Biomedical Computing,U. of Utah;Engineering Department,Northeaster University, Boston, MA, [5]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany, [6]Institute of Computer Science, University of Leipzig, Leipzig, Germany

First Author:

Sebastian Eichelbaum - Lecture Information | Contact Me
Leipzig University, Image and Signal Processing Group
Leipzig, Germany

Introduction:

Electrical activity of neuronal populations is a crucial aspect of brain activity. This activity is not measured directly but recorded as electrical potential changes using head surface electrodes (electroencephalogram - EEG). Head surface electrodes can also be deployed to inject electrical currents in order to modulate brain activity (transcranial direct current stimulation, tDCS) for therapeutic purposes. For EEG and tDCS, electrical fields mediate between electrical signal sources and regions of interest.
These fields can be very complicated in structure, and are influenced in a complex way by the conductivity profile of the human head. Visualization techniques play a central role to grasp the nature of those fields because such techniques allow for an effective conveyance of complex data and enable quick qualitative and quantitative assessments. Visualization can unveil structures and properties inside the data that statistical measures cannot. However, not every visualization technique is equally adequate for different analysis tasks and types of data. Additionally, the vast amount of available techniques makes it hard to decide for an optimal visualization approach.

Methods:

We evaluate a number of widely used visualization techniques for EEG (influence of hole in the skull and influence of different skull-bone tissue models) and tDCS data. We assess volume (DVR) and surface (Isosurfaces) visualization, streamlines and line integral convolution (LIC) for their applicability in EEG and tDCS electrical field data. In particular, we focus on the extractability of quantitative and qualitative information from the obtained images, their effective integration of anatomical context information, and their interaction.

Results:

We where able to identify the pros and cons of each method, and described the findings for each example with the different visualization methods. Surface rendering (Fig. 1) is advantageous for gaining insight into spatial distribution of potential fields directly. It allowed easy embedding of anatomical context but is prone to noise and sampling artifacts.
The DVR approach (Fig. 2) allows for understanding the spatial distribution of the electrical field as a whole volume. This was especially useful for analyzing large scale changes in the electric field, triggered by changes in the modelling of the skull. Unlike surface rendering, the DVR method suffers a complex, and domain-specific transfer function design process. Additionally, embedding of anatomical context is difficult.
The streamline approach (Fig. 3) provided insights into the directional structures globally, in 3D. This was especially interesting for comparing the electrical field, induced by anomalies in the skull. Additionally it perfectly shows the field between two probes of a tDCS dataset. The streamline method mainly suffers the occlusion problem.
The LIC approach (Fig. 4) was perfect for analyzing and comparing small scale features. It clearly showed how the different modelling of skull bone tissue influenced the electric field. Unfortunately, LIC is not able to depict quantitative information. The combination with color coding is difficult, since the LIC changes brightness of the underlying color.

Conclusions:

During our evaluation, we found that we can divide the visualization techniques into two categories. 1) Visualization of local details (LIC). These methods usually profit from high grade of detail, but they suffer a missing spatial embedding. 2) Visualization of global structural information (Streamlines, volume and surface rendering). These methods provide insight into large scale field properties, including spatial correlations in the data, but tend to suffer from the visual occlusion problem and the difficult embedding into contextual data.
This means, there are visualization methods available for every kind of analysis and data, but they have to be chosen appropriately to really provide additional insight into the data.

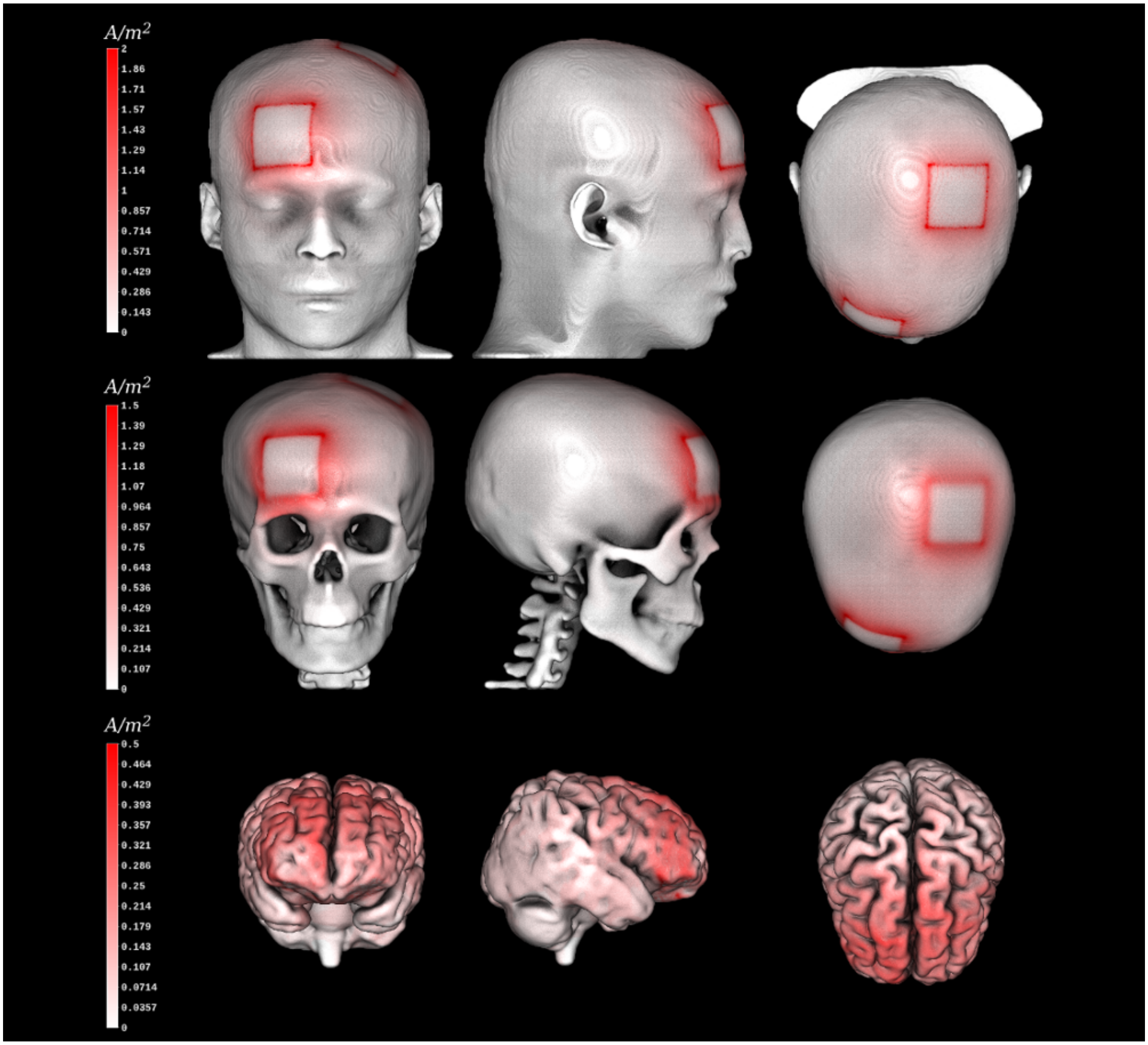

Figure 1: Current density magnitude plot for tDCS on material boundaries. We use different windowing intervals for each boundary to cope with the rapidly decreasing current density. Surface visualization is especially useful with boundary masks or given regions of interest.

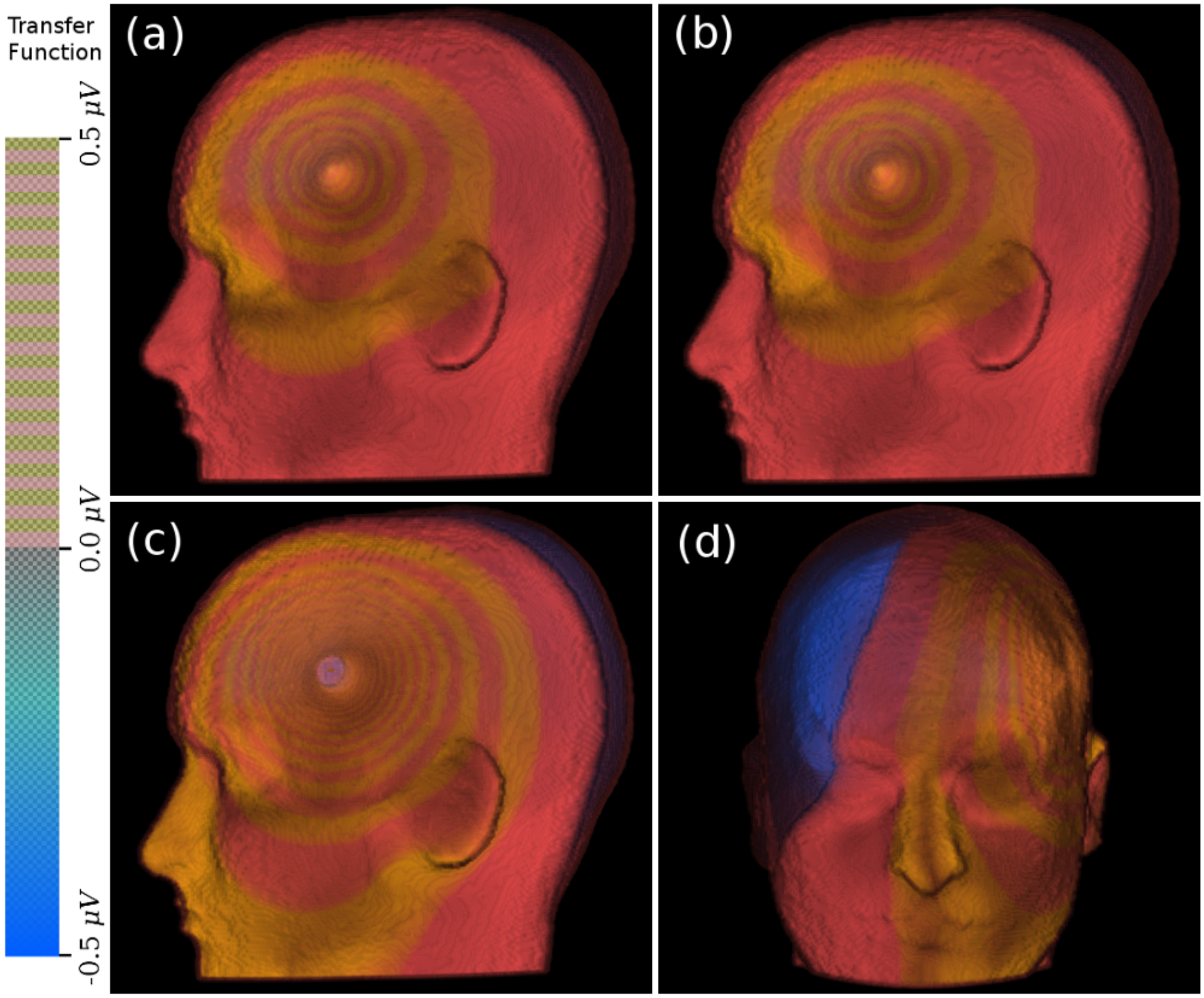

Figure 2: Direct Volume Rendering (DVR) for a Skull-Hole-Model with radial dipole direction (a), first tangential direction (b), and second tangential direction (c,d). The used transfer-function (TF) shows the spreading potential difference between the Skull-Hole-Model data and the corresponding reference field. The used TF is conceptually similar to isolines, but has the advantage of also showing the spatial extend of intervals. As also shown in Figure 3, the hole has a major influence for the second tangential dipole direction (c and d). Volume visualization is especially useful for showing the global, spatial distribution of data.

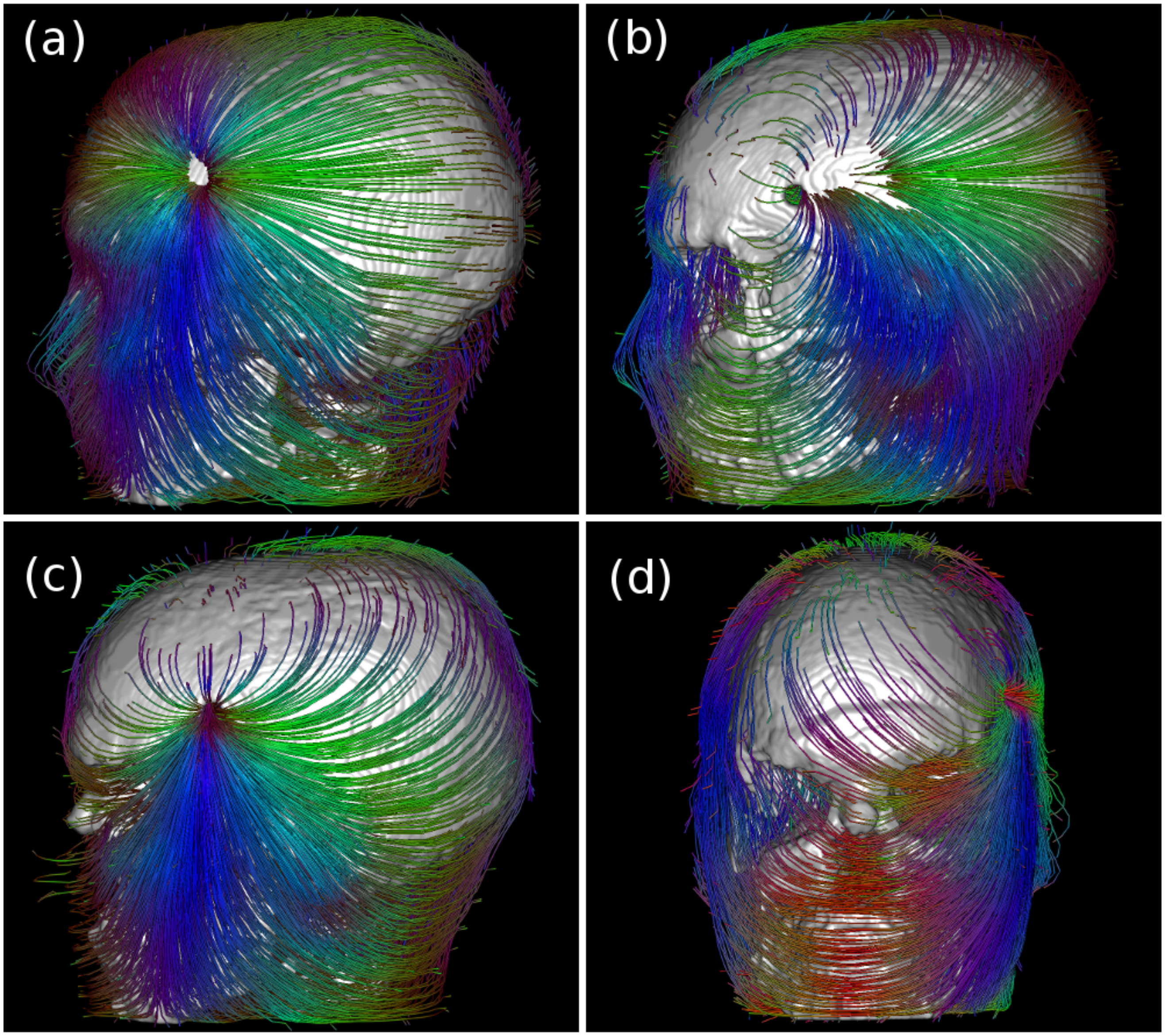

Figure 3: Streamlines depict the electrical flow field in a skull model with a hole. (a) Dipole placed radially. In (b), the first tangential direction is shown and in (c,d) the second tangential dipole direction. Only in (c) and (d), the streamlines leave the skull through the hole, which can be clearly seen using streamlines. Streamlines are good for capturing global, spatial relations of the field, especially with regions of interest.

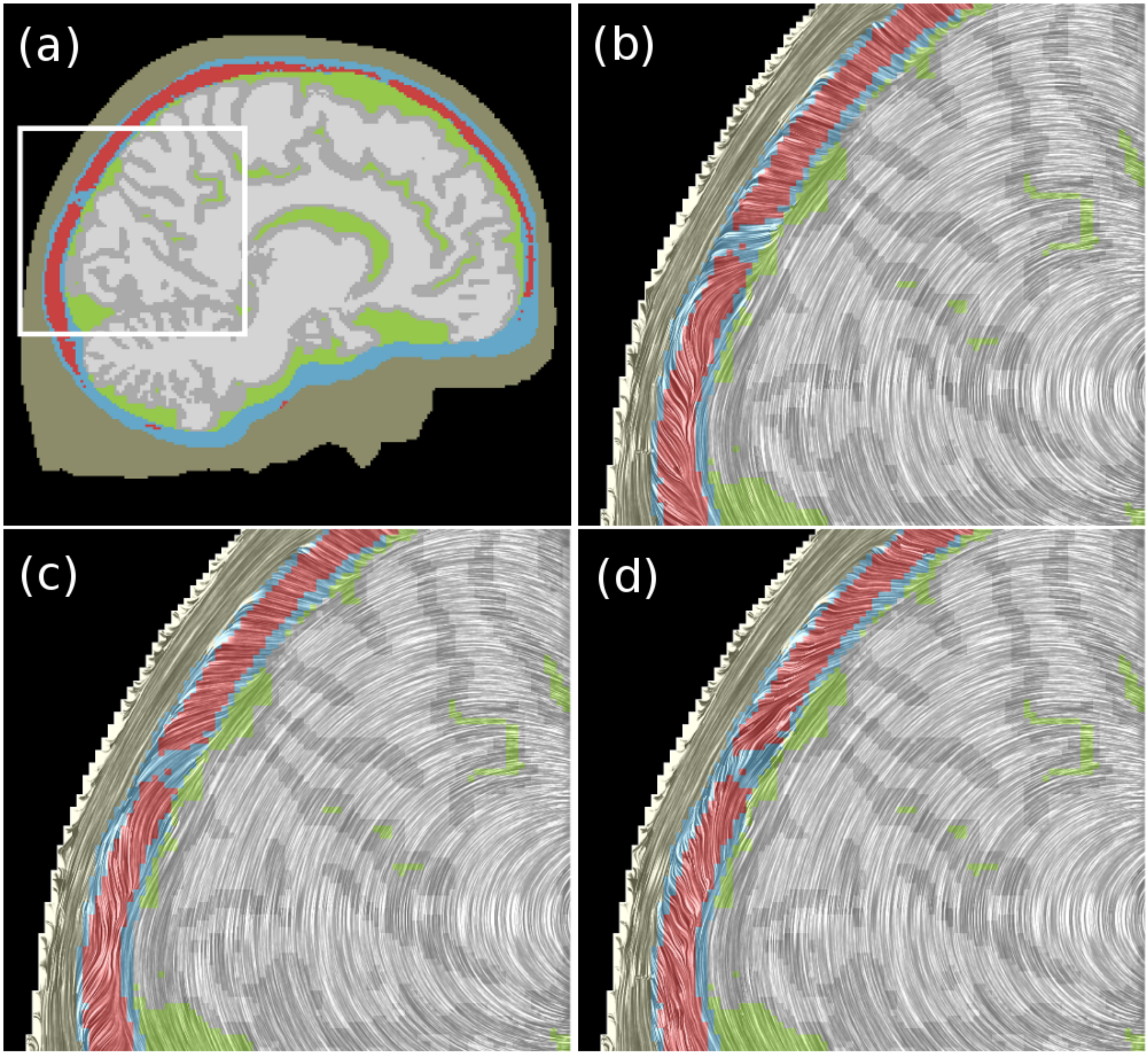

Figure 4: Line Integral Convolution for different skull conductivity models. (a) Tissue mask, including hard-bone (red) and soft-bone (blue). (b-d) Zommed at the occipital fontanel to show its influence in different skull tissue conductivity models. (d) Shows the hard- and soft-bone tissue with different conductivities. LIC is especially useful for showing local, directional properties in the data.

Brain Stimulation Methods:

TDCS