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Tissue Conductivity based Human Head Model Study for EEG

A Dissertation Submitted by

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Abstract

The electroencephalogram (EEG) is a measurement of neuronal activity inside the brain over a period of time by placing electrodes on the scalp surface and is used extensively in clinical practices and brain researches, such as sleep disorders, epileptic seizure, electroconvulsive therapy, transcranial direct current stimulation and transcranial magnetic stimulation for the treatment of the long term memory loss or memory disorders.

The computation of EEG for a given dipolar current source in the brain using a volume conductor model of the head is known as EEG forward problem, which is repeatedly used in EEG source localization. The accuracy of the EEG forward problem depends on head geometry and electrical tissue property, such as conductivity. The accurate head geometry could be obtained from the magnetic resonance imaging; however it is not possible to obtain *in vivo* tissue conductivity. Moreover, different parts of the head have different conductivities even with the same tissue. Not only various head tissues show different conductivities or tissue inhomogeneity, some of them are also anisotropic, such as the skull and white matter (WM) in the brain. The anisotropy ratio is variable due to the fibre structure of the WM and the various thickness of skull hard and soft bones. To our knowledge, previous work has not extensively investigated the impact of various tissue conductivities with the same tissue and various anisotropy ratios on head modelling.

In this dissertation, we investigate the effects of tissue conductivity on EEG in two aspects: inhomogeneous and anisotropic conductivities, and local tissue conductivity. For the first aspect, we propose conductivity models, such as conductivity ratio approximation, statistical conductivity approximation, fractional anisotropy based conductivity approximation, the Monte Carlo method based conductivity approximation and stochastic method based conductivity approximation models. For the second aspect, we propose a local tissue conductivity model where location specific conductivity is used to construct a human head model. We use

spherically and realistically shaped head geometries for the head model construction. We also investigate the sensitivity of inhomogeneous and anisotropic conductivity on EEG computation.

The simulated results based on these conductivity models show that the inhomogeneous and anisotropic tissue properties affect significantly on EEG. Based on our proposed conductivity models, we find an average of 54.19% relative difference measure (RDM) with a minimum of 4.04% and a maximum of 171%, and an average of 1.64 magnification (MAG) values with a minimum of 0.30 and a maximum of 6.95 in comparison with the homogeneous and isotropic conductivity based head model. On the other hand, we find an average of 55.16% RDM with a minimum of 12% and a maximum of 120%, and 1.18 average MAG values with a minimum of 0.22 and a maximum of 2.03 for the local tissue conductivity based head model. We also find 0.003 to 0.42 with an average of 0.1 sensitivity index, which means 10% mean scalp potential variations if we ignore tissue conductivity properties. Therefore, this study concludes that tissue properties are crucial and should be accounted in accurate head modelling.

Declaration

I certify that this dissertation has not been previously submitted for a degree or diploma in any university. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the text.

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I would like to dedicate this dissertation to my parents whom I always miss in my foreign life.

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List of Acronyms

AD- Alzheimer's disease
AP – Action potential
ASA- Advanced source analysis

BEM – Boundary Element Method
BEV –Brain element variation
BTDL- Brain tissue distortion level

CC – Correlation coefficient
CDL – Cortical dipole layer
CRA- Conductivity ratio approximation
CSF – Cerebrospinal Fluid
CT- Computed tomography

DB- Dipole bunch
DT- Diffusion tensor
DT-MRI- Diffusion tensor magnetic resonance imaging

EEG- Electroencephalography

FA- Fractional anisotropy
FE – Finite Element
FDM – Finite Difference Method
FEM – Finite Element Method

GM- Gray matter

LTC-Local tissue conductivity

MAG – Magnification factor
MEG- Magnetoencephalography
MLE- Maximum likelihood estimator
MRI-Magnetic resonance imaging

PDF- probability density function

SC-Somatosensory cortex
SCA- Statistical conductivity approximation

SCEV – Scalp element variation
SEV – Skull element variation

RDM – Relative difference measure
RE- Relative errors

VC- Volume constraint

WC-Wang's constraint
WM- White matter

Notations and Symbols

ρ- Charge density (ρ)

μ - Mean or homogeneous conductivity of a tissue layer

ξ - Anisotropy or conductivity ratio

σ^2 – Variance of conductivity

σ - Conductivity

$\underline{\underline{\sigma}}$ - Conductivity tensor

σ_t, – Transversal conductivity of the white matter, Tangential conductivity of the skull

σ_{trans} – Transversal conductivity of the white matter

σ_{long} – Longitudinal conductivity of the white matter

σ_{rad} – Radial conductivity of the skull

σ_{tan} – Tangential conductivity of the skull

ε-Relative error

η-Correlation coefficient

B - Magnetic field
D - Electric field
E- Electric field
H - Magnetic field
K^+ - Potassium ion

Na^+ – Sodium ion

Cl^- – Chloride ion

m- Maximum likelihood estimator

Publications

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