SOLO: An EEG Processing Software Framework for Localising Epileptogenic Zones

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Abstract. *The paper describes an EEG signal processing software framework designed for performing validation tests in the ENIAC-CSI FP7 project for wireless EEG measurement sensors. The project aims at improving imaging devices and processing methods used in the localisation of epileptogenic zones in epileptic patients. The developed software allows specialist to view multi-channel EEG signals, identify epileptic features and perform source localisation operations based on realistic head models, and generate equivalent dipole data that can be used in localisation accuracy and reproducibility error analysis.*

Keywords: EEG processing, Epilepsy, Interictal Spikes, Source Localisation

1. Introduction

Epilepsy is a devastating disease affecting about 1% of the population. About 60% of all epilepsy patients have symptomatic focal epilepsies [1]. In these cases, one particular portion of the brain is affected by the disease. This region, referred to as focus, is responsible for the epileptic seizures. The focal concept of the epilepsies can be formed by overlapping epileptic zones representing different aspects of the epileptic transformation in the patient's brain [2]. These zones may be measured or estimated by various diagnostic tools, the most important of which is the EEG, which is selectively capable of detecting interictal and ictal electrical changes, thus identifying the irritative, ictal onset and spread zones. The final purpose of the identification of these zones is to plan surgical intervention, in order to remove the epileptogenic zone (EZ) and render the patient seizure free. Epilepsy surgery is superior to drug therapy in drug resistant epilepsy groups [3], with powers of average 60% (range 45-90%) seizure freedom with surgery versus 2-3% with additional drugs. The failure of the surgery, occurring 40% on average, is most often due to the false localisation of the EZ. Even intracranial placement of the electrodes cannot localise EZ in all cases requiring additional electrode placement [4].

The goal of improving source localisation techniques is inherently linked to epilepsy surgery and to the need of better localisation of the EZ. The work reported in this paper is part of the ENIAC Central Nervous System Imaging project[1] which is aiming at developing new brain imaging sensors, devices and data processing methods. Our focus in this cooperation is the evaluation of the accuracy, reliability and reproducibility of wireless EEG sensor-based measurements with respect to epileptogenic zone localisation. Since no software system was found suitable for this task, a new EEG processing and visualisation software framework was developed helping to conduct the source localisation experiments.

In Section 2 the validation goals and experiment protocol is described followed by an overview of the features and architecture of the developed SOLO program in Section 3. Section 4 presents the results of our development to date following with a discussion on future tasks.

[1] http://www.eniac-csi.org/CSI/

2. Proposed Validation Methods

This section describes the context of the validation tasks required in the project. The clinical partner performs long-term EEG monitoring of a selected set of epileptic patients. The EEG data is recorded simultaneously by a wired reference and a wireless development electrode set. The recorded EEG data are stored and later examined and annotated by a specialist. Interictal spikes whose presence indicates epilepsy are identified and marked in the data set. Short segments of the large data set containing the interictal spikes are stored in separate files for effective further processing.

The data segment files are next processed in the SOLO program, which includes the display of the 64-channel EEG data, setting a marker at the interictal spike time epoch and executing an equivalent dipole search based on solving the electromagnetic inverse problem on a patient-specific realistic head model using anatomy based anisotropic conductivity values.

The location, magnitude and orientation of the located best matching dipoles representing the centres of epileptogenic zones are recorded. The validation focuses on the error between localisation results of the reference and the new wireless electrode measurements. Subsequently, the accuracy and reproducibility are also examined verifying that spikes of a given patient localise to regions that math those also found with the reference electrodes and confirmed by clinical examinations.

3. Features and Architecture of the SOLO Software

A rich feature set is required for the processing software to perform the above validation experiments. A complete EEG signal browser, shown in Fig. 1, is developed to display and browse the multi-channel data set. The time scale and amplitude range adjustments help specialists to locate the interictal spikes quickly. A moveable marker is provided to mark the time instance, i.e. the measurement epoch, for which the dipole source localisation is performed.

Source localisation is performed using a realistic, patient-based head model. Patient MR images are segmented into scalp, inner and outer skull and brain surface meshes using the third party programs FSL[2] and Freesurfer[3]. The SOLO program can input these mesh objects and display a 3D view of the patient head geometry. The Electrode Manager module of the program computes the location of the measurement electrodes on the patient head geometry based on the cap layout system. The 3D head model, the placement of the electrodes and the visualisation of the measured potential values using spherical spline interpolation is shown in Fig. 2. Once the measured potential data set is selected with the marker, the program generates a configurable number of candidate dipole positions on the cerebral cortex by travelling the cortical surface following its curvature. The orientation of the dipole thus can always be set perpendicular to the cortical surface.

A boundary element solver [5] is used to compute the simulated potentials on the scalp at the electrode locations based on the parameters of each candidate dipole. The dipole producing the minimum squared mean error for the potential values is selected as the source. Once the localisation stops, the data describing the selected dipole is stored and the location is marked on the 3D model of the cortex.

[2] http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/
[3] http://surfer.nmr.mgh.harvard.edu/

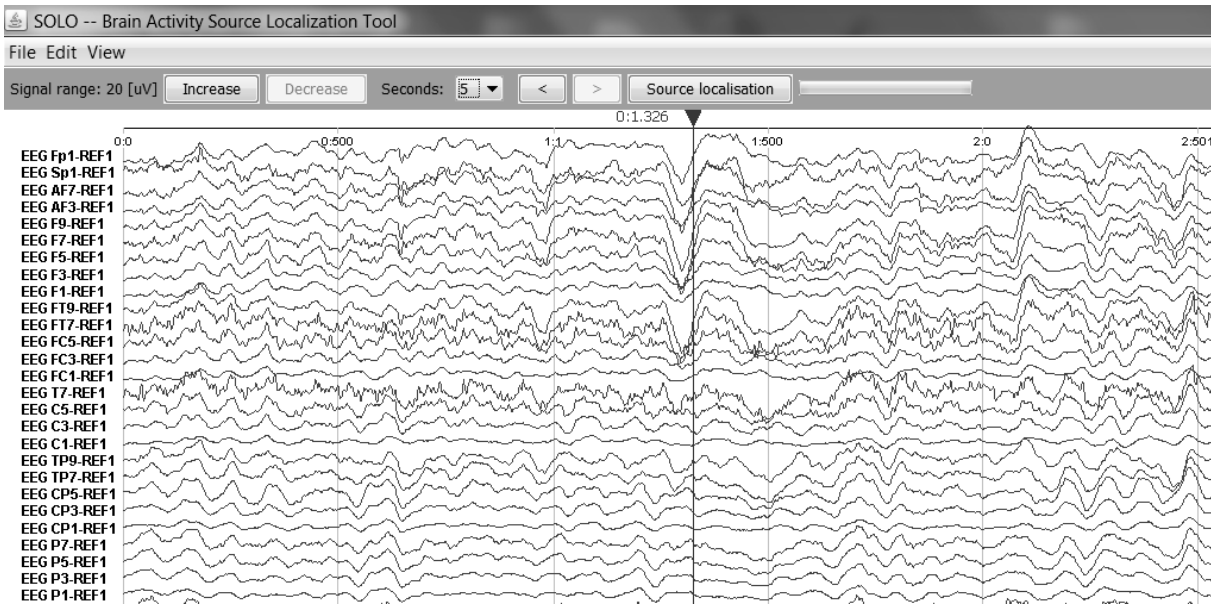

Fig. 1. The EEG signal browser panel (partial snapshot). The specialist can change the time resolution and amplitude range of the signals, browse the data setto locate and mark interictal events.

4. Results

The work presented in this paper is still in progress. At the time of writing, the SOLO software system is fully functional in displaying the EEG data, selecting measurement epochs, visualizing patient head, the electrode cap and the measured potential values. It also performs the dipole search based source localisation.

Collaboration with the National Institute of Neurosciences (Budapest, Hungary) within the project has led to further additional developments in the program. In order to better support epilepsy surgery planning, special visualisation functionality has been added to display intracranial electrodes within the patient head geometry model. This allows the specialist to better understand the anatomical location of the electrode grids or strips, as well as to display the measured intracranial potential values on the head model. One such example with a rather complex set of intracranial electrodes is shown in Fig. 3.

5. Discussion

The first functional version of the SOLO software is functional. The wireless electrodes are in the final testing stage as of March 2013. Live measurements on selected patients are expected to start in April allowing the validation work to start by May. Since the evaluation must finish by the summer, the execution time of the source localisation stage is of prime importance. The current solver finds one dipole in 4 minutes, resulting in approx. 8.5 days execution time per epoch assuming 2500 candidate dipoles (approx. 1 dipole per cm^2 resolution). Execution time becomes prohibiting should we need to analyze several epochs per interictal spike. We are actively working on optimizations of the solver as well as on the development of a massively parallel, GPU-based solver implementation in order to reduce localisation execution time to an acceptable level.

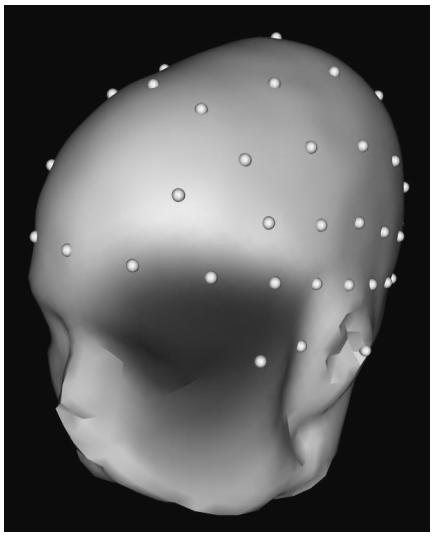

Fig. 2. 3D visualisation of the potential map, electrodes and the realistic head model.

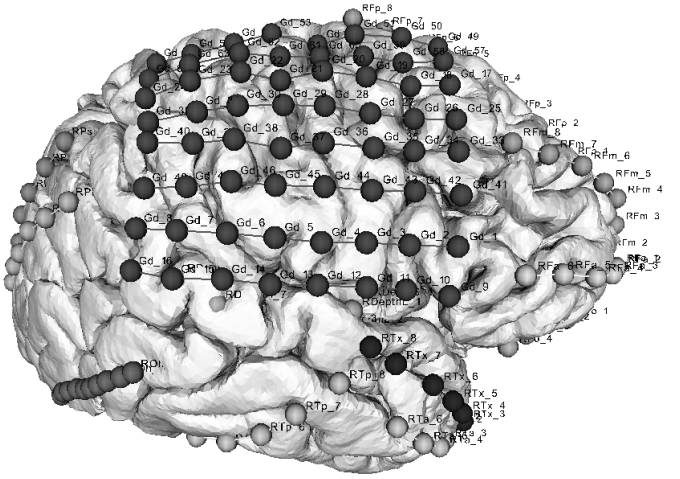

Fig. 3. 3D visualisation of the intracranial electrodes. The colour of the electrodes may represent either electrode group membership or the potential value measured at the given position of cortical surface.

6. Conclusions

This paper described the validation tasks to be performed within the ENIAC CSI project related to the development of new EEG measurement sensors, devices and data processing methods. A new EEG processing and visualisation software framework has been developed within the project to execute the required dipole-based source localisation based validation and error analysis tests. The first version of the software is functional and further improvements are in development to ensure the evaluation can be finished by the required deadline. It is hoped that the software in its full form will support epilepsy and EEG imaging research outside our current project as well.

Acknowledgements

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