

Digital Enhancement of EEG/MEG Signals

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“Las cosas hay que hacerlas bien, nada de al ‘ahí se va’ ”...
Teniendo siempre presentes estas palabras y siguiendo tu ejemplo
de disciplina y constancia, es como he tratado de hacer las cosas siempre...
Besitos hasta el cielo mi abuelito hermoso.

“Everything has to be done perfectly well, not just ok”...
Bearing in my mind these words and following your example
of discipline and perseverance is how I have tried to do everything...
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“Meine Hoffnung und meine Freude, meine Stärke, mein Licht...Mein Gott”

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Abstract

Electroencephalography (EEG) and Magnetoencephalography (MEG) recordings are commonly used for analyzing the brain. However, in most cases, the recordings not only contain brain waves, but also artifacts of physiological (ocular, muscle, ECG artifacts) or technical (electrode popping, power-line) origins, and noise from different sources. The main aim of the work described in this thesis is the noise reduction and artifact suppression from EEG and MEG signals.

Different techniques for artifact suppression have been used: A Low-Pass Filter (LPF), an instantaneous Independent Component Analysis (ICA) algorithm, a combination of ICA and LPF, a combination of ICA and State-Space Modeling (SSM), a combination of ICA and Wiener filters, and a hybrid filter (i.e., a filter that works in the time- and frequency-domains). These techniques have been tested only offline in the present work.

Additionally, two artifact suppression methods that could work either offline or in real-time have been tested in real-time. The first one is a recent approach used for signal enhancement, called Empirical Mode Decomposition (EMD). This method is employed in this work for denoising, for detrending, and for suppressing the muscle artifacts from EEG signals. The second method is an algorithm here called Classification-based Signal Enhancement (CBSE). It was also used to suppress muscle artifacts in EEG signals, in real-time, using Wiener filters for signal enhancement.

In order to use any artifact suppression technique, the artifacts to be removed have to be previously identified. If the artifact suppression is done offline, the detection can be carried out by visual inspection of the data by an expert, or in an automatic way. On the other hand, if the suppression of artifacts has to be done in real-time, the artifacts have to be detected automatically. A detection technique is proposed in the present work. First, different features are extracted from the independent components, and then a threshold-based classification is performed to determine which components are contaminated, what kind of artifacts they contain, and how the suppression of the artifacts is realized. This method was tested in an offline manner in this thesis.

The effectiveness of the proposed artifact suppression techniques was demonstrated by application to either “semi-simulated” EEG signals artificially contaminated with artifacts, or to real EEG/MEG data from a healthy subject or a patient suffering from epilepsy (inherently contaminated with different kinds of artifacts). It is shown by visual inspection and in a quantitative manner that, after applying the different techniques, the EEG/MEG

signals are enhanced.

To reduce the noise, an equalizer and a Wiener filter have been used. The signals employed for this purpose correspond to those from the newly developed magnetoelectric (ME) sensors at Kiel University.

Zusammenfassung

Elektroenzephalographie (EEG) und Magnetoenzephalographie (MEG) sind gängige Messtechniken für die Hirnstromanalyse. Die Aufnahmen enthalten jedoch meistens nicht nur Gehirnsignale, sondern auch Artefakte physiologischen Ursprungs (Augen-, Muskel-, Herzschlagartefakte) oder technischer Ursachen (Elektrodenbewegungen, Spannungsversorgungs-Einkoppelungen) sowie Rauschen aus verschiedenen Quellen. Hauptziel der in diese Arbeit beschriebenen Bemühungen sind die Rausch- und Artefaktreduktion für EEG- und MEG-Signale.

Unterschiedliche Techniken zur Artefaktunterdrückung wurden genutzt: Tiefpassfilterung (Low-Pass Filtering, LPF), Kurzzeiterlegungen der Signale in unabhängige Komponenten (Independent Component Analysis, ICA), die Kombination von ICA mit einer Zustandsraum-Modellierung (State-Space Modelling, SSM) oder mit einem Wiener-Filter sowie ein so genanntes Hybridfilter, das sowohl Zeit- als auch Frequenzbereich zur Artefaktbereinigung nutzt. In der vorgestellten Arbeit wurden diese Techniken lediglich off-line realisiert.

Zusätzlich wurden zwei Artefaktunterdrückungsmethoden on-line getestet, die sowohl off-line wie in Realzeit verwendet werden können. Die erste Methode ist ein relativ neuer Ansatz für die Signalverbesserung, der als “Empirical-Mode Decomposition” (EMD) bezeichnet wird. Sie wird hier zur Rauschreduktion, zur Beseitigung von “Trends” (d.h. langsam veränderlichen Gleichanteilen) und zur Unterdrückung von Muskelartefakten in EEG-Aufnahmen verwendet. Die zweite ist ein Algorithmus, der hier als “Signalverbesserung auf Klassifikationsbasis” bezeichnet wird (Classification-based Signal Enhancement, CBSE) und ebenfalls zur Echtzeit-Reduktion von Muskelartefakten im EEG herangezogen wurde; er beruht im Kern auf einem Wiener-Filter.

Vor jeder Anwendung eines Verbesserungsansatzes müssen die zu bekämpfenden Artefakte identifiziert werden. Bei einer Off-line-Technik kann das mittels visueller Inspektion der Signale durch einen Experten geschehen oder auch automatisch. Zur Echtzeit-Signalverbesserung muss die Detektion automatisch vorgenommen werden. Ein Detektionsverfahren wird in dieser Arbeit vorgeschlagen. Dabei werden zunächst verschiedene Merkmale aus den unabhängigen Komponenten extrahiert; damit entscheidet dann eine Klassifikation auf Schwellwertbasis, welche Komponenten gestört sind, welche Artefaktarten sie enthalten und wie zur Beseitigung vorzugehen ist. Der Ansatz wurde in Off-line-Simulationen getestet.

Die Wirksamkeit der vorgeschlagenen Artefaktunterdrückungen wurde nachgewiesen, indem sie auf “semi-simulierte” EEG-Signalen angewandt wurden, die künstlich durch Addition (realer) Artefakte gestört wurden. Demonstriert wurde sie darüber hinaus durch die Verwendung realer, durch verschiedene Artefakte gestörter EEG- und MEG-Daten eines Gesunden und eines Epilepsiepatienten. Die visuelle Prüfung wie auch ein quantitatives Maß zeigen, dass tatsächlich Verbesserungen erzielt werden.

Zur Rauschminderung wurden ein Wiener-Filter und ein Entzerrer eingesetzt. Die dafür herangezogenen Signale entsprechen denen aus an der Universität Kiel neu entwickelten magnetoelektrischen Sensoren.

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