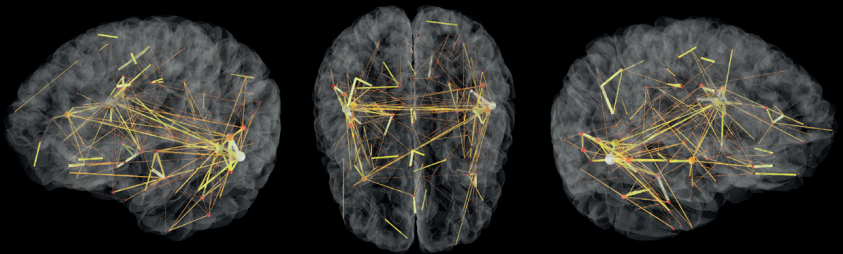


Real-Time Estimation and Visualization of Functional Connectivity in the Human Brain

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Dissertation

Real-Time Estimation and Visualization of Functional Connectivity in the Human Brain

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Abstract

Real-time processing of neural data provides new opportunities for neuroscience research. This approach yields more intuitive insights into instantaneous brain functions and creates the foundation for a wide range of neurofeedback scenarios. Real-time processing also allows early assessment of data quality and validity of the experiment setup. This enables early identification of possible problems and thus helps to optimize the measurement procedure. Magnetoencephalography (MEG) and Electroencephalography (EEG) are non-invasive electrophysiological methods with a high temporal resolution. Tools and software toolboxes have already been proposed that monitor and process M/EEG data in real-time.

This work introduces new tools to acquire and process electrophysiological data streams in real-time. A special emphasis is put on the estimation and visualization of functional connectivity networks. Functional connectivity estimation has been hardly ever considered in the real-time setting so far. The methods described in this work allow the real-time estimation and visualization of large functional connectivity networks based on sensor- and source-level M/EEG data. The new tools were integrated into the open-source MNE-CPP software, which provides an API and standalone GUI applications. The MNE-CPP project caters both software developers and users with little or no coding experience.

The new real-time tools introduced in this Thesis are able to process both spontaneous and evoked data. A proof-of-principle measurement was conducted to validate the new real-time functional connectivity tools on source-level evoked responses to electrical median nerve stimulation. The results show that the implemented tools work as expected and are able to give insight into functional connectivity networks during an ongoing measurement session. The implemented tools open up new ways to monitor MEG measurements to eliminate possible setup problems early. Moreover, the real-time functional connectivity results can be used in subsequent processing steps, e.g., when the data are used in a neurofeedback setting.

Zusammenfassung

Aus neurowissenschaftlicher Sicht sind die Möglichkeiten für die Echtzeitverarbeitung neuronaler Daten vielfältig. Echtzeit-Tools ermöglichen nicht nur einen schnelleren und intuitiveren Einblick in augenblickliche Gehirnfunktionen, sondern schaffen eine Grundlage für eine Vielzahl von Neurofeedback-Szenarien. Darüber hinaus ermöglichen sie eine frühzeitige Beurteilung der Datenqualität und des Versuchsaufbaus. Dies erlaubt ein frühes Eingreifen und Beheben von möglichen Fehlern. Aufgrund ihrer hohen zeitlichen Auflösung sind Magnetoenzephalographie (MEG) und die Elektroenzephalographie (EEG) geeignete Messverfahren für die Echtzeitdatenverarbeitung.

Es existieren bereits Software-Toolboxen, welche in der Lage sind, M/EEG-Daten in Echtzeit zu überwachen und zu verarbeiten. Diese Arbeit stellt eine Reihe neuer Werkzeuge zur Erfassung und Verarbeitung elektrophysiologischer Datenströme vor. Die Methoden in dieser Arbeit ermöglichen die Schätzung und Visualisierung großer funktionaler Netzwerke in Echtzeit. Bereits existierende Arbeiten haben sich bisher stets auf Netzwerke mit wenigen Knoten konzentriert. Alle neuen Tools wurden in das Open-Source-Projekt MNE-CPP integriert, welches eine API und GUI-Anwendungen bereitstellt. Damit stehen die neuen Tools sowohl für Entwickler als auch Anwendern, welche keine oder nur wenig Programmiererfahrung besitzen, zur Verfügung.

Die neuen Echtzeit-Tools sind in der Lage funktionale Netzwerke auf Sensor- und Quellebene zu verarbeiten. Im Rahmen dieser Arbeit wurde eine Proof-of-Principle-Messung durchgeführt, welche funktionale Netzwerke auf Quellniveau und evozierten Reaktionen, die durch eine Stimulation des sog. Nervus medianus ausgelöst wurden, geschätzt. Die Ergebnisse zeigen, dass die implementierten Echtzeit-Tools wie erwartet funktionieren und in der Lage sind, während einer laufenden Messung, Einblicke in funktionale Netzwerke zu geben. Die implementierten Tools ermöglichen es dadurch eine laufende Messung zu überwachen und Experiment- bzw. Einrichtungsprobleme frühzeitig zu erkennen. Weiterhin können die Echtzeitergebnisse genutzt werden, um neuartige Gehirn-Maschinen Schnittstellen zu entwerfen.

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Contents

1	Introduction	1
1.1	Thesis Structure	1
1.2	Motivation	1
1.3	Objectives	2
2	Background	5
2.1	Overview	5
2.2	Electrophysiology of the Human Brain	5
2.3	Measuring the Human Brain	6
2.4	Estimating Neuronal Activity	9
2.5	Estimating Neuronal Connectivity	11
2.6	Real-Time Data Processing	14
2.6.1	Motivation	14
2.6.2	Software	15
2.6.3	MNE-CPP	15
2.6.4	MNE Scan	16
3	Methods	21
3.1	Overview and Contributions	21
3.2	The Connectivity Library	21
3.2.1	Architecture	21
3.2.2	Usage	23
3.2.3	Connectivity Metrics	23
3.2.4	Real-Time Capability	27
3.3	The Disp3D Library	30
3.3.1	Architecture	30
3.3.2	Usage	30
3.3.3	Supported Data Types and Items	32
3.3.4	User Interaction	35
3.3.5	Real-Time Capability	36
3.4	Real-Time Functional Connectivity Pipeline	37
3.4.1	Overview	37
3.4.2	Acquisition Plug-ins	37
3.4.3	Noise Reduction Plug-in	39
3.4.4	Averaging Plug-in	40
3.4.5	Covariance and RTC-MNE Plug-in	40
3.4.6	Neuronal Connectivity Plug-in	41
3.5	Real-Time Determination of Head Position	42
3.6	Verification and Validation	43
3.6.1	Connectivity and Disp3D Library	43
3.6.2	Real-Time Connectivity Pipeline	45

4	Results	47
4.1	Overview	47
4.2	Functional Connectivity Library	47
4.2.1	Performance	47
4.2.2	Simulation	53
4.3	3D Visualization Library	57
4.4	Proof-of-Principle Measurement	60
4.4.1	Offline Findings	60
4.4.2	Real-Time Findings	64
4.4.3	Performance	67
4.4.4	Real-Time Determination of Head Position	69
5	Discussion	71
5.1	Overview	71
5.2	Connectivity Library	71
5.2.1	Architecture	71
5.2.2	Performance	73
5.2.3	Simulated Functional Connectivity	74
5.3	Disp3D Library	74
5.4	Real-Time Connectivity Pipeline	75
5.4.1	Acquisition	75
5.4.2	Noise Reduction	75
5.4.3	Averaging	76
5.4.4	RTC-MNE	76
5.4.5	Functional Connectivity	76
5.4.6	Performance	78
5.4.7	Real-Time Determination of Head Position	78
5.5	MNE-CPP	78
6	Conclusion	81
6.1	Overview	81
6.2	Summary and Outlook	81
6.3	The Future of MNE-CPP	82
6.3.1	Connectivity Library	82
6.3.2	Disp3D Library	83
6.3.3	MNE Scan	83
6.3.4	MNE Analyze	83
6.3.5	Deployment via WebAssembly	84
6.4	Upcoming MNE Scan Use-Cases	84
6.4.1	Integration of Closed-Loop TMS/EEG	84
6.4.2	Monitoring ECoG and sEEG Implantation	86
6.4.3	New Device Support	87
6.5	Concluding Remarks	88
	References	89
	List of Figures	99
	List of Tables	101
	List of Code Snippets	103

List of Abbreviations	103
A MNE Scan	107
A.1 Architecture	107
A.2 GUI	108
B MNE-CPP Contributions	115
C Connectivity library	119
D Disp3D library	121
D.1 Architecture	121
D.2 Framegraph	122
E MNE Analyze	123
F MNE Browse	127
List of Publications	129