Abstract

Brain Source Localization (BSL) using Electroencephalogram (EEG) has been an active area of research because of its cost-effective and noninvasive nature. As the EEG data is spatially sampled over head, the subsequent localization performance is limited by the head-shape assumption for efficient data representation. In the literature, the human head is approximated by spherical shape. Hence, Spherical Harmonics (SH), the corresponding basis functions, have been the natural choice for EEG source reconstruction and localization. However, it requires more number of SH coefficients due to discontinuities at the boundary of the head. This thesis addresses the brain source localization problem in spatial and anatomical harmonics (spherical and head harmonics) domain. In particular, a novel set of basis functions called Head Harmonics (H^2) are developed to accurately represent the data sampled over head. The basis functions are formulated based on more realistic head dimension. The three spatio-temporal forward data models that include Infinite Homogeneous Isotropic Conductor (IHIC), Three Layer Concentric Spherical Head (TLCSH) and four shell, are presented with their respective gain matrix, orientation matrix and signal intensity matrix. A framework is presented to transform the spatio-temporal forward model to anatomical harmonics domain. The anatomical harmonics domain formulation leads to dimensionality reduction and increased contribution of source eigenvalues resulting in decreased computation and increased accuracy respectively. Subsequently, the inverse methods that include Minimum Variance Distortionless Response (MVDR), Multiple Signal Classification (MUSIC), Recursive MUSIC (R-MUSIC) and, Recursively Applied and Projected MUSIC (RAP-MUSIC) are formulated in H^2 domain for advanced BSL. The theory is additionally verified with real EEG data corresponding to epilepsy seizure, visual stimuli and mental arithmetic task.

For efficient BSL in the spatial domain, a novel Subspace Principal Vector Projection (SPVP) based approach is proposed that suppresses interference present in the activity state. SPVP method utilizes subspace correlation based mutual interference statistics and thus relaxes the strict spatial stationarity condition. In real time Brain Computer Interface (BCI) application, efficient interference suppression is advantageous to extract useful information from the raw EEG signals. The role of BSL in decoding the intended hand movement for

the potential BCI applications is additionally explored. As the EEG sensor records electrical activity from all cortical sources including region of no interest, that may be the reason for the poor performance in the sensor space. Classification of left and right hand movement from EEG signals in sensor and cortical source space (through BSL) is presented. It is to note that the conventional classification based BCI system controls external devices by providing discrete control signals to the actuator. A continuous kinematic reconstruction from EEG signal is better suited for practical BCI applications. Therefore, three novel source aware deep learning models i.e. Multi Layer Perceptron (MLP), Convolutional Neural Network - Long Short Term Memory (CNN-LSTM), and Wavelet Packet Decomposition (WPD) CNN-LSTM are proposed for Motion Trajectory Prediction (MTP). BSL is utilized for channel selection and accurate EEG trial selection in continuous trajectory prediction. Qualitative comparison of proposed model with state-of-the-art Multi-variable Linear Regression (MLR) model is presented.

The idea of utilizing anatomical basis for accurate EEG data representation is further extended for the representation of different anatomical shapes, including human scalp, skull, brain, tooth, face, lung, ventricle and brain cortical surfaces. Spherical harmonics are widely used for anatomical shape description. However, establishing a one-to-one correspondence between the object surface and the entire unit sphere may induce a large geometric distortion, in case the shape of the surface is too different from a perfect sphere. Thus, we proposed adaptive area-preserving parameterization methods for simply-connected open and closed surfaces. The key idea is to compute an adaptive area-preserving parameterization of any input surface onto the optimal spherical cap region of the unit sphere, which allows us to utilize the adaptive basis functions for the shape description and reconstruction.