5 Summary and Future work

5.1 Summary

In the thesis, we described the in-house development of MCG facility at IGCAR, Kalpakkam and the development of suitable methods for preprocessing and analysis of the recorded MCG data. The salient features of the thesis are:

- Setting up of a multichannel Magnetocardiography (MCG) measurement facility which involved a careful assembly and wiring of SQUID sensors arranged inside a flat bottom liquid helium cryostat is described. The MCG system has been progressively upgraded from an instrument with a single SQUID channel to an instrument with 37 SQUID channels arranged in a plane as a hexagonal array of 37 SQUID sensors with an inter-sensor spacing of 3 cm.

- The sensor output was calibrated by coupling a magnetic field of known strength and recording the system response. All the SQUID sensors were characterized by making detailed measurements of spectral density of voltage noise as a function of frequency. Recording of MCG data on normal human subjects as well as those with a cardiac dysfunction is described.

- Ensemble Empirical Mode Decomposition (EEMD) method is adopted for MCG signal denoising and the procedure for extracting the Intrinsic Mode Functions (IMFs) is described in chapter 3. In the EEMD method, we introduced the empirical relation for noise amplitude related to the standard deviation of the second order time derivative of the signal (as against the conventional use of the amplitude related to the standard deviation of the signal itself) in order to prevent mode mixing, and achieve substantial reduction of noise using relatively lower number of ensemble averages. The use of interval thresholding method has been described to
reduce the discontinuities in the reconstructed denoised signal, which usually appear when direct thresholding is applied.

- The elimination of baseline drift associated with smooth low frequency variations which sometimes arise due to the subject’s breathing and movement has been elucidated. A novel method to eliminate the sudden and discontinuous changes in the baseline termed as high frequency baseline drift has been proposed. The EEMD based method eliminates the high frequency baseline drift more effectively as compared to the standard wavelet based method.

- The EEMD hard-interval thresholding method is applied to denoise the single channel MCG data and its performance is compared with that achieved using other standard techniques such as wavelet transform and Independent Component Analysis (ICA). The signal quality has been shown to be significantly improved by EEMD based denoising method when compared to that obtained by wavelet and ICA based denoising methods.

- The EEMD based method has also been used to detect the extremely weak signal associated with His-bundle magnetic field employing considerably lower number of cardiac cycles for signal averaging using QRS onset as the fiducial reference point.

- A method based on a combination of Ensemble Empirical Mode Decomposition (EEMD) and Independent Component Analysis (ICA) is proposed with a view to substantially reduce computational burden associated with EEMD alone for denoising of multichannel MCG data with a large number of channels and is shown to achieve superior signal-to-noise ratio (SNR) with lower computational burden compared to either ICA alone or wavelet enhanced ICA.

- A simple Equivalent Current Dipole (ECD) model is adopted for cardiac source and the methods for visualizing the cardiac source through the construction of Pseudo Current Density (PCD) map and the estimation of source parameters through the solution of the inverse problem are described in chapter 4.

- A nonlinear least square optimization technique with independent sets of pseudo-random numbers as initial estimates of source parameter values is used for solving the inverse problem; use of independent sets of pseudo-random numbers over a large number of trials is
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shown to be successful in avoiding the possibility of the solution getting trapped in a local
minimum. In view of the non-uniqueness of the solution to the inverse problem, necessity of
imposing realistic constraints to obtain the physiologically relevant solution is emphasized.
The method was successfully applied to the experimental data corresponding to the magnetic
field distribution produced by a current carrying source coil at a known position. The method
was shown to yield a localization error of ±2 mm for the known dipole location and was thus
demonstrated to yield a reliable estimate of the source parameters from an analysis of the
magnetic field distribution.

- The influence of noise on the source localization accuracy was investigated by simulating the
  magnetic field distribution produced by single and two equivalent current dipoles with various
  levels of input noise deliberately added to the data; the results show that the localization error
  increases with increase in the added noise level. These results emphasize the importance of
  pre-processing of MCG signals for noise reduction.

- The effect of denoising the MCG data, by ICA, wICA and EEMD-ICA, on the magnetic field
  maps (MFM) and the Pseudo Current Density (PCD) maps has been elucidated for the 37
  channel MCG data. It is shown that the data denoised by EEMD-ICA technique provides
  stable empirical source estimate through the PCD map at different instants of cardiac cycle
during the T-wave when compared to that obtained by ICA and wICA. Further, the effect
  of signal denoising on the estimation of source parameters obtained by solving the inverse
  problem was analyzed for the 37 channel MCG data. It is shown that the denoising of the
  37 channel MCG data using a combination of EEMD and ICA yielded a robust estimation of
  the source parameters compared to what can be achieved using ICA or wICA for denoising.

The present study shows that, although the noise reduction is crucial for realizing
a lower source localization error, it is also important to choose an appropriate
method like EEMD-ICA for signal pre-processing, for better noise suppression and,
consequently, a robust and credible source estimation.
5.2 Future Work

- It is well known that a cardiac source could not always be modeled with reasonable accuracy as a single Equivalent Current Dipole (ECD) embedded in a horizontal layered conductor, and hence, there is a considerable scope for adopting more realistic models for the source as well as the volume conductor during the analysis of the measured MCG data. It is also important to use anatomical information derived from studies such as Magnetic Resonance Imaging (MRI) to constrain the solution to correspond to the physiologically relevant solution. There is a need to develop suitable algorithms to project the locations of sources (dipoles, currents etc.) inferred by an analysis of MCG data onto an MRI image of the subject in order to assist the clinician in better visualizing the information derived from an analysis of the MCG data.

- The signal preprocessing techniques developed in the context of the MCG data could also be used for the preprocessing of experimental MEG data measured with the 86 channel whole head Magnetoencephalography (MEG) system, which is getting ready for measurements in our laboratory.
List of Publications:

(a). Published:


(b). Communicated:


(c). Conferences/Proceedings:


