Future prospects for fusion of multi-modality functional imaging techniques

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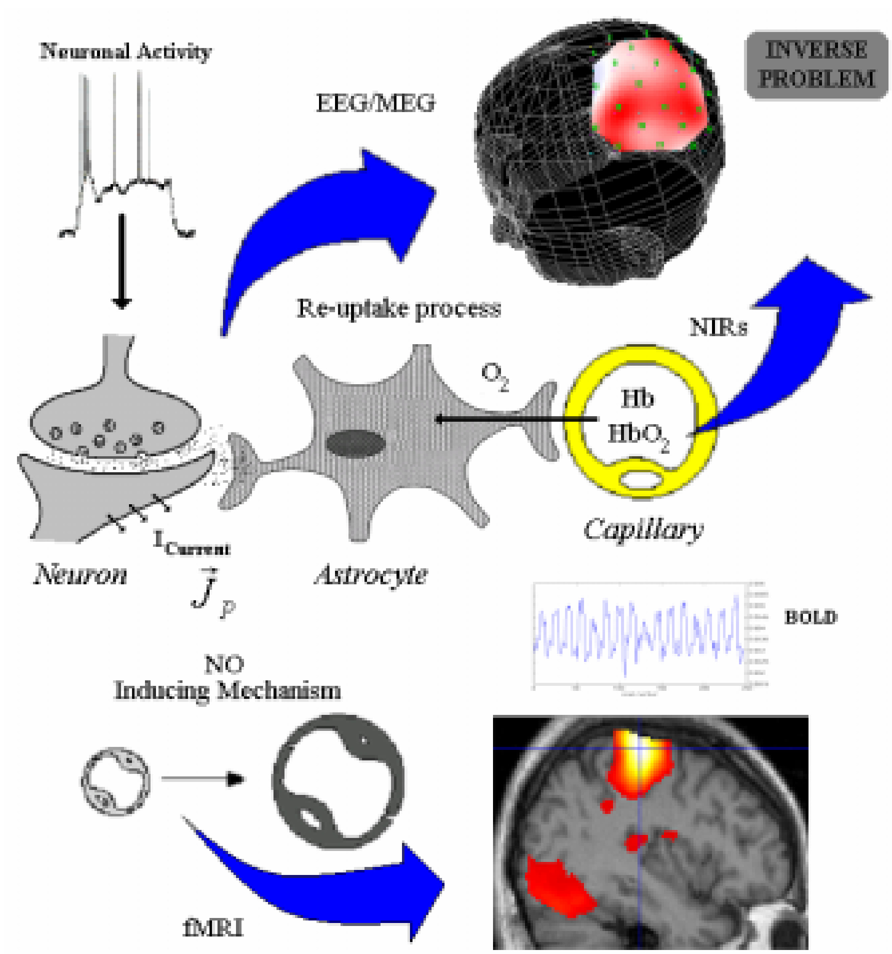
The elucidation of the temporal dynamic and connectivity patterns of neuronal activation in specific brain areas, associated with particular motor, sensorial or cognitive events, constitutes a current problem of great interest in neuroimaging. Considerable progress has been possible due to the use of functional Magnetic Resonance Images (fMRI), Electro and Magneto Encephalograms (EEG/MEG) and Near Infrared Spectroscopy (NIRs) modalities, which permit the exploration of both electro-chemical and hemodynamical changes in the brain tissues. However, the data as originally obtained from these separated image modalities has several limitations in the temporal or spatial resolution, respectively. Furthermore, these imaging modalities reflect different aspects of the underlying physiological mechanisms, which include electrophysiological and vascular/metabolic processes interacting dynamically. Fortunately, significant insights about the main principles of traducing synaptic activation into signals that trigger specific controlling systems have been widely reported in the literature in the last decade. In spite of the very limited usage, in the recent years, the simultaneous recording of fMRI, EEG and NIRs data has become realizable, given to researchers the possibility to use those complementary techniques in a unified scenario with the integration of the spatio-temporal characteristics. The development of methods to obtain a real-time picture of the neuronal activation from a fusion of data coming from these techniques constitutes nowadays one of the most fascinating subject for theoretical neuroscientists. Though these methods would have a tremendous impact on data analysis, there is little theoretical works developed to date.

The Blood Oxygen Level Dependence (BOLD) represents the image contrast most commonly used in human fMRI studies. The BOLD signal has a non-linear multiphasic nature, reflecting relative changes in the concentration of de-oxyhemoglobine Hb and the cerebral blood volume; the later, caused by the Nitric Oxide (NO) induced signaling. As a consequence of the temporal mismatches between underlying hemodynamic and metabolic process, the BOLD signal clearly shows an initial dip, follows by a robust increase and a post-stimulus undershoot. The BOLD response can be obtained for a very high voxel resolution (order of mm), but unfortunately its resolution in time is very poor (order of seconds, time scale for which the changes of vascular/metabolic brain system can be detected). The Primary Current Density (PCD) $\vec{J}_P$ is a vector field that results from the spatial-temporal integration of post-synaptic electric currents ($\mathrm{I}_{\mathbf{Current}}$) in the brain space. The voltage difference and the variation of magnetic flux, known as the EEG and MEG respectively, are recorded by sensors on a discrete set of places external to the head. The electrophysiological inverse problem consists of the estimation of PCD from EEG and/or MEG, mathematically represented by the solution of independent and inhomogeneous vector Fredholm integral equations of the first type with the lead fields as the kernels. Unfortunately, this IP does is ill posed; hence, it is necessary to add a priori information about the PCD. The NIRS constitutes an external reflection of the change in the absorption coefficient of brain tissues for a set of different wavelengths in the infrared range. Over the NIR wavelength range the absorption of blood is not only fairly significant, but also the absorption of Hb and oxyhemoglobine (HbO_2) are quite different. Based on this fact, the scalp is illuminated in several places with high peak Laser diodes and, after being absorbed and scattered by brain tissues inside the head, a signal is recorded in a set of different scalp sites by using low-light sensitive photodetectors. It is used two wavelengths in order to compute relative changes of Hb and HbO_2 in the capillary bed, which is separated from the scalp by the order of centimeters. The most significant fact is that NIRS signal can be recorded with the very high temporal resolution (order of milliseconds). However, to reconstruct the absorbing coefficient patterns inside the head from the light intensity observed on the discrete set of sites on the scalp, a non-linear ill-posed inverse problem must be solved. The NIRs is strongly damped due to the effect of nuisance tissues (i.e. skull, scalp, etc). The image reconstruction method depends on developing a forward model for simulating boundary measurements for a given experimental setup and known the optical properties of tissue. The forward model can be represented after a set of approximation for the light transport inside brain by the photon diffusion equation.



In this work, four relevant topics that constitute challengers for the fusion of images multi-modality will be discussed:

1- The non-linear dynamics of BOLD signals that appear as a consequence of the complexity of the linking mechanisms between electrical and vascular processes.
2- The major capabilities and limitations of EEG and MEG inverse problems.
3- The blurring effect produced by the nuisance tissues on the NIRs signals.
4- The use of Bayesian formalism to combine information provided by different physical magnitudes.