Regularized temporal ensemble averaging for EIT

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Electrical Impedance Tomography (EIT) estimates the conductivity distribution within a body based on current injection and voltage measurements at electrodes on the body surface. EIT shows significant advantages for monitoring physiological changes, such as those associated with air and blood movement in the thorax. While current EIT hardware has relatively high frame rates, these physiological events are sufficiently rapid that individual timing of each voltage measurement in a data frame must be considered. An additional constraint is that ensemble averaging is needed to improve SNR for cardiac frequency events. In this case, we have a time sequence of EIT data and a synchronization (QRS) signal, but each indivitual EIT measurement is not synchronized in time to the QRS. We wish to estimate the internal conductivity change at times (relative to the QRS) which may there may not be any measured data. We propose a novel regularized inverse algorithm to estimate the ensemble averaged EIT image in this scenario. A regularized image estimate $\hat{\mathbf{x}}$ is calculated from a sequence of data frames $\mathbf{y}$ as $\hat{\mathbf{x}} = \mathbf{\Sigma_x J}^t(\mathbf{J\Sigma_x J}^t + \mathbf{\Sigma_n})^{-1}\mathbf{y}$, where $\mathbf{J}$ represents the column concatenated Jacobian matrix for each data element, and $\mathbf{\Sigma_x}$ and $\mathbf{\Sigma_y}$ represent estimates of the image and noise co-variance terms. In order to create an ensemble average estimate, we estimate $\mathbf{\Sigma_x}$ from spatial and temporal terms such that $[\mathbf{\Sigma_x}]_{i,j} = \exp(-\frac{\Delta t}{\tau} - \frac{\Delta d}{\gamma})$ where image elements i and j are spaced by a time difference Δt and a spatial distance Δd, and τ, γ are temporal and spatial constants. Based on this formalation, we calculate a time series of ensembled averaged EIT images throughout the cardiac cycle, as a function of the time difference from the QRS peak. Images show improved quality with respect to naïve approaches to ensemble averaging.