Application of PLS-DA method in separation of venous and arterial phase in 4D CE-MRA data

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Introduction: Contrast enhanced MR angiography (CE-MRA) provides useful information about the geometry and flow properties of the vessels. In order to have a better visualization of the venous phase or for further processing of the data, it is often desired to separate the arterial phase from the venous phase and visualize them separately. This task can be very complicated especially in patients with venous abnormalities as the flow through the veins is accompanied with various delays or is obstructed. In these cases, it may not be possible to identify a clear arterial phase in the image for subtraction from other time points. Therefore, we developed an algorithm based on a partial least squares discriminant analysis (PLS-DA)[1] to isolate the venous and arterial phase in a 4D CE-MRA dataset. This algorithm has been applied successfully in other fields of data and image analysis[2]. The advantage of this PLS-DA and other partial least squares methods is their ability to handle highly correlated datasets as well as their ability to handle large amounts of data[3].

Algorithm and theory: the algorithm is based on a latent variable (LV) analysis of the data. At the first step, the data (at each time point) is smoothed using a 3D Gaussian filter. In the next step the user selects four regions of interest (ROI): two from the arteries (high intensity and low intensity) and two from the veins (high and low intensity regions). These four ROIs are used to train the PLSDA algorithm and to calculate the prediction coefficients. When the training set is selected it is unfolded, so that each ROI in each 4D dataset is a matrix of the size (nROI×nTimePoints). The unfolded training ROIs are later concatenated to construct the training set input matrix (X). A corresponding **Y** matrix is constructed by assigning one vector for each class, where the elements of each vector are 1 for the corresponding class and zero elsewhere, resulting in an orthogonal matrix. Once the coefficients are calculated, the rest of the voxel intensities in the image are unfolded the same way and fed to the dataset to determine their likelihood of belonging to each class (corresponding y values). At the end, the predicted **Y** values are refolded to form the 3D matrix of the arterial or venous phase estimates. The following figure shows the steps involved in the process
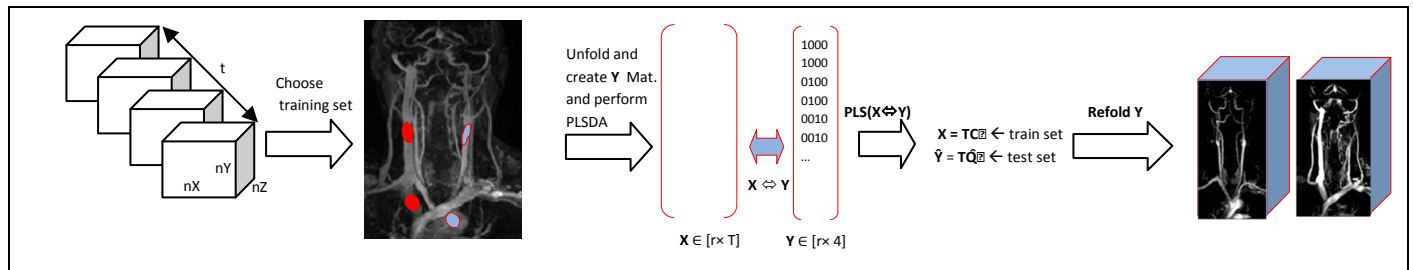

Figure 1: The processing steps for PLS-DA image analysis. From left to right: 4D CE-MRA data. MIPed MRI image highlighting the locations of the training data acquired. The unfolding stage of the training data and the corresponding **Y** matrix. Performing PLSDA and finally reconstructing the venous phase from **Y** data.

Results: To test our results, we acquired data from 20 subjects, after acquiring their consents for IRB. The data was acquired in a Siemens 3T TRIO scanner. The CE-MRA protocol used was a time resolved interleaved scan with stochastic trajectories (TWIST) with imaging parameters: TR: 2.96ms, TE: 1.12ms, FA: 18deg. Matrix size: 384×288× 96 with isotropic voxel size of 0.9 mm. The scanning rate was one volume every 6 seconds. 5 to 10 ml of contrast agent (Magnevist, Bayer, Wayne New Jersey) was injected into the right arm using a pressure injector at a rate of 1 ml/sec. the injection took place after 6 consecutive background volumes were acquired. Figure 2 (left) shows the maximum intensity projections (MIP) of the extracted venous and arterial phases from one of the datasets (time points 11to15) and on the right we can see the PLS-DA results for veins and arteries. It can be seen that PLS-DA can effectively separate the arterial and the venous phases from each other. The advantage of this method compared to simple regression is that is insensitive to the low rank structure of the data in the **X.**

Discussion: Compared to a simple correlation, the PLS-DA provides better estimates as the training is performed using multiple vectors. This provides a variable range from which the data can be classified. In addition to using Y directly as a map for visualizing the venous and arterial phases, the user can project each individual raw data onto the **Y** dataset to provide dedicated venous or arterial maps of each temporal phase of interest. We are currently measuring the effectiveness of the method by having a trained investigator analyze each dataset to determine how well the method has performed in removing the arterial phase from venous phase.
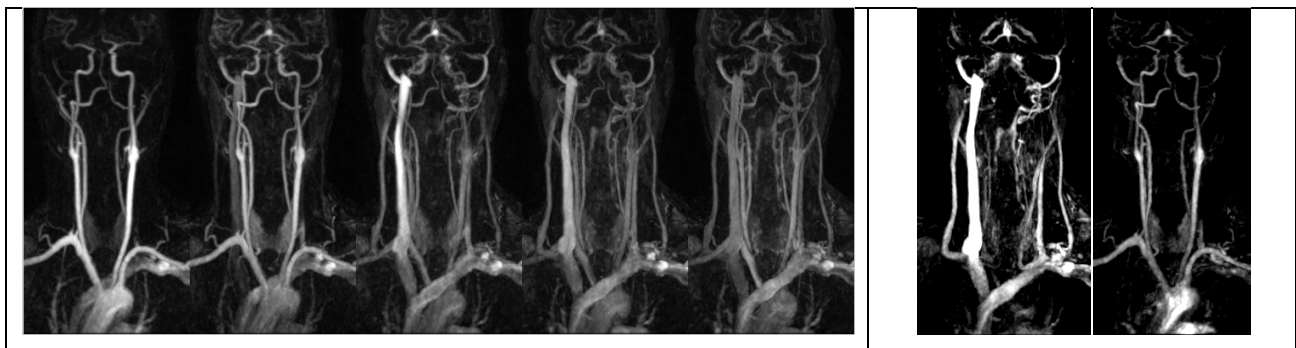

Figure 2: (a) MIPed images from CE-MRA data for various time points. (b) and (c) the MIPed projections of the venous and arterial phases after PLS-DA.

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