# Optimized pre-processing of time-resolved 2D and 3D Phase Contrast MRI data

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**Introduction:**

Phase contrast (PC) MRI has been widely used for the analysis of blood flow and tissue motion [1-3]. However, several sources of error such as eddy-currents or method-specific problems such as velocity aliasing and noise are existent and should be eliminated in order to improve the data quality before further data processing or visualization. Particularly for time-resolved (CINE) 3D PC-MRI, additional preparation and extraction of derived parameters such as magnitude weighted absolute velocities for subsequent display as 3D PC-angiography data is useful. For such pre-processing of velocity encoded PC-MRI data a customized software package (Velomap-Tool) was developed which includes several useful pre-processing functions embedded in an user-friendly graphical interface. Integration into the data processing chain for 3D flow analysis of 2D and 3D CINE PC-MRI data demonstrated the utility of the tool for user friendly and reliable pre-processing in in-vivo flow studies in 53 subjects.

**Methods:**

The Velomap-Tool was implemented using MATLAB (The MathWorks, Inc.) and all pre-processing steps were integrated into a graphical user interface. The tool provides several noise-masking functions, correction of eddy-currents as well as phase unwrapping algorithms. Noise masking was performed by thresh-holding of the signal intensity in the magnitude data to exclude regions with low signal intensity such as air in the lungs or outside the object. Further noise reduction and separation of static tissue and vessels was achieved by comparing the standard deviation (stdev) of the velocity-time course for each pixel in the PC-MRI data set [4]. Since velocity noise results in higher variations along the temporal direction compared to blood flow or static tissue, the standard deviation was used to identify noisy regions. In order to isolate tissue and blood a noise mask was created based on the flexible combination of both magnitude and stdev based data analysis. A built-in pre-view function permitted the interactive adjustment of thresh-holds for optimal noise and background suppression (see also figure 1). Eddy current correction consisted of three steps: 1. separation of static regions from blood flow and noise using the velocity-time standard deviation, 2. fit a plane with least squares method to the static regions from the last time frame (late diastole), 3. apply the correction, (e.g. subtraction of the fitted plane) to the PC-MRI data in every time frame. Additionally, the velocity-time standard deviation could also be used to eliminate static tissue from the data (so that only blood flow data will be processed). Fully automated correction for velocity aliasing, i.e. the measured velocity exceeded the user selected velocity sensitivity (venc), was based on the assumption that adjacent pixels velocities in temporal or slice direction should not differ by more than venc. For processing of 3D CINE PC-MRI data, additional features of the tool include the calculation of a phase contrast angiography (PC-MRA) from the measured three-directional velocities. Magnitude and filtered velocity images were used to generate time resolved 3D PC-MRA data by calculating absolute velocity images with background suppression by magnitude weighting according to equation (1),



**Fig.2** *3D visualization of phase contrast angiography of the entire thoracic aorta using iso-surface rendering*

$$I_i^{PC-MRA}(\vec{r}) = I_i^{Mag}(\vec{r})\sqrt{\sum_{j=x,y,z} v_{j,i}^2(\vec{r})} \quad i=1,...N \quad (1)$$

$$I_{WS}^{PC-MRA}(\vec{r}) = \frac{1}{N}\sum_{i=1}^{N} I_i^{PC-MRA}(\vec{r})^2 \quad (2)$$

where $r$ is the spatial location within the 3D volume, $j$ represents the velocity encoding direction in image coordinates ($x$=read, $y$=phase, $z$=slice) and $i$ the measured time frame within the cardiac cycle out of a total number of $N$ frames. Magnitude and velocity images are denoted by $I$ and $v$, respectively. To further enhance vascular regions with high flow and suppress background signal, an additional time independent 3D PC-MRA data set was generated as the squared sum of the individual 3D PC-MRA images (equation 2). Furthermore, for user-friendly data handling functions like previewing or queuing were implemented. The previewing function permits the visual inspection of modification for a given slice with the user selected parameters before processing the entire data set. Queuing function provides the possibility to modify several data sets successively and to start pre-processing afterwards. Finally, the modified data can be converted into other formats such as avi-file or 3D-Visualization-format such as EnSight (CEI, NC, USA). The Velomap-Tool was applied to pre-processing of 2D-CINE-PC and 3D-CINE-PC in-vivo data sets from 11 volunteer and 42 patients within studies of thoracic aorta.

**Results:**

Fig. 1 shows the user interface of the Velomap-Tool for pre-processing of a time-resolved 3D PC data set of the thoracic aorta. The window highlighted by the blue rectangle illustrates the preview functionality for the example of velocity images of a single slice and time frame encoded along the head-foot ($y$) direction. The individual images represent the original (left) and modified data (right) after noise masking, eddy current correction and phase unwrapping. Additional removal of static tissue is clearly visible if original and modified image are compared. Note that the modified image exhibits reduced noise and initially aliased blood flow velocities were successfully corrected after applying phase unwrapping (arrows in Fig. 1). A second representative example for comparison of original and modified velocity data for time-resolved 2D PC MRI is displayed in Fig. 3. Fig. 2 shows a typical example for 3D PC-MRA calculated with the Velomap-Tool and visualized as 3D iso-surface using EnSight illustrating the potential to generate complex arterial geometries from the measured velocity data. Pre-processing with the Velomap-Tool has been successfully applied to 53 2D and 3D PC-MRI data sets from volunteer and studies. Typical thresholds could be determined empirically and show only minor inter-individual deviations (table 1). As a result default thresholds were established, which shortened the time needed for user interaction for threshold-definition. After thresh-hold definition the duration of pre-processing and conversion for a 2D data set is about 3 minutes and for a 3D data set approx. 10 minutes.

| function | threshold range |
|---|---|
| noise masking using stdev | (20 ± 4) % of maximal stdev |
| noise masking using magnitude data | (9 ± 3) % of maximal signal intensity in magnitude data |
| eddy current correction | (10 ± 2) % of maximal stdev |

**Tab.1** *range of threshold for different functions*

**Discussion:**

The introduced user-friendly and robust tool facilitates a reliable pre-processing of time-resolved PC-MRI data. Consequently, it is used as self-contained program for data pre-processing for further clinical studies or as load-and- pre-processing program within other tools. Due to flexible implementation the introduced tool can be easily extended with additional functionalities. Future work includes the integration of advanced vessel segmentation algorithms using additionally acquired high-resolution MR angiography data as well as functional information such as flow and pulsatility.

**References:**

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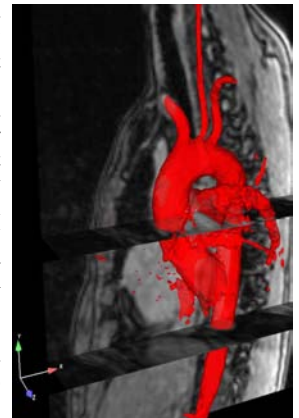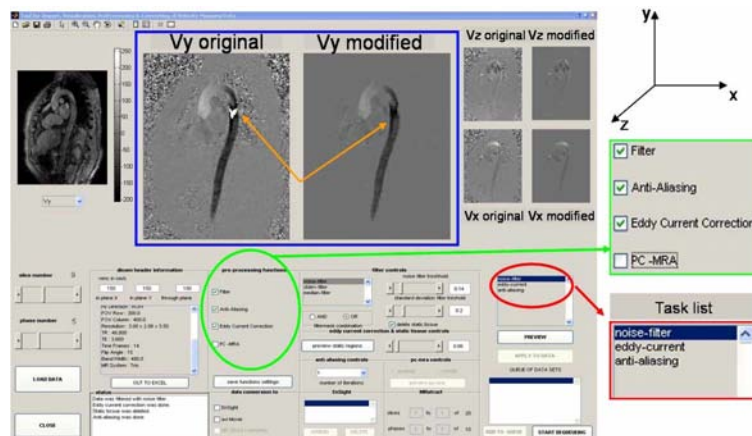[4] Walker PG, et al. J Magn Reson Imaging 1993;3:521-30.

**Fig.1** *Screenshot of the Velomap-Tool interface showing original and modified velocity data for one selected slice and time frame from a 3D PC MRI data set of the thoracic aorta; user selectable data processing features (green rectangle) and task list with applied pre-processing functions (red rectangle) are displayed in an enlarged view*
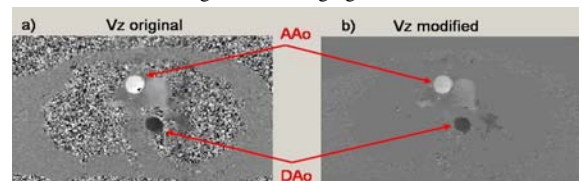


**Fig.3** *Velocity data from a 2D measurement of blood flow in the ascending (AAo) and descending thoracic aorta (DAo)*
*a ) original velocity data*
*b) modified velocity data with noise masking and phase*