Improving SWI Contrast

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Introduction: Susceptibility Weighted Imaging (SWI) has been proposed by Haacke et al. [1] to enhance the image contrast, especially between small veins and surrounding tissues. A filter generated from the image phase is multiplied with the magnitude images. The improved image contrast has received wide acceptance in clinical MR studies and SWI showed advantages in MR diagnosis. On the other hand, it was not discussed in detail whether this filter indeed optimally exploits magnitude and phase information. Here, we proposed a more generalized filter for SWI contrast enhancement. The new filter can be parameterized and thus can be dynamically adapted to the data input to improve the overall SWI contrast.

Theory: For a MR image with magnitude *M* and phase *φ*, the SWI image M_s is defined as $M_S = M * F_H$, where F_H is the Haacke filter defined as $F_H = (1+\varphi/\pi)^4,\ \varphi \le 0;$ and $F_H = 1,\ \varphi \ge 0$. In the original SWI paper, the noise amplification due to this process was discussed and the noise level was approximated by the derivative of F_H. However, since the derivative of F_H has a non-continuous point at zero, it will introduce strong noise for signal with zero phase, e.g. the average phase in the image for all tissue components (GM, WM, blood, CSF). This aspect of noise propagation and its effect on the filter quality was not fully discussed. Here, we proposed to use a more generalized filter for SWI contrast generation. The new filter, F_Z, is based on a Sigmoidal function, i.e. $F_Z = 1/(1+e^{\alpha(\varphi+\beta)})$, with two parameters α and β (Fig. 1). Compared to F_H, the advantage of F_Z is that the SWI contrast can be parameterized by the two parameters α and β and adapted dynamically to the input data. Additionally, the separate definition of positive or negative SWI contrast in F_H can be avoided, since this contrast is determined by the sign of α. It also can be shown that the derivative of F_Z is continuous and scales much lower compared to that of F_H, thus reducing noise propagation.

Methods: SWI data were acquired on a 7 T MR scanner (Siemens MAGNETOM, Erlangen, Germany) using a 24-channel head coil. RF-spoiled 3D gradient echo images were collected for SWI analysis (378x448 matrix, 0.5x0.5 mm^2 in-plane resolution; TR/TE = 20/12 ms; flip angle = 35°; 64 slices, slice thickness 2 mm). MATLAB and SPM5 were used for data processing. The image phase maps were combined using the adaptive combination method [2] and filtered by a homodyne filter before for SWI image generation. SWI images (filtered magnitude images and minimal intensity projection (MIP) images) with F_H and F_Z filters were created separately. The F_Z filter parameters α and β were varied and compared to the F_H filter for the best SWI contrast. The co-occurrence matrix (CoM), previously shown to help the analysis of image contrast [3], was used and applied to the MIP images to identify F_Z filter parameters with the highest contrast.

Results and Discussion: SWI and MIP images generated with F_H and F_Z filters are shown in Fig.2. The F_Z filter showed a clear SWI contrast enhancement compared to F_H. This is consistent with the prediction that the F_Z filter introduces less noise into the SWI image. The dependence of F_Z on α and β, normalized to the CoM value of F_H, is shown in Fig. 3. The overall contrast enhancement was over 50% for F_Z with α between 2 to 4 and β around -0.1 compared to F_H, again verifying the observation in Fig. 2. The gradient echo images used for this study had a TE of 12 ms. At 7 T, this already created a very strong SWI contrast, even for the original F_H filter. Therefore, it will be very interesting to systemically investigate the F_Z filter behavior for short TE at 7 T and also for low field strength, where the phase contrast is smaller. This will provide a complete picture of the new filter and its enhancement of the SWI contrast.

Conclusion: A generalized filter based on the sigmoidal function was applied for SWI contrast and showed higher contrast compared to the original SWI filter. It therefore should improve the outcome of future studies utilizing the SWI contrast.

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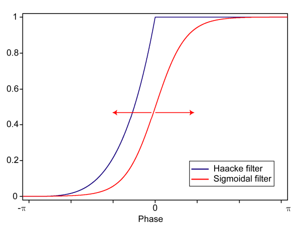

Fig 1: Comparison of the Haacke filter F_H (blue) and the new filter F_Z (red). F_Z has a higher flexibility and can be adjusted dynamically to the input data while F_H is fixed around 0.

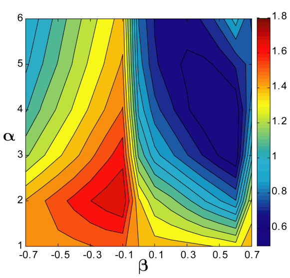

Fig 3: Determination of the optimal parameters α and β for F_Z, using CoM. The optimal α is 2 to 4 with β around -0.1 and a contrast enhancement over 50% compared to F_H.

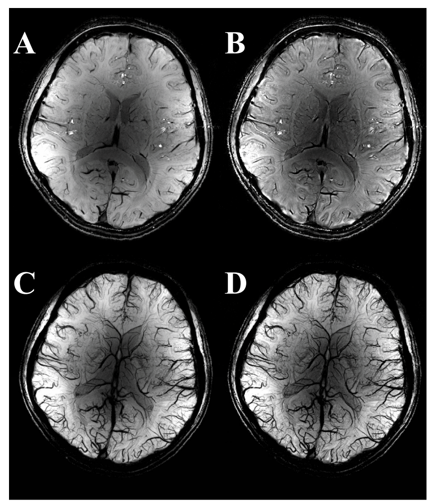

Fig 2: A selected slice showing the SWI (A,B) and MIP (C, D) images with F_H and F_Z filters (α = 3, β = -0.1). Compared to F_H (left), the F_Z (right) showed clear improvement in the tissue contrast, both between gray and white matter tissue (B vs. A) and between veins and surrounding tissues (D vs. C).

References: 1. Haacke EM *et al.* *MRM* 52:612–8 (2004)
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3. Yang, S. *et al. Proc. Intl. Soc. Mag. Reson. Med.* 17:4574 (2009)