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 $\varphi$, the SWI image $M_\alpha$ is defined as $M_\alpha = M * F_{\alpha \varphi}$, where $F_{\alpha \varphi}$ is the Haake filter defined as $F_{\alpha \varphi} = (1 + \varphi/\pi)^\alpha$, $\varphi \leq 0$; and $F_{\alpha \varphi} = 1, \varphi \geq 0$. In the original SWI paper, the noise amplification due to this process was discussed and the noise level was approximated by the derivative of $F_{\alpha \varphi}$. However, since the derivative of $F_{\alpha \varphi}$ 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, $F_{Z\alpha \beta}$, is based on a Sigmoidal function, i.e. $F_{Z\alpha \beta} = 1/(1 + e^{\alpha (\varphi - \beta)})$, with two parameters $\alpha$ and $\beta$ (Fig. 1). Compared to $F_{\alpha \varphi}$, the advantage of $F_{Z\alpha \beta}$ is that the SWI contrast can be parameterized by the two parameters $\alpha$ and $\beta$ and adapted dynamically to the input data. Additionally, the separate definition of positive or negative SWI contrast in $F_{\alpha \varphi}$ can be avoided, since this contrast is determined by the sign of $\alpha$. It also can be shown that the derivative of $F_{Z\alpha \beta}$ is continuous and scales much lower compared to that of $F_{\alpha \varphi}$, 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 mm² 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 $F_{\alpha \varphi}$ and $F_{Z\alpha \beta}$ filters were created separately. The $F_{Z\alpha \beta}$ filter parameters $\alpha$ and $\beta$ were varied and compared to the $F_{\alpha \varphi}$ filter for the SWI contrast generation. 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 $F_{Z\alpha \beta}$ filter parameters with the highest contrast.

Results and Discussion: SWI and MIP images generated with $F_{\alpha \varphi}$ and $F_{Z\alpha \beta}$ filters are shown in Fig.2. The $F_{Z\alpha \beta}$ filter showed a clear SWI contrast enhancement compared to $F_{\alpha \varphi}$. This is consistent with the prediction that the $F_{Z\alpha \beta}$ filter introduces less noise into the SWI image. The dependence of $F_{Z\alpha \beta}$ on $\alpha$ and $\beta$, normalized to the CoM value of $F_{\alpha \varphi}$, is shown in Fig. 3. The overall contrast enhancement was over 50% for $F_{Z\alpha \beta}$ with $\alpha$ between 2 to 4 and $\beta$ around -0.1 compared to $F_{\alpha \varphi}$, 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, which is consistent with the prediction that the $F_{Z\alpha \beta}$ filter introduces less noise into the SWI image. The dependence of $F_{Z\alpha \beta}$ on $\alpha$ and $\beta$, normalized to the CoM value of $F_{\alpha \varphi}$, is shown in Fig. 3. The overall contrast enhancement was over 50% for $F_{Z\alpha \beta}$ with $\alpha$ between 2 to 4 and $\beta$ around -0.1 compared to $F_{\alpha \varphi}$, again verifying the observation in Fig. 2. The gradient echo images used for this study had a TE of 12 ms.

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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