Object orientation independence of Susceptibility Weighted Imaging by using a Sigmoid-type phase window

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Introduction: Susceptibility Weighted Imaging (SWI) uses the phase information of MRI, to enhance the contrast of small magnetic susceptibility differences not easily observed in the magnitude images [1]. In SWI, the linear phase accumulation is removed from a phase image, and then the filtered phase (ϕ_c) is mapped to values from 0 to 1 by either using positive, negative or triangular windows, as those shown in Figure 1. Then, the "q" power of the created mask multiplies the magnitude image to achieve a desired contrast. Unfortunately, a single-side window is sensitive to the orientation, with respect to the main magnetic field, of the object that produces the phase difference, such as a blood vessel. The triangular window, although more independent of the orientation, tends to overestimate the size of the object and therefore, the combination of positive and negative phase windows is required for the accurate detection of features both closely aligned and perpendicular to the main magnetic field [2]. Values of "q" normally range between 2 and 5 although higher values have been reported [3]. While higher values of "q" may enhance the presence of small features, eventually it also reduces the SNR of the processed images [1-3]. In this work, we propose the use of a sigmoid-type window to enhance the contrast of SWI independently of the orientation of the object, as long as it produces a phase change with respect to the surrounding tissue.

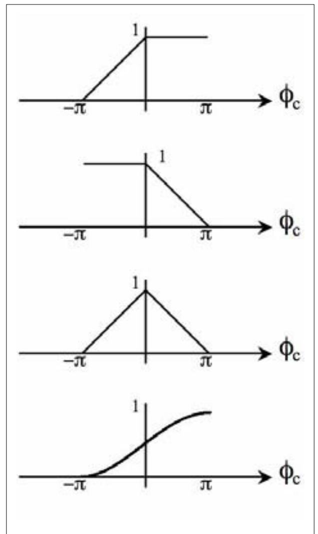
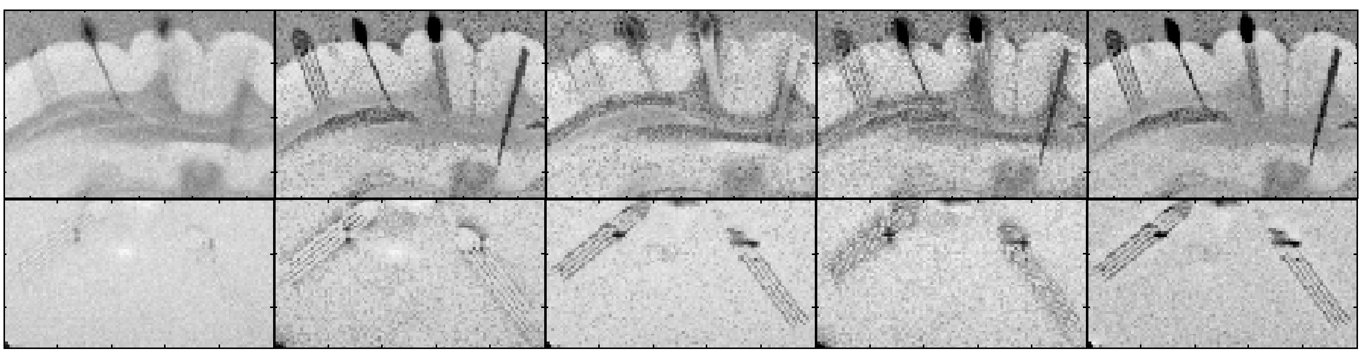


Figure 1. From top to bottom: Negative, positive, triangular, and sigmoid windows for SWI.

Methods: Two MRI phantoms that produced small but noticeable phase changes were built using silicon microeloectrodes ($\Delta\chi$ Silicon-Tissue ≈ 5 ppm [4]). The first phantom consisted of two silicon microelectrodes placed perpendicular to each other and mounted on a glass plate immersed in water doped with a 3mM of Gadolinium (Omniscan Labs.) to reduce T1 to approximately 100ms. Each electrode had four shanks of 3.75 mm length, 15 µm thick, variable shank width from 35µm, near the tip of the electrode up to 110µm at the base of the shank, and shank spacing of 200 µm [5]. The phantom was placed inside the magnet such as the flat face of the electrode was parallel to the main magnetic field. The second phantom consisted of a fixed Guinea pig brain (4% formaldehyde) implanted with 4 different types of silicon microelectrodes. Three of them similar to the one described before, and another one with a single shank of 8 mm in length, same thickness and shank width of 60 µm near the tip of the electrode up to 400µm at the base. This phantom was placed inside the magnet such as the flat face of two electrodes were perpendicular to the main magnetic field, one of them being the single-shank electrode. 2D Gradient Echo (GE) images were acquired on a 2T Varian system with the following imaging parameters: Field of view of 2x2 cm^2, slice thickness of 0.5 mm, matrix size of 200x200, TR/TE=100/15ms/ms, and 16 averages.

The parameters "a" and "b" of a sigmoid mask equation $M(\phi)=1/(1+\exp(-a\ (\phi - b)))$ were iteratively adjusted to achieve a good balance between contrast and SNR, and the same was done for the parameter "q" for the windows commonly used in SWI.

Results: Figures 2 show the results of normal magnitude MRI images as well as SWI using negative, positive, triangular, and sigmoid-type windows. As observed, the sigmoid-type window does facilitate the detection of the electrodes by enhancing the contrast regardless of the orientation of the object.



Magnitude | Negative Window | Positive window | Triangular window | Sigmoid window

Figure 2. Effects of object orientation and phase windows for SWI. The value of "q" was 10 for all the conventional windows, which can be considered relatively high, but it was required because the electrodes are barely seen on the original magnitude images. The values for the pair (a, b) were (10, -0.2) for the top row, and (-10, 0.2) for the bottom row. Note that positive or negative windows do a very good job for particular orientations, whereas the triangular window always blurs the objects. As can be seen, the sigmoid window enhances the presence of susceptibility changes regardless of the orientation.

Discussion: These preliminary results show that object orientation dependence, observed on SWI, is avoided by using a sigmoid-type function. By changing the parameters "a" and "b" we can achieve similar SNR and CNR as those observed with conventional SWI. In addition, in the presence of both positive and negative phase variations with respect to the background, varying the parameter "a" while keeping b=0, enhances negative and positive phase changes with darker and brighter colors respectively. We are currently working on the automatic selection of optimal values of the parameters of the sigmoid equation, which will simplify the usage of this method not only for the detection of implanted silicon microelectrodes but also in other potential clinical applications such as MR BOLD-Venography.

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